

C H A P T E R I V

APPLICATION OF MEYER'S LAW AND KICK'S LAW
TO RHOMBOHEDRAL CRYSTALS : CALCITE AND SODIUM NITRATE

CHAPTER IV

APPLICATION OF MEYER'S LAW AND KICK'S LAW TO RHOMBO- HEDRAL CRYSTALS : CALCITE AND SODIUM NITRATE

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4.1 INTRODUCTION:

From the hardness point of view, there are two ways of studying the mechanical response of a material to the applied load:

- (i) Variation of applied load (p in gm) with diagonal length (d in μm) of the indentation mark,
- (ii) Variation of hardness (H in kg/mm^2) represented by hardness number, with applied load.

In this chapter, it is proposed to discuss quantitatively the variation of applied load with diagonal length of the indentation mark produced by a Knoop indenter on a freshly cleaned surface of synthetic single crystals of sodium nitrate and natural single crystals of calcite. For ball and pyramidal indenters, two empirical laws are suggested. They are as follows: (i) Meyer's law, and (ii) Kick's law.

4.1.1 Meyer's Law:

On the basis of experimental observations, Meyer (1908) had given a relation between applied load and the diameter of the indentation mark produced by a ball indenter, viz., for a given diameter of a ball indenter, the variation of the applied load (P in gm) with the diameter of the indentation mark (d in μm) is given by the following relation:

$$P = ad^n \quad \dots \quad (4.1)$$

where 'a' and 'n' are constants for a given material. The above expression symbolically represents Meyer's law /1/. 'n' varies from about 2.0 to 2.5 depending on the condition of the material. It has a higher value for a fully softened state and decreases with the degree of cold working given to the specimen. The value of 'n' can

be considered as the capacity for work hardening /2/.

4.1.2 Kick's Law:

Kick (1885) /3/ has given a formula connecting applied load with diagonal length of indentation mark produced by an indenter. It is given by

$$P = ad^n \quad \dots \quad \dots \quad (4.1)$$

where 'a' is termed the 'Standard hardness' of the material for an indenter of fixed diameter and 'n' is an exponent giving a measure of the variation in hardness as a function of 'P' or 'd'. It has been shown that in case of Vicker's microhardness, 'n' is equal to 2 (Kick's law, 1885) for all indenters that give geometrically similar impressions. Hanemann and Schultz (1941) /4/ from their observations concluded that in the low load region 'n' generally has a value less than 2. Onitsch (1947) /5/ found such low values of 'n' (1 to 2) by observing variation of hardness with load while Grodzinski (1952) /6/ found variation of 'n' values from 1.3 to 4.9; the value of 'n' was nearly found to be 1.8.

Since the applied load value (P) in the above formula is a product of two quantities, the change in the values of 'n' for a constant 'd' is accompanied by a change in the values of 'a', the standard hardness of the material. Hence these values thus obtained were expected to yield constant results but actual results obtained by different workers revealed disparities amounting to 30 - 50%. These disparities may be attributed to the following reasons:

- (1) Equation $P = ad^n$ is not valid.
- (2) Microstructures exercise considerable influence on measurements involving very small indentations.
- (3) The experimental errors due to mechanical polishing, preparation of specimen, vibrations, loading rate, indenter shape,

measurement of impression, etc., affect the hardness determinations considerably.

The microindentation hardness refers to the hardness measurements on the microscopic scale. Some authors prefer the term low load hardness for the above. In the present case, the microhardness refers to the applied loads ranging from the lowest possible load to maximum load of 200 gms. Further in what follows the term 'hardness' and 'microhardness' of crystals are used to indicate the same meaning. Chemical formulae NaNO_3 and CaCO_3 will be used to indicate sodium nitrate and calcium carbonate materials/single crystals. In general, wherever chemical formula is used, it indicates chemical material/single crystal. In the tables the measured and calculated quantities are given upto four places after decimal, as the calculations were carried out by the use of mathematical tables/calculators. However the accuracy is upto the first figure after the decimal place. This value is normally considered during discussion. The present work is taken up with the express purpose of critically re-examining the Meyer's law and Kick's law by systematically studying microhardness of synthetic single crystals of NaNO_3 and natural CaCO_3 crystals. It is an extension of the work reported by earlier workers in this laboratory /7,8,9,10,11/.

4.2 EXPERIMENTAL:

Single crystals of NaNO_3 grown from melt by methods described in chapter II and natural crystals of CaCO_3 obtained from different localities such as Pavagarh, Chhota Udaipur (Gujarat State) and Rajasthan were used for the purpose of present study. Small crystal cleavages from a big block of rhombohedral NaNO_3 and CaCO_3 were used in the present investigation. Every time freshly cleaved crystals of approximately equal sizes were used so that a comparison of treated and untreated samples can be easily made without introducing other factors affecting the determinations of 'a' and 'n'. Freshly cleaved blocks having dimensions 10 x 10 x 2 mm were fixed on glass plates

with an adhesive. The levelling of the specimens was tested by using a table microscope. The hardness tester described in chapter II was used to produce indentations on a freshly cleaved surface by using rhomb-based knoop pyramidal indenter. The filar micrometer eyepiece was used to measure the surface dimensions of the indentation marks. In order to avoid the influence of one indentation mark on the other, the distance between two consecutive indentations was maintained at least eight times the diagonal length of indentation mark, the indentation time for all specimens was kept 15 seconds. For CaCO_3 the load was varied from 1.25 gm to 80 gm and for NaNO_3 from 1.25 gm to 1.60 gm. Care was taken to see that errors introduced during the work of indentation and measurements are avoided or minimized. The indentation marks were produced for different orientations of the longer diagonal of the knoop indenter with respect to $[100]$ direction on a fresh cleavage plane (100) . These orientations were designated by angle 'A' between the direction $[100]$ and longer diagonal of knoop indentation mark.

The different angles in degrees for which measurements were made are as under:

for Calcite:

A = 0, 7, 14, 21, 28, 35

for NaNO_3 :

A = 0, 13, 26, 39, 52, 65, 78.

The selection of these values of the angles was based on division of the angle between the directions $[100]$ and $[0\bar{1}0]$ into equal parts on both sides of the diagonal $[\bar{1}\bar{1}0]$, i.e., 39° . Due to non-availability of a hot stage and optical components of microscope to be used with it in hardness tester, the indentation work was carried out at room temperature (298°k for NaNO_3 and 303°k for CaCO_3) for annealed and/or quenched crystals for studying the variations of hardness with temperature. For these experiments, crystals of approximately equal

sizes were used. They were gradually raised to a desired temperature and kept at this temperature for identical periods running into few hours (24 hours in the present case). They were then quenched to room temperature. The quenching rates were made as high as possible and were adjusted so that the quenched crystals maintained their shapes. In the present case the rate of quenching varied from $1.6^{\circ}\text{C}/\text{sec}$ to $11.6^{\circ}\text{C}/\text{sec}$. These experiments were conducted upto a temperature of 220°C for NaNO_3 and 500°C for CaCO_3 because the melting temperature of NaNO_3 and dissociation temperature of CaCO_3 are 308°C and 500°C respectively. It should be noted that the dissociation temperature of CaCO_3 mentioned in the standard textbooks (e.g., see reference in table 1, chapter I) is 850°C . However the thermal etching work carried out on cleavage faces of calcite in this laboratory has convincingly shown it to be 500°C . (cf. ref.3, chapter I).

4.3 OBSERVATIONS:

The longer diagonals of the knoop indentation marks produced by various loads for different orientations of indenter were measured. It is assumed that there is negligible elastic recovery in the major diagonal direction compared to the minor diagonal direction when the indenter is removed /12/. Several sets consisting of a large number of observations on freshly cleaned surfaces of thermally treated and/or untreated NaNO_3 and CaCO_3 crystals indented by various loads at room temperature for different orientations of indenter were taken and a typical set of observations, recorded in table 4.1 A & B, (i) to (v) were studied graphically by plotting $\log d$ versus $\log P$ (Fig.4.1 A & B (i) to (v)) for different 'A's, where 'P' is the load in gms, 'A' is the angle in degrees, 'd' is the average value of the longer diagonal length of the indentation mark in microns.

4.4 RESULTS AND DISCUSSION:

4.4.1 Straight line plot of $\log P$ Vs. $\log d$:

Taking logarithms of both sides of the equation representing Meyer's law for ball indenter or Kick's law for pyramidal indenter yields-

$$\log P = \log a + n \log d \quad \dots \quad (4.2)$$

The values of constants 'a' and 'n' can thus be determined from a graph of log d versus log P. Since the relation between log P and log d is linear, the graph is a straight line, the slope of this line gives the value of 'n' and the intercept on log P axis gives the value of log a and hence 'a'. For all indenters that give geometrically similar shapes (impressions), Meyer's law/Kick's law postulates a constant value of 'n' viz., $n = 2$. This implies a constant hardness value for all loads according to the definition of Knoop hardness number (KHN).

A careful study of the graphs (log d Vs. log P) shows that there are two clearly recognizable straight lines for CaCO_3 of different slopes meeting at a kink which is obtained at a load of 5 gm/3.75 gm at room temp. These loads will henceforth be referred to as transition loads P_k . Splitting of the straight line plot into two distinct lines is not observed in case of NaNO_3 whereas for CaCO_3 splitting does occur. The first part of the straight line corresponding to observations taken at low loads upto P_k at room temperature has slope (n_1) of higher value whereas for the second part of straight line for higher loads, the slope (n_2) has values less than 2. Since 'n' values are different in different regions of the graphs of log d versus log P, being greater in first region, the 'a' values also vary in two regions being less in first region of low loads and more in second region of high loads. For Knoop indentation on cleavage faces of NaNO_3 and CaCO_3 ; the values of n and a for NaNO_3 in table 4.3 A(i) to (v) and n_1 , n_2 and corresponding a_1 and a_2 are recorded in table 4.3 B(I) & (II), (i) to (v) for CaCO_3 .

Table 4.3 B(I) also shows the load at kink (P_k) for various quenching temperatures for calcite.

It may be remarked in passing that several workers have reported visible scattering in 'n' values, e.g., see Hanemann and Schultz /4/, Onitach /5/, Grodzinski /6/.

However, none has reported the splitting of graphs into two straight lines and their characteristics. The study of variation of load with diagonal length of Vickers indentation mark on faces of different types (c-, m-, d- and o- faces) of natural and synthetic barite crystals /13/ has shown very clearly the existence of two distinctly recognizable straight lines of the graph of $\log d$ versus $\log P$. Later, Mehta /14/, Shah /7/ and Acharya /8/ verified the splitting of graph of $\log d$ versus $\log P$ on CaCO_3 , Zn, TGs, KBr, NaCl and KCl crystals. In the present investigation, the author has verified for CaCO_3 , the splitting of the graph into two regions using Knoop pyramidal indenter. The splitting varies with the orientation of the indenter with respect to crystal lattice. While there is no such splitting observed for NaNO_3 . It is thus certain that the splitting of the graph into two straight lines is natural and is due to varied reactions of the crystal surfaces to different applied loads used for producing indentations.

It is indeed interesting to note that although both these crystals are isostructural/isomorphous, the splitting of the straight line plot into two recognizable distinct parts is positive for CaCO_3 and is absent for NaNO_3 . This is likely to be due to fine differences in their crystal structures and different physical and chemical properties. They are as follows:

- (i) An isodiametric structure of slightly smaller size of $(\text{NO}_3)^-$ group as compared to $(\text{CO}_3)^{--}$ group.
- (ii) Increased polarization of coordinated oxygen atoms by the pentavalent nitrogen atom.
- (iii) Stability of Nitrates. and Carbonates.
- (iv) Chemical activity of Nitrates and Carbonates.
- (v) Fine differences in the planar structures of $(\text{NO}_3)^-$ and $(\text{CO}_3)^{--}$ groups.

- (vi) Chemical and thermal etching characteristics of these crystals.
- (vii) Solubility of NaNO_3 and CaCO_3 in water.

It is difficult to give a precise reason which is responsible for observing a single straight line for NaNO_3 . However, it should be mentioned that hardness behaviour of synthetic single crystals of NaNO_3 are significantly affected by (1) impurity content in the chemical used to grow these crystals, and (2) the method of growing these crystals (e.g., solution-grown and melt-grown crystals /15/). These factors are likely to be responsible for the non-splitting of the straight line plot into two straight lines.

This is evident from the hardness studies of synthetic solution-grown and melt-grown crystals of NaNO_3 grown from LR quality chemicals /10/. The present author had used fine chemical (NaNO_3) for growing single crystals for which single straight line plot of $\log d$ Vs. $\log P$ was experimentally observed.

4.4.2 Modification in Kick's law and Meyer's law:

The analysis of hardness data based on Kick's law and Meyer's law postulates a constant value for n , namely 2, for all indenters and for all geometrically similar impressions. Schultz and Hanemann /4/ supported the above analysis by proposing that hardness number and macrohardness values were comparable. However, Kick's law represented by equation (4.1) has not received wide acceptance on account of the fact that ' n ' usually has a value less than 2. Hays and Kendall /16/ attempted to overcome this difficulty by assuming that a resistance to deformation could be evaluated by considering it as a Newtonian resistance pressure of the specimen itself. They assumed that a part of the applied load is used in overcoming a resistance/pressure ' W ' which depends on the nature of the material under test. It is further understood that ' W ' does not allow any plastic deformation. Hence according to them the effective load which produces indentation and therefore plastic deformation

is (P-W) for which the variation is proportional to the square of the diagonal length of the indentation mark, i.e., d^2 . Thus modified Kick's law according to the above understanding is-

$$P - W = bd^2 \quad \dots \quad \dots \quad (4.3)$$

or

$$\log (P - W) = 2 \log d + \log b \quad \dots \quad \dots \quad (4.4)$$

where 'b' is a constant, likely to be characteristic of the material and the exponent of 'd' is 2. Since the factor 'W' allows the limiting case to prevail where microhardness is independent of load, 'n' should turn out to be 2. Elimination of P from equation 4.1 and 4.3 yields the value of W:

$$W = ad^n - bd^2 \quad \dots \quad \dots \quad (4.5)$$

or

$$d^n = \frac{b}{a} d^2 + \frac{W}{a} \quad \dots \quad \dots \quad (4.6)$$

The equations (4.2), (4.4) and (4.6) can be used to verify experimentally the validity of modified Kick's law (4.3) and assumption for existence of resistance pressure 'W' by plotting graphs based on experimental observations. Thus by the plot of $\log d$ Vs. $\log P$ (Fig.4.1 A & B (i) to (v)), one can obtain the values of exponent 'n' and standard hardness 'a' as follows (cf. Figs.4.1 A & B (i) to (v)):

$$\left. \begin{array}{l} \text{Slope} = n \\ \text{Intercept} = \log a \quad \dots \\ \text{or } a = \text{Antilog (Intercept)} \end{array} \right\} \dots \quad (4.7)$$

Using the value of 'n' from the above, a graph of d^n Vs. d^2 (Fig.4.2 A & B) can be plotted. The plot indicates it to be a straight line graph with the slope and intercept given by

$$\left. \begin{array}{l} \text{Slope} = b/a \\ \text{Intercept} = W/a \end{array} \right\} \text{ (cf. Figs.4.2 A \& B)}$$

$$\text{Hence, } \left. \begin{array}{l} b = a \times \text{slope} \\ W = a \times \text{Intercept} \end{array} \right\} \dots \dots (4.8)$$

where the value of 'a' obtained from (4.7) is substituted on the right hand side of (4.8). The values of b and W obtained above can be substituted in (4.4) for a plot of $\log (P - W)$ Vs. $\log d$ (Fig.4.3 A & B). The slope of this graph should be 2 which in turn should establish the validity of modified Kick's law. This is indeed found to be the case for the present study of cleavage faces of synthetic single crystals of NaNO_3 . Modified Kick's law was also found to be valid for alkali halide crystals /17/. For cleavage faces of natural crystals of calcite, the graph of $\log d$ Vs. $\log P$ (cf. Fig.4.1 B(i) to (v)) consists of two recognizable straight lines with different slopes n_1 and n_2 and intercepts a_1 and a_2 for low load region (LLR) and high load region (HLR) respectively. Hence for calcite crystals corresponding to two straight lines representing effects of LLR and HLR, there should be two values of b and W, namely b_1, W_1 and b_2, W_2 .

4.4.3 Variation of standard hardness and exponent with quenching temperature and orientation:

In order to determine the relative importance of various factors affecting the values of 'a' and 'n', the study was carried out for various orientations of indenter and crystal surfaces which were quenched from high temperatures to room temperature. It is obvious from table 4.3 B for CaCO_3 that the values of a_1 and n_1 for LLR show comparatively large differences at all quenching temperatures T_q and for all orientations (A) of the indenter. Further, their variations appear to have no clear relation with A whereas a_2 and n_2 values obtained from the second part of the graph are independent of A. Similarly it can be conjectured from the values of n_1 and a_1, n_2 and a_2 at different ' T_q 's that n_1, a_1 values do depend on T_q and n_2, a_2 values are almost independent of T_q . For NaNO_3 crystals

'n' and 'a' values are independent of A but depends on T_q . In view of observations for these two crystals only it is not possible to develop with certainty empirical relations between these variables.

Application of modified Kick's law should eliminate the variation in the exponent of 'd'. The variations of standard hardness values a_1 and a_2 replaced by b_1 and b_2 in case of calcite and, a replaced by b in case of NaNO_3 with T_q and A will now be considered. It is clear from Table 4.3 B(I) that b_1 values are almost three times the values of a_1 for all 'A's and ' T_q 's. It is also interesting to note that variations among b_1 values for all 'A's and ' T_s 's are comparatively smaller than the corresponding variations of a_1 values for different 'A's and ' T_q 's. Further there are observable differences of ' n_1 ' values from 2. Hence modified Kick's law is not applicable to LLR of hardness of natural crystals of calcite. The comparison of b_2 and a_2 values for different but constant A and T_q values indicate that a_2 values are 2-3 times the b_2 values. Further the internal differences among b_2 values and among a_2 values for different values of orientations and quenching temperatures are comparatively less. ' n_2 ' and 'n' values are not significantly different from 2. This suggests that modified Kick's law is valid for HLR of hardness of natural calcite and synthetic sodium nitrate crystals.

It is reported that 'n' represents the capacity of workhardening of the crystal specimen and that a higher value (> 2) of 'n' indicates the fully softened state and a lower value the degree of cold-working of the specimen /2/. Symbolically for calcite crystals this can be represented in a tabular form:

Region	Meyer's law/Kick's law		Modified Kick's law	
	Exponent	Intercept	Exponent	Intercept
LLR	$n > 2$	a_1 low	$n > 2$	b_1 high
HLR	$n \leq 2$	a_2 high	$n \approx 2$	b_2 low almost constant

It is clear from the above that the physical meaning of fully softened state and degree of cold-working can not be quantitatively deduced from the observations on Applied load and dimension of indentation mark. The indentation does produce plastic deformation and cold-working alongwith some elastic recovery. However, the above data is insufficient to explain the physics of static indentation hardness. It further implies that there are several factors such as surface energy, concentration of differnt types of impurities and imperfections and their interactions, effect of penetration of indenter in the surface and propagation of stress waves along different directions in the crystal, anisotropy, etc., which operate in a way unpredictable from the present study and are responsible for experimentally observed deviations in the analysis.

In order to find out the work-hardening and cold-working of cleavage surfaces of CaCO_3 and NaNO_3 for different applied loads, experiments were carried out for different applied loads on different thermally treated and untreated specmens. The ageing effects of these specimens were also studied. It was found from the measurements of the dimensions of the indentation marks that there were not noticeable differences in the dimension of indentations produced by the same applied, load on fresh and/or aged and/or worked specimens. This also indicates the limitations of the present analyses.

It should be mentioned here that although the indentation work was carried out on freshly cleaved surfaces of quenched crystals with the intention of removing surface hardening of quenched specimens, the hardness study of the cleaved surfaces which were once the inner parts or interiors of quenched crystal has shown a noticeable change with quenching temperature, i.e., 'body' hardness is affected by heat treatment. Of course this change is obviously smaller than that of directional hardness due to different orientations of indenter and that of surface hardening of the quenched specimens.

A careful study of values of ' n_1 '_{mod} and ' W_1 ' (Table 4.3

B(I)) for different, but constant, values of 'A' and ' T_q ' reveals surprising and interesting results. Except at room temperature (303°K) the modified n_1 values for different ' T_q 's and 'A's are noticeably different from 2. Further, for most of the values of 'A's and ' T_q 's (except for $A = 0,7^\circ$ & $T_q = 698^\circ\text{K}$) the resistance pressure values ' W_1 ' are negative. This means that the resistance pressure which is not assumed to produce plastic deformations helps applied load (LLR) in producing plastic deformation. This interpretation defeats the very purpose of assuming resistance pressure. Hence this implied meaning can not be accepted. This (negative value) can be understood in terms of reactions of the surface layers and bulk material of this crystal. The properties of the first few surface layers are different from those of the bulk material and this difference is likely to be responsible for the negative value of W_1 . This also strengthens the consideration of splitting of single straight line plot into two straight line plots. The modified n_1 values and negative W_1 values in LLR suggest that modified Kick's law is not applicable to LLR of hardness of natural calcite crystals. Further modified values of n_1 at room temperature (303°K) namely $\simeq 2$ indicate that while considering the applicability of modified Kick's law, more weightage should be given to negative values of ' W_1 ' and less to n_1 values. With the progressive increase of 'A' for constant temp. (room), the value of ' W_1 ' becomes less negative and reduces to zero for orientations 28° and 35° . The observed value of ' n_1 ' is 2 whereas its modified value is little more than 2 for these orientations. This suggests that in LLR, value of ' W_1 ' is zero near about 39° , i.e., near about the direction $[\bar{1}\bar{1}0]$. This direction is the projection of [111] direction on cleavage plane $\{100\}$. It is well-known that for usual doubly refracting crystals such as CaCO_3 and NaNO_3 the optic axis is the direction along which the velocities of extraordinary and ordinary monochromatic light rays are identical and that ordinary ray propagates with the same velocity in all directions in a homogeneous isotropic crystal. Hence direction [111] is the one along which the homogeneous isotropic character of the crystals can be observed. Further optical study indicates that

crystal properties are symmetrical about its optic axis. This is also true for hardness properties of calcite and NaNO_3 (cf. chapter V). Hence it can be conjectured from the data of ' n_1 '_{mod} and ' n_1 '_{obs} and ' W_1 ' for 28° and 35° at 303°K for calcite that high value of ' n_1 '_{obs} (or ' n_1 '_{mod}) and finite ' W_1 ' should indicate the anisotropic character of the crystal along this direction instead of work-hardening capacity /2/. This conclusion is supported by values of ' n_2 '_{mod} and ' W_2 ' in HLR for calcite. Consideration of the values of ' n '_{mod} and W (Table 4.3A (i) to (v)) for NaNO_3 on the basis of these arguments leads to the above conclusion.

The above discussion suggests that for $n = 2$ and finite resistance pressure, the Meyer's law/Kick's law is independent of the geometrical nature of the indenter. However it should be remarked that optical study of microstructures of indented surfaces by high resolution microscopy indicate that indentations for different applied loads and fixed orientations are similar but not identical.

4.5 CONCLUSIONS:

The following conclusions can be drawn from the experimental study of variation of applied load with longer diagonal of the Knoop indentation mark for different orientations and quenching temperatures.

- (a) For calcite, the graph of $\log d$ versus $\log P$ consists of two clearly recognizable straight lines having different slopes (n_1 and n_2) and intercepts (giving the values for a_1 and a_2) on the axis for low and high applied loads respectively, whereas in case of NaNO_3 , for all applied loads, only a single straight line can be obtained for different orientations and quenching temperatures. For calcite, the variations of n_1 , a_1 appear to have no clear relation with A and T_q whereas n_2 , a_2 are almost independent of both A and T_q . For NaNO_3 crystals a and n are independent of A but depend on T_q .

- (b) The variation in the exponent of 'd' can be eliminated by employing modified Kick's law, where the exponent is $\simeq 2$ and standard hardness values 'a₁' and 'a₂' replaced by b₁ and b₂ in case of calcite and 'a' replaced by 'b' in case of NaNO₃, where b₁ > a₁ and b₂ < a₂ for different orientations and quenching temperatures.
- (c) The sign (+ve or -ve value) of the resistance pressure is more important for considering the applicability of modified Kick's law and less for modified n₁ values. W₁ has negative values in LLR. Hence in case of natural crystals of calcite modified Kick's law is not applicable for low values of applied loads whereas it is applicable for high load values. For NaNO₃ it is applicable.
- (d) The indentation does produce plastic deformation (hence work-hardening) and cold working along with some elastic recovery; however the present analysis is insufficient to explain the physics of static indentation hardness.
- (e) For n = 2 and finite resistance pressure W, Meyer's law/Kick's law is independent of the indenter geometry.
- (f) The values of 'n' different from 2 and finite W for different but constant values of orientations at room temperature are indicative of the anisotropic character of crystal.

TABLE 4.1 A(i)

(for NaNO_3)Room Temperature : $T_1 = 298^\circ\text{K}$

Log P	Log d						
	A = 0°	A = 13°	A = 26°	A = 39°	A = 52°	A = 65°	A = 78°
0.0969	1.3588	1.3888	1.4168	1.4168	1.5349	1.3888	1.3740
0.3979	1.5244	1.5451	1.5451	1.5649	1.6106	1.5649	1.5451
0.5740	1.6359	1.6520	1.6440	1.6675	1.6898	1.6751	1.6520
0.6989	1.6970	1.7178	1.7440	1.7441	1.7505	1.7441	1.7110
0.7958	1.7505	1.7567	1.7867	1.8037	1.8037	1.7925	1.7629
0.8750	1.8093	1.8093	1.8411	1.8461	1.8411	1.8411	1.8201
0.9420	1.8359	1.8512	1.8754	1.8754	1.8801	1.8801	1.8512
1.0000	1.8659	1.8894	1.9029	1.9160	1.9245	1.9029	1.8754
1.0511	1.8894	1.9116	1.9202	1.9451	1.9491	1.9410	1.9073
1.0969	1.9116	1.9328	1.9570	1.9647	1.9835	1.9609	1.9328
1.1383	1.9328	1.9647	1.9761	1.9872	2.0015	1.9872	1.9491
1.1760	1.9723	1.9761	1.9908	2.0051	2.0154	2.0051	1.9685
1.2108	1.9835	2.0015	2.0420	2.0289	2.0355	2.0222	1.9685
1.2430	1.9981	2.0189	2.0515	2.0452	2.0515	2.0420	1.9872
1.2730	2.0120	2.0383	2.0575	2.0578	2.0760	2.0700	2.0222
1.3010	2.0355	2.0484	2.0700	2.0790	2.0877	2.0819	2.0355
1.3979	2.0819	2.1020	2.1317	2.1369	2.1421	2.1238	2.0877
1.4771	2.1292	2.1421	2.1741	2.1765	2.1812	2.1621	2.1344
1.6020	2.1949	2.2170	2.2481	2.2380	2.2521	2.2359	2.1994
1.6989	2.2441	2.2638	2.2919	2.2972	2.3026	2.2846	2.2461
1.7781	2.2900	2.3078	2.3446	2.3494	2.3414	2.3283	2.2937
1.8451	2.3216	2.3349	2.3785	2.3888	2.3888	2.3650	2.3249
1.9031	2.3557	2.3725	2.4100	2.4195	2.4113	2.3916	2.3619
2.0000	2.4100	2.4235	2.4582	2.4703	2.4606	2.4418	2.4127
2.0791	2.4469	2.4679	2.5027	2.5137	2.5082	2.4857	2.4495
2.1461	2.4857	2.5027	2.5349	2.5421	2.5390	2.5328	2.4880
2.2041	2.5137	2.5297	2.5716	2.5772	2.5697	2.5451	2.5159

TABLE 4.1 A(ii)

(for NaNO_3)Quenching Temperature: $T_{q_1} = 343^\circ\text{K}$

Log P	Log d						
	A = 0°	A = 13°	A = 26°	A = 39°	A = 52°	A = 65°	A = 78°
0.0969	1.3588	1.3588	1.4030	1.4030	1.3888	1.3888	1.4679
0.3979	1.5244	1.5349	1.5649	1.5649	1.5837	1.5649	1.6192
0.5740	1.6359	1.6359	1.6751	1.6598	1.6675	1.6675	1.6751
0.6989	1.6970	1.7178	1.7377	1.7377	1.7312	1.7246	1.7377
0.7958	1.7505	1.7750	1.7981	1.7925	1.7925	1.7750	1.7809
0.8750	1.7925	1.8201	1.8461	1.8411	1.8461	1.8093	1.8307
0.9420	1.8259	1.8561	1.8801	1.8801	1.8801	1.8411	1.8659
1.0000	1.8610	1.8894	1.9116	1.9073	1.9073	1.8754	1.8894
1.0511	1.8894	1.9202	1.9451	1.9328	1.9410	1.9073	1.9116
1.0969	1.9160	1.9410	1.9685	1.9530	1.9647	1.9369	1.9202
1.1383	1.9410	1.9647	1.9872	1.9723	1.9835	1.9570	1.9451
1.1760	1.9609	1.9872	1.0120	1.9980	1.9981	1.9835	1.9685
1.2108	1.9761	2.0051	2.0322	2.0189	2.0154	2.0051	1.9980
1.2430	1.9944	2.0189	2.0484	2.0420	2.0322	2.0189	2.0086
1.2730	2.0189	2.0289	2.0609	2.0515	2.0515	2.0355	2.0222
1.3010	2.0355	2.0547	2.0819	2.0700	2.0730	2.0578	2.0355
1.3979	2.0819	2.1048	2.1369	2.1212	2.1344	2.0963	2.0819
1.4771	2.1291	2.1547	2.1765	2.1669	2.1740	2.1421	2.1344
1.6020	2.1927	2.2170	2.2421	2.2339	2.2359	2.2017	2.2017
1.6989	2.2441	2.2715	2.2937	2.2827	2.2900	2.2580	2.2501
1.7781	2.2846	2.3096	2.3316	2.3249	2.3283	2.3008	2.2882
1.8451	2.3148	2.3510	2.3695	2.3572	2.3680	2.3332	2.3266
1.9031	2.3572	2.3755	2.3974	2.3902	2.4072	2.3634	2.3603
2.0000	2.4016	2.4302	2.4482	2.4406	2.4569	2.4341	2.4154
2.0791	2.4444	2.4679	2.4903	2.4822	2.4982	2.4727	2.4545
2.1461	2.4798	2.5027	2.5276	2.5137	2.5286	2.5005	2.4994
2.2041	2.5082	2.5370	2.5551	2.5400	2.5866	2.5359	2.5223

TABLE 4.1 A(iii)

(for NaNO_3)Quenching Temperature: $T_{q_2} = 393^\circ\text{K}$

Log P	Log d						
	A = 0°	A = 13°	A = 26°	A = 39°	A = 52°	A = 65°	A = 78°
0.0969	1.4914	1.4168	1.4557	1.4557	1.4557	1.4557	1.4557
0.3979	1.6106	1.5837	1.6106	1.5929	1.6276	1.6018	1.6106
0.5740	1.6825	1.6751	1.6898	1.7110	1.7040	1.6751	1.6898
0.6989	1.7246	1.7441	1.7750	1.7690	1.7809	1.7441	1.7441
0.7958	1.7809	1.7981	1.8147	1.8307	1.8147	1.8037	1.7981
0.8750	1.8147	1.8411	1.8659	1.8801	1.8610	1.8411	1.8407
0.9420	1.8659	1.8754	1.8984	1.9029	1.9073	1.8801	1.8659
1.0000	1.8939	1.9073	1.9287	1.9328	1.9328	1.8939	1.9029
1.0511	1.9116	1.9287	1.9609	1.9609	1.9530	1.9160	1.9287
1.0969	1.9410	1.9609	1.9723	1.9872	1.9723	1.9530	1.9451
1.1383	1.9723	1.9761	1.9980	2.0120	2.0015	1.9761	1.9723
1.1760	2.0015	1.9980	2.0189	2.0256	2.0256	2.0051	1.9908
1.2108	2.0154	2.0154	2.0452	2.0387	2.0420	2.0120	2.0086
1.2430	2.0154	2.0355	2.0609	2.0578	2.0578	2.0322	2.0256
1.2730	2.0452	2.0547	2.0760	2.0819	2.0760	2.0484	2.0484
1.3010	2.0609	2.0700	2.0877	2.0963	2.0963	2.0609	2.0639
1.3979	2.1158	2.1158	2.1421	2.1547	2.1369	2.1212	2.1158
1.4771	2.1621	2.1621	2.1858	2.1904	2.1812	2.1547	2.1572
1.6020	2.2191	2.2234	2.2599	2.2541	2.2461	2.2276	2.2234
1.6989	2.2677	2.2734	2.3096	2.3096	2.3008	2.2734	2.2753
1.7781	2.3148	2.3199	2.3494	2.3710	2.3478	2.3148	2.3096
1.8451	2.3430	2.3572	2.3844	2.3815	2.3888	2.3510	2.3430
1.9031	2.3844	2.3815	2.4141	2.4302	2.4262	2.3888	2.3740
2.0000	2.4275	2.4341	2.4691	2.4715	2.4667	2.4341	2.4235
2.0791	2.4751	2.4715	2.5082	2.5223	2.5104	2.4739	2.4679
2.1461	2.5027	2.5082	2.5431	2.5451	2.5501	2.5060	2.5061
2.2041	2.5328	2.5451	2.5753	2.5856	2.5810	2.5451	2.5297

TABLE 4.1 A (iv)

(for NaNO_3)Quenching Temperature: $T_{q3} = 443^\circ\text{K}$

Log P	Log d						
	A = 0°	A = 13°	A = 26°	A = 39°	A = 52°	A = 65°	A = 78°
0.0969	1.4557	1.4679	1.4431	1.4798	1.4302	1.3888	1.4168
0.3979	1.5837	1.5744	1.5929	1.6106	1.5837	1.5744	1.5929
0.5740	1.6675	1.6751	1.6898	1.7040	1.6898	1.6751	1.6898
0.6989	1.7441	1.7377	1.7629	1.7809	1.7629	1.7312	1.7441
0.7958	1.7867	1.7981	1.8307	1.8255	1.8255	1.7925	1.7981
0.8750	1.8201	1.8512	1.8659	1.8848	1.8610	1.8561	1.8411
0.9420	1.8707	1.8848	1.8939	1.9116	1.8984	1.8848	1.8754
1.0000	1.8939	1.9029	1.9328	1.9451	1.9287	1.9116	1.9073
1.0511	1.9202	1.9287	1.9570	1.9723	1.9570	1.9369	1.9328
1.0969	1.9451	1.9530	1.9835	1.9944	1.9723	1.9609	1.9491
1.1383	1.9685	1.9761	2.0051	2.0154	1.9944	1.9798	1.9723
1.1760	1.9908	1.9981	2.0256	2.0289	2.0489	1.9980	1.9944
1.2108	2.0086	2.0120	2.0484	2.0547	2.0452	2.0222	2.0086
1.2430	2.0222	2.0355	2.0670	2.0700	2.0639	2.0322	2.0256
1.2730	2.0387	2.0387	2.0906	2.0877	2.0819	2.0484	2.0420
1.3010	2.0547	2.0700	2.1048	2.1020	2.1020	2.0730	2.0609
1.3979	2.1103	2.1212	2.1596	2.1547	2.1572	2.1238	2.1130
1.4771	2.1497	2.1645	2.1949	2.1972	2.1904	2.1596	2.1497
1.6020	2.2170	2.2276	2.2638	2.2677	2.2599	2.2297	2.2234
1.6989	2.2638	2.2827	2.3096	2.3148	2.3182	2.2827	2.2734
1.7781	2.3043	2.3233	2.3572	2.3680	2.3510	2.3266	2.3130
1.8451	2.3414	2.3557	2.3888	2.3988	2.4002	2.3665	2.3510
1.9031	2.3665	2.3844	2.4208	2.4275	2.4367	2.3888	2.3815
2.0000	2.4168	2.4302	2.4715	2.4739	2.4619	2.4393	2.4249
2.0791	2.4619	2.4751	2.5202	2.5244	2.5137	2.4751	2.4739
2.1461	2.4937	2.5093	2.5531	2.5501	2.5451	2.5137	2.5082
2.2041	2.5255	2.5349	2.5819	2.5883	2.5730	2.5431	2.5370

TABLE 4.1 A(v)

(for NaNO_3)Quenching Temperature: $T_{q4} = 493^\circ\text{K}$

Log P	Log d						
	A = 0°	A = 13°	A = 26°	A = 39°	A = 52°	A = 65°	A = 78°
0.0969	1.4030	1.4431	1.4798	1.4798	1.4679	1.4030	1.3888
0.3979	1.5551	1.5744	1.6276	1.6192	1.6106	1.6018	1.5929
0.5740	1.6598	1.6898	1.7040	1.7178	1.7040	1.7040	1.6751
0.6989	1.7312	1.7567	1.7690	1.7867	1.7629	1.7629	1.7567
0.7958	1.7809	1.7981	1.8255	1.8411	1.8255	1.8201	1.7867
0.8750	1.8255	1.8359	1.8659	1.8754	1.8659	1.8659	1.8359
0.9420	1.8561	1.8754	1.9073	1.9116	1.8894	1.9073	1.8754
1.0000	1.8894	1.9116	1.9328	1.9369	1.9287	1.9328	1.9116
1.0511	1.9116	1.9245	1.9530	1.9647	1.9547	1.9570	1.9328
1.0969	1.9451	1.9531	1.9872	1.9835	1.9761	1.9835	1.9530
1.1383	1.9647	1.9723	2.0086	2.0086	1.9980	1.9980	1.9835
1.1760	1.9761	1.9908	2.0289	2.0256	2.0189	2.0189	2.0015
1.2108	1.9908	2.0051	2.0515	2.0420	2.0420	2.0452	2.0154
1.2430	2.0120	2.0289	2.0639	2.0639	2.0578	2.0609	2.0322
1.2730	2.0256	2.0420	2.0760	2.0877	2.0700	2.0730	2.0484
1.3010	2.0420	2.0609	2.0877	2.1020	2.0877	2.0877	2.0609
1.3979	2.0963	2.1130	2.1446	2.1693	2.1421	2.1446	2.1185
1.4771	2.1497	2.1547	2.1812	2.1972	2.1788	2.1788	2.1596
1.6020	2.2127	2.2191	2.2521	2.2657	2.2541	2.2541	2.2234
1.6989	2.2541	2.2638	2.3148	2.3008	2.3026	2.2919	2.2753
1.7781	2.3043	2.3078	2.3588	2.3680	2.3430	2.3510	2.3182
1.8451	2.3316	2.3430	2.3945	2.3916	2.3770	2.3665	2.3510
1.9031	2.3588	2.3740	2.4141	2.4275	2.4072	2.3959	2.3800
2.0000	2.4168	2.4208	2.4679	2.4739	2.4532	2.4557	2.4302
2.0791	2.4619	2.4655	2.5159	2.5191	2.4971	2.5027	2.4751
2.1461	2.4937	2.5038	2.5481	2.5501	2.5265	2.5318	2.5071
2.2041	2.5234	2.5297	2.5791	2.5883	2.5590	2.5531	2.5349

TABLE 4.1 B(i)

(for CaCO_3)Room Temperature: $T_1^{\circ}\text{K} = 303^{\circ}\text{K}$

Log P	Log d						
	A = 0°	A = 7°	A = 14°	A = 21°	A = 28°	A = 35°	A = 39°
0.0969	1.1141	0.9909	1.0256	1.0420	1.0080	0.9908	1.0578
0.3979	1.2062	1.1291	1.1547	1.1421	1.1421	1.1291	1.1788
0.5740	1.2747	1.2017	1.2339	1.2234	1.2234	1.2017	1.2541
0.6989	1.3146	1.2541	1.2919	1.2827	1.2827	1.2638	1.3096
0.7958	1.3549	1.3182	1.3430	1.3510	1.3510	1.3182	1.3740
0.8750	1.3924	1.3665	1.3815	1.4100	1.4100	1.3588	1.4235
0.9420	1.4208	1.4030	1.4168	1.4431	1.4431	1.3959	1.4619
1.0000	1.4705	1.4431	1.4557	1.4739	1.4857	1.4557	1.5137
1.0511	1.5039	1.4857	1.4798	1.4914	1.5137	1.5083	1.5600
1.0969	1.5336	1.5191	1.5137	1.5297	1.5400	1.5297	1.6062
1.1383	1.5573	1.5551	1.5400	1.5501	1.5600	1.5974	1.6318
1.1761	1.5756	1.5929	1.5791	1.5744	1.5791	1.6318	1.6520
1.2108	1.6045	1.6106	1.6018	1.6149	1.5929	1.6520	1.6751
1.2430	1.6199	1.6359	1.6149	1.6318	1.6234	1.6713	1.6934
1.2730	1.6400	1.6521	1.6318	1.6480	1.6440	1.6898	1.7246
1.3010	1.6571	1.6675	1.6520	1.6788	1.6713	1.7345	1.7567
1.4771	1.7483	1.7567	1.7279	1.7598	1.7567	1.8411	1.8561
1.6021	1.8184	1.8281	1.8174	1.8436	1.8147	1.8848	1.9095
1.6989	1.8770	1.8778	1.8659	1.8916	1.8801	1.9224	1.9349
1.7781	1.9182	1.9202	1.9116	1.9224	1.9430	1.9530	1.9628
1.8450	1.9644	1.9628	1.9430	1.9628	1.9723	1.9872	2.0051
1.9030	1.9878	1.9908	1.9742	1.9761	1.9980	2.0339	2.0339

TABLE 4.1 B(ii)

(for CaCO_3)Quenching Temperature : $T_{q1}^{\circ\text{K}} = 498^{\circ\text{K}}$

log P	log d					
	A = 0°	A = 7°	A = 14°	A = 21°	A = 28°	A = 35°
0.0969	0.9908	0.9908	0.9908	1.0086	1.0086	1.0086
0.3979	1.1291	1.1291	1.1291	1.1421	1.1421	1.1421
0.5740	1.2127	1.2127	1.2127	1.2234	1.2234	1.2234
0.6989	1.2827	1.2827	1.2827	1.2919	1.2919	1.3008
0.7958	1.3349	1.3430	1.3430	1.3510	1.3510	1.3588
0.8750	1.3815	1.3888	1.3888	1.3959	1.4030	1.4100
0.9420	1.4235	1.4367	1.4367	1.4367	1.4431	1.4495
1.0000	1.4557	1.4619	1.4619	1.4679	1.4619	1.4857
1.0511	1.4857	1.4798	1.4857	1.4914	1.4914	1.5137
1.0969	1.5137	1.5027	1.5137	1.5137	1.5191	1.5400
1.1383	1.5400	1.5451	1.5501	1.5551	1.5501	1.5649
1.1761	1.5600	1.5649	1.5697	1.5744	1.5697	1.5929
1.2108	1.5744	1.5791	1.5837	1.5837	1.5883	1.6062
1.2430	1.5929	1.5929	1.5974	1.6018	1.6018	1.6234
1.2730	1.6106	1.6149	1.6149	1.6234	1.6276	1.6440
1.3010	1.6234	1.6276	1.6318	1.6400	1.6440	1.6713
1.4771	1.7246	1.7279	1.7377	1.7409	1.7441	1.7720
1.6021	1.8009	1.8093	1.8147	1.8228	1.8333	1.8461
1.6989	1.8535	1.8659	1.8659	1.8754	1.8778	1.8916
1.7181	1.9051	1.9116	1.9202	1.9266	1.9328	1.9451
1.8450	1.9430	1.9471	1.9511	1.9570	1.9685	1.9817
1.9030	1.9685	1.9723	1.9761	1.9854	1.9908	2.0103

TABLE 4.1 B(iii)

(for CaCO_3)Quenching Temperature : $T_{q2}^{\circ\text{K}} = 573^{\circ\text{K}}$

log P	log d					
	A = 0°	A = 7°	A = 14°	A = 21°	A = 28°	A = 35°
0.0969	0.9723	0.9723	0.9908	0.9908	1.0086	1.0086
0.3979	1.1158	1.1158	1.1291	1.1291	1.1421	1.1421
0.5740	1.1904	1.1904	1.2017	1.2017	1.2017	1.2127
0.6989	1.2734	1.2734	1.2734	1.2827	1.2827	1.2919
0.7958	1.3266	1.3349	1.3349	1.3430	1.3430	1.3510
0.8750	1.3740	1.3815	1.3815	1.3888	1.3959	1.4030
0.9420	1.4168	1.4235	1.4235	1.4302	1.4302	1.4431
1.0000	1.4495	1.4557	1.4557	1.4619	1.4619	1.4798
1.0511	1.4798	1.4857	1.4857	1.4857	1.4914	1.5082
1.0969	1.5082	1.5191	1.5191	1.5082	1.5137	1.5297
1.1383	1.5340	1.5400	1.5400	1.5451	1.5501	1.5600
1.1761	1.5501	1.5600	1.5551	1.5600	1.5791	1.5883
1.2108	1.5649	1.5697	1.5744	1.5791	1.5837	1.6018
1.2430	1.5837	1.5883	1.5929	1.5974	1.5974	1.6106
1.2730	1.6018	1.6062	1.6106	1.6149	1.6192	1.6400
1.3010	1.6149	1.6192	1.6234	1.6276	1.6318	1.6637
1.4771	1.7178	1.7246	1.7345	1.7377	1.7409	1.7690
1.6021	1.7953	1.8009	1.8037	1.8120	1.8281	1.8333
1.6989	1.8536	1.8586	1.8610	1.8635	1.8707	1.8871
1.7181	1.9006	1.9029	1.9073	1.9095	1.9224	1.9390
1.8450	1.9328	1.9430	1.9471	1.9491	1.9530	1.9723
1.9030	1.9628	1.9685	1.9742	1.9817	1.9817	1.9908

TABLE 4.1 B(iv)

(for CaCO_3)Quenching Temperature : $T_{q3}^{\circ\text{K}} = 698^{\circ\text{K}}$

log P	log d					
	A = 0°	A = 7°	A = 14°	A = 21°	A = 28°	A = 35°
0.0969	0.9530	0.9530	0.9530	0.9723	0.9723	0.9723
0.3979	1.1020	1.1020	1.1020	1.1158	1.1158	1.1158
0.5740	1.2017	1.2017	1.2127	1.2234	1.2234	1.2339
0.6989	1.2734	1.2734	1.2827	1.2827	1.2919	1.2919
0.7958	1.3096	1.3182	1.3182	1.3266	1.3349	1.3430
0.8750	1.3588	1.3588	1.3665	1.3665	1.3740	1.3815
0.9420	1.4100	1.4100	1.4168	1.4168	1.4235	1.4302
1.0000	1.4367	1.4367	1.4431	1.4495	1.4557	1.4619
1.0511	1.4679	1.4739	1.4798	1.4857	1.4914	1.4971
1.0969	1.4971	1.4971	1.5027	1.5027	1.5082	1.5137
1.1383	1.5297	1.5297	1.5349	1.5349	1.5400	1.5451
1.1761	1.5400	1.5451	1.5501	1.5600	1.5649	1.5744
1.2108	1.5600	1.5697	1.5791	1.5837	1.5883	1.5929
1.2430	1.5791	1.5837	1.5929	1.5971	1.6018	1.6062
1.2730	1.5974	1.6018	1.6106	1.6192	1.6276	1.6318
1.3010	1.6106	1.6192	1.6276	1.6359	1.6440	1.6520
1.4771	1.7110	1.7178	1.7246	1.7345	1.7441	1.7567
1.6021	1.7896	1.7953	1.7981	1.8065	1.8093	1.8174
1.6989	1.8487	1.8536	1.8635	1.8707	1.8778	1.8825
1.7181	1.8916	1.9029	1.9116	1.9202	1.9287	1.9328
1.8450	1.9349	1.9390	1.9430	1.9491	1.9570	1.9609
1.9030	1.9570	1.9628	1.9666	1.9761	1.9742	1.9817

TABLE 4.1 B(v)

(for CaCO_3)Quenching Temperature: $T_{Q4} \text{ } ^\circ\text{K} = 773^\circ\text{K}$

log P	log d					
	A = 0°	A = 7°	A = 14°	A = 21°	A = 28°	A = 35°
0.0969	0.9530	0.9530	0.9530	0.9723	0.9723	0.9723
0.3979	1.0877	1.0877	1.0877	1.1020	1.1020	1.1020
0.5740	1.1904	1.1788	1.1904	1.1904	1.1904	1.2017
0.6989	1.2638	1.2638	1.2538	1.2734	1.2734	1.2827
0.7958	1.3182	1.3182	1.3182	1.3266	1.3266	1.3349
0.8750	1.3665	1.3665	1.3740	1.3740	1.3815	1.3888
0.9420	1.4030	1.4030	1.4100	1.4168	1.4168	1.4135
1.0000	1.4367	1.4367	1.4431	1.4495	1.4495	1.4557
1.0511	1.4619	1.4679	1.4739	1.4798	1.4857	1.4914
1.0969	1.4914	1.4971	1.5027	1.5082	1.5137	1.5191
1.1383	1.5244	1.5244	1.5297	1.5349	1.5400	1.5400
1.1761	1.5349	1.5400	1.5501	1.5600	1.5649	1.5697
1.2108	1.5551	1.5649	1.5697	1.5744	1.5791	1.5883
1.2430	1.5744	1.5791	1.5837	1.5929	1.5974	1.6018
1.2730	1.5883	1.5974	1.6062	1.6149	1.6192	1.6276
1.3010	1.6062	1.6149	1.6234	1.6318	1.6400	1.6440
1.4771	1.7144	1.7212	1.7279	1.7345	1.7409	1.7505
1.6021	1.7867	1.7953	1.8065	1.8120	1.8174	1.8228
1.6989	1.8411	1.8487	1.8536	1.8635	1.8683	1.8778
1.7181	1.8894	1.8939	1.9006	1.9073	1.9116	1.9224
1.8450	1.9224	1.9266	1.9328	1.9390	1.9491	1.9570
1.9030	1.9530	1.9589	1.9647	1.9742	1.9798	1.9854

TABLE 4.2(A)

NaNO₃

Temp = 298°K

Orientation (A) = 0°

P in gm	d in μ	log P	log d	d^2 $\times 10^3$	d^n $\times 10^3$	(P-W) gm	log(P-W)
1.25	22.85	0.0969	1.3588	0.522	0.328	0.52	2.7160
2.5	33.46	0.3979	1.5244	1.119	0.665	1.302	0.1146
3.75	43.25	0.5740	1.6359	1.870	1.070	2.552	0.4068
5.0	49.76	0.6989	1.6970	2.476	1.387	3.802	0.5800
6.25	56.30	0.7958	1.7505	3.169	1.744	5.052	0.7034
7.5	64.46	0.8750	1.8093	4.155	2.241	6.302	0.7994
8.75	68.54	0.9420	1.8359	4.697	2.510	7.552	0.8781
10.0	73.44	1.0000	1.8659	5.393	2.853	8.802	0.9445
11.25	77.52	1.0511	1.8894	6.009	3.153	10.052	1.0022
12.5	81.60	1.0969	1.9116	6.658	3.467	11.302	1.0531
13.75	85.68	1.1383	1.9328	7.341	3.795	12.552	1.0987
15.0	93.84	1.1760	1.9723	8.805	4.492	13.802	1.1399
16.25	94.29	1.2108	1.9835	8.890	4.532	15.052	1.1775
17.5	99.55	1.2430	1.9981	9.910	5.011	16.302	1.2122
18.75	102.82	1.2730	2.0120	10.571	5.320	17.552	1.2443
20.0	108.52	1.3010	2.0355	11.776	5.879	18.802	1.2742
25.0	120.77	1.3979	2.0819	14.585	7.167	23.802	1.3766
30.0	134.64	1.4771	2.1292	18.127	8.766	28.802	1.4594
40.0	156.67	1.6020	2.1949	24.545	11.605	38.802	1.5888
50.0	175.44	1.6989	2.2441	30.779	14.311	48.802	1.6884
60.0	195.02	1.7781	2.2900	38.032	17.408	58.802	1.7693
70.0	205.71	1.8451	2.3216	43.978	19.914	68.802	1.8376
80.0	226.85	1.9031	2.3557	51.460	23.033	78.802	1.8965
100.0	257.04	2.0000	2.4100	66.069	29.029	98.802	1.9947
120.0	279.89	2.0791	2.4469	78.338	33.988	118.802	2.0748
140.0	306.00	2.1461	2.4857	93.88	40.189	138.802	2.1423
160.0	326.40	2.2040	2.5137	106.53	45.181	158.802	2.2008

TABLE 4.2(B)

CaCO₃

Temp = 303°K

Orientation (A) = 0°

P in gm	d in μ	log P	log d	d ² x10 ²	d ⁿ x10 ²	(P-W) gm	log(P-W)
1.25	13.0	0.0969	1.1141	1.69	4.71	1.922	0.2837
2.5	16.1	0.3979	1.2062	2.59	7.87	3.172	0.5013
3.75	18.8	0.5740	1.2747	3.53	11.42	4.422	0.6456
5.0	20.6	0.6989	1.3146	4.24	14.23	5.672	0.7537
6.25	22.6	0.7958	1.3549	5.10	17.77	6.922	0.8402
7.5	24.7	0.8750	1.3924	6.10	22.00	8.172	0.9123
8.75	26.4	0.9420	1.4208	6.96	25.81	9.422	0.9741
10.0	29.5	1.0000	1.4705	8.70	33.69	10.676	1.0282
11.25	31.9	1.0511	1.5039	10.17	3.13	3.695	0.5676
12.5	34.2	1.0969	1.5336	11.69	3.51	4.945	0.6941
13.75	36.1	1.1383	1.5573	13.03	3.85	6.195	0.7920
15.0	37.6	1.1761	1.5756	14.13	4.11	7.445	0.8718
16.25	40.2	1.2108	1.6045	16.16	4.60	8.695	0.9392
17.5	41.7	1.2430	1.6199	17.38	4.89	9.945	0.9976
18.75	43.7	1.2730	1.6400	19.09	5.28	11.195	1.0490
20.0	45.4	1.3010	1.6571	20.61	5.63	12.445	1.0949
30.0	56.0	1.4771	1.7483	31.36	7.97	22.445	1.3511
40.0	65.8	1.6021	1.8121	43.29	10.42	32.445	1.5111
50.0	75.3	1.6989	1.8770	56.70	13.04	42.445	1.6278
60.0	82.8	1.7781	1.9182	68.55	15.27	52.445	1.7197
70.0	92.1	1.8450	1.9644	84.82	18.22	62.445	1.7954
80.0	97.2	1.9030	1.9878	94.47	19.93	72.445	1.8600

TABLE 4.3 (A)

NaNO₃

Part I

(i) Room Temperature = 298°K					
Angle (A)	n _{obs}	n _{mod}	W	b x 10 ⁻³	a x 10 ⁻³
0	1.8518	1.928	1.198	1.5339	3.595
13	1.8	2.084	6.038	1.28	4.285
26	1.7857	2.0439	6.334	1.06	3.9165
39	1.7854	2.0179	6.1127	1.00	3.727
52	1.7307	2.2473	7.7453	0.927	4.8394
65	1.7302	2.2072	8.3747	1.1567	5.953
78	1.847	2.0644	4.6515	1.39	3.495
(ii) Quenching Temperature = 343°K					
0	1.86	2.0709	4.5082	1.53	3.5465
13	1.7755	2.1644	7.2911	1.293	5.029
26	1.8292	2.1035	5.2846	1.164	3.292
39	1.8556	2.0173	4.8545	1.2717	3.069
52	1.80	2.1609	5.9755	1.1635	3.908
65	1.8289	2.0177	5.1583	1.2766	3.6279
78	1.9769	1.8906	0.5166	1.105	1.727
(iii) Quenching Temperature = 393°K					
0	1.9354	2.026	2.014	1.362	2.01
13	1.8478	2.0506	4.529	1.202	3.023
26	1.9148	1.951	2.685	1.178	1.985
39	1.8627	1.9747	4.1759	1.066	2.478
52	1.8947	1.917	3.188	1.122	2.14
65	1.9587	1.9008	1.2757	1.367	1.755
78	1.9148	2.0357	2.516	1.297	2.168

Table 4.3 (A) (Contd.)

Part II

(iv) Quenching Temperature = 443°K					
Angle (A)	n_{obs}	n_{mod}	W	$b \times 10^{-3}$	$a \times 10^{-3}$
0	1.8478	2.0950	4.635	1.316	3.29
13	1.9230	2.0483	2.549	1.418	2.258
26	1.8367	2.0509	5.064	1.06	2.892
39	1.875	1.9848	3.872	1.068	2.304
52	1.7916	2.1192	6.311	1.034	3.708
65	1.8627	2.0433	4.385	1.316	3.022
78	1.8913	1.986	3.335	1.339	2.58
(v) Quenching Temperature = 493°K					
0	1.875	2.0807	3.977	1.408	2.985
13	1.875	2.0698	3.8458	1.327	2.818
26	1.875	2.0035	5.341	1.5675	3.371
39	1.8846	1.9729	3.539	1.064	2.164
52	1.9130	1.9955	2.611	1.177	1.999
65	1.9387	2.0008	1.974	1.30	1.8865
78	1.9387	2.0018	1.988	1.4248	2.062

TABLE 4.3 B(i)

CaCO_3
(For low load region)

Part I

(i) Temperature = 303°K						
Angle (A)	n_1 obs	n_1 mod	W_1	$b_1 \times 10^{-2}$	$a_1 \times 10^{-3}$	Load at kink P_k in gm ^k
0	2.4	2.359	-0.672	1.24	3.23	5.0
7	2.3	2.1591	-0.48	1.55	5.89	5.0
14	2.2	1.9971	-0.351	1.41	7.25	5.0
21	2.11	2.0335	-0.191	1.4	9.75	5.0
28	2.0	2.1454	0.0	1.25	12.5	3.75
35	2.0	2.2379	0.0	1.44	14.4	3.75
(ii) Quenching Temperature = 498°K						
0	2.11	1.8673	-0.187	1.42	9.87	3.75
7	2.11	1.8673	-0.187	1.42	9.87	3.75
14	2.37	1.6425	-0.691	1.75	5.26	3.75
21	2.22	1.8071	-0.403	1.52	7.39	3.75
28	2.22	1.8071	-0.403	1.52	7.39	3.75
35	2.0	1.9319	0.0	1.25	12.5	3.75
(iii) Quenching Temperature = 573°K						
0	2.37	1.6061	-0.678	1.82	5.49	3.75
7	2.62	1.4238	-1.217	2.16	2.49	3.75
14	2.33	1.7907	-0.589	1.68	5.75	3.75
21	2.33	1.6745	-0.603	1.69	5.75	3.75
28	2.44	1.7206	-0.861	1.83	4.36	3.75
35	2.2	1.8298	-0.355	1.47	7.58	3.75

Table 4.3 B(i) (Contd.)

Part II

(iv) Quenching Temperature = 698°K						
Angle (A)	n_1 obs	n_1 mod	W_1	$b_1 \times 10^{-2}$	$a_1 \times 10^{-3}$	Load at kink P_k in gm $_k$
0	1.9	1.9394	0.175	1.4	19.5	-
7	1.9	1.9394	0.175	1.4	19.5	-
14	2.2	1.4727	-0.407	1.92	10.0	-
21	2.08	1.7416	-0.144	1.52	11.7	-
28	2.08	1.6518	-0.146	1.52	11.7	-
35	2.08	1.6518	-0.146	1.52	11.7	-
(v) Quenching Temperature = 773°K						
0	2.2	1.5235	-0.375	1.9	10.0	2.5
7	2.37	1.2915	-1.072	2.35	6.92	2.5
14	2.11	1.4961	-0.447	1.85	12.5	2.5
21	2.18	1.5852	-0.323	1.7	9.51	3.75
28	2.18	1.5851	-0.323	1.7	9.51	3.75
35	2.08	1.5831	-0.136	1.52	11.7	3.75

TABLE 4.3 B(ii)

CaCO_3
(For high load region)

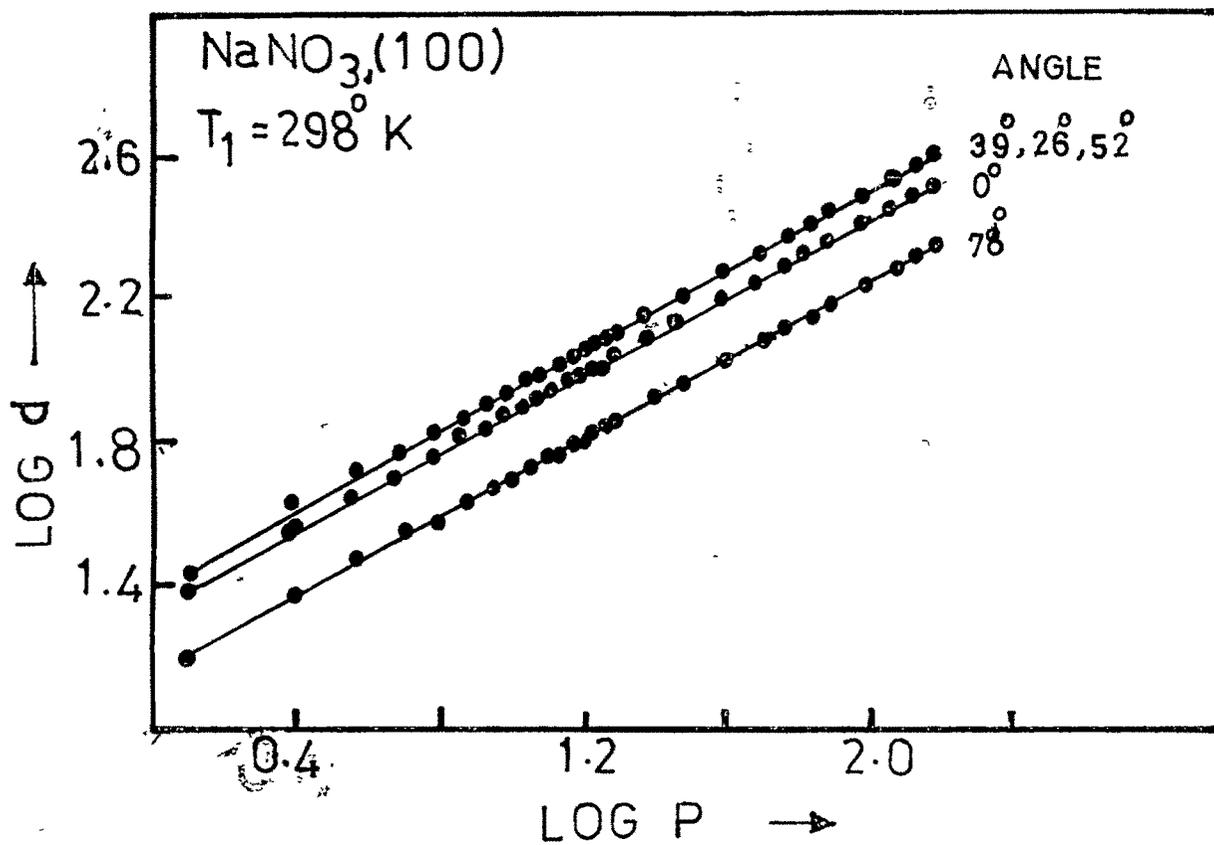
Part I

(i) Temperature = 303°K					
Angle (A)	n_2 obs	n_2 mod	W_2	$b_2 \times 10^{-3}$	$a_2 \times 10^{-2}$
0	1.66	2.124	7.555	7.0	3.7
7	1.68	2.1832	7.7259	7.497	3.6
14	1.75	1.9728	6.7781	8.368	2.81
21	1.64	2.368	7.8887	6.77	3.94
28	1.66	2.1129	7.6589	6.80	3.62
35	1.6	2.0306	7.3688	6.99	3.77
(ii) Quenching Temperature = 498°K					
0	1.66	2.0573	7.075	7.25	3.77
7	1.66	2.0588	7.169	7.235	3.77
14	1.66	2.1241	7.3912	7.199	3.77
21	1.61	2.1089	8.0097	6.407	4.32
28	1.69	2.0275	6.873	7.159	3.26
35	1.64	2.1714	8.133	6.309	3.75
(iii) Quenching Temperature = 573°K					
0	1.66	2.0722	7.496	7.907	4.09
7	1.66	2.0708	7.319	7.505	3.9
14	1.66	2.1162	7.369	7.27	3.8
21	1.63	2.1135	8.042	6.97	4.25
28	1.7	2.0698	6.735	7.48	3.23
35	1.66	2.3148	7.8186	6.823	3.63

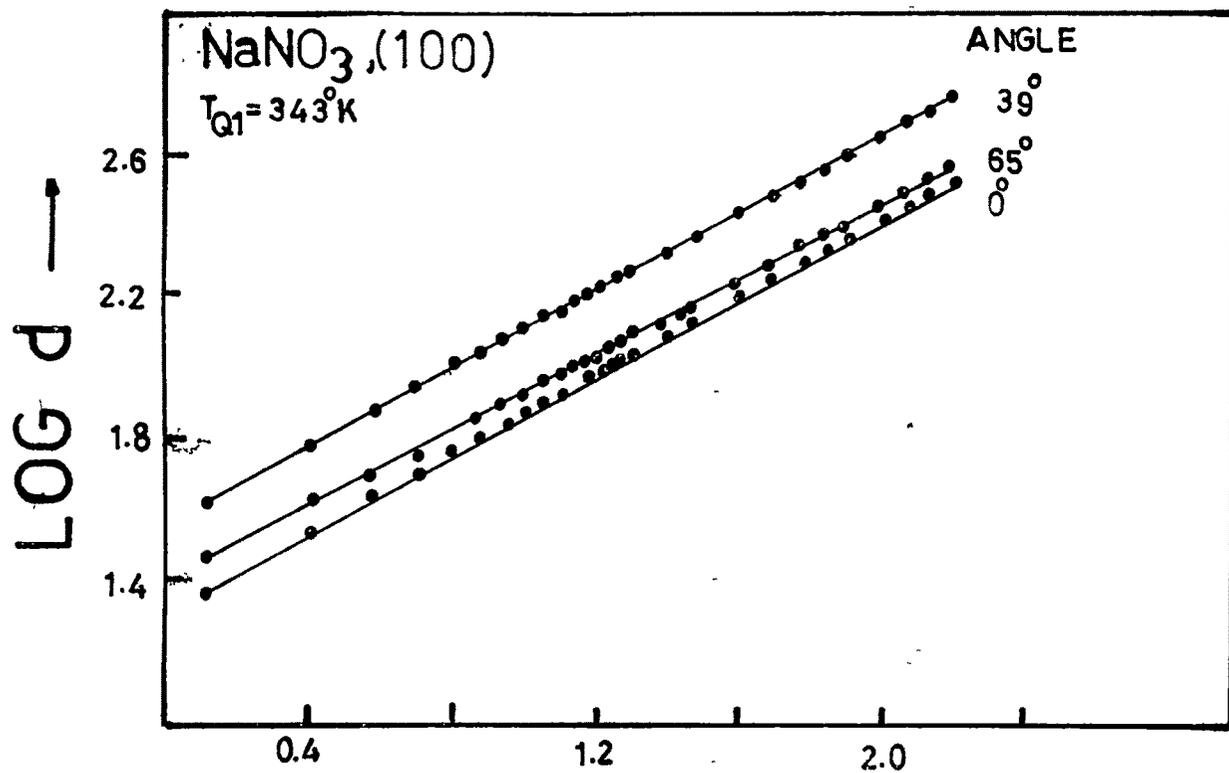
Table 4.3 B(ii)

Part II

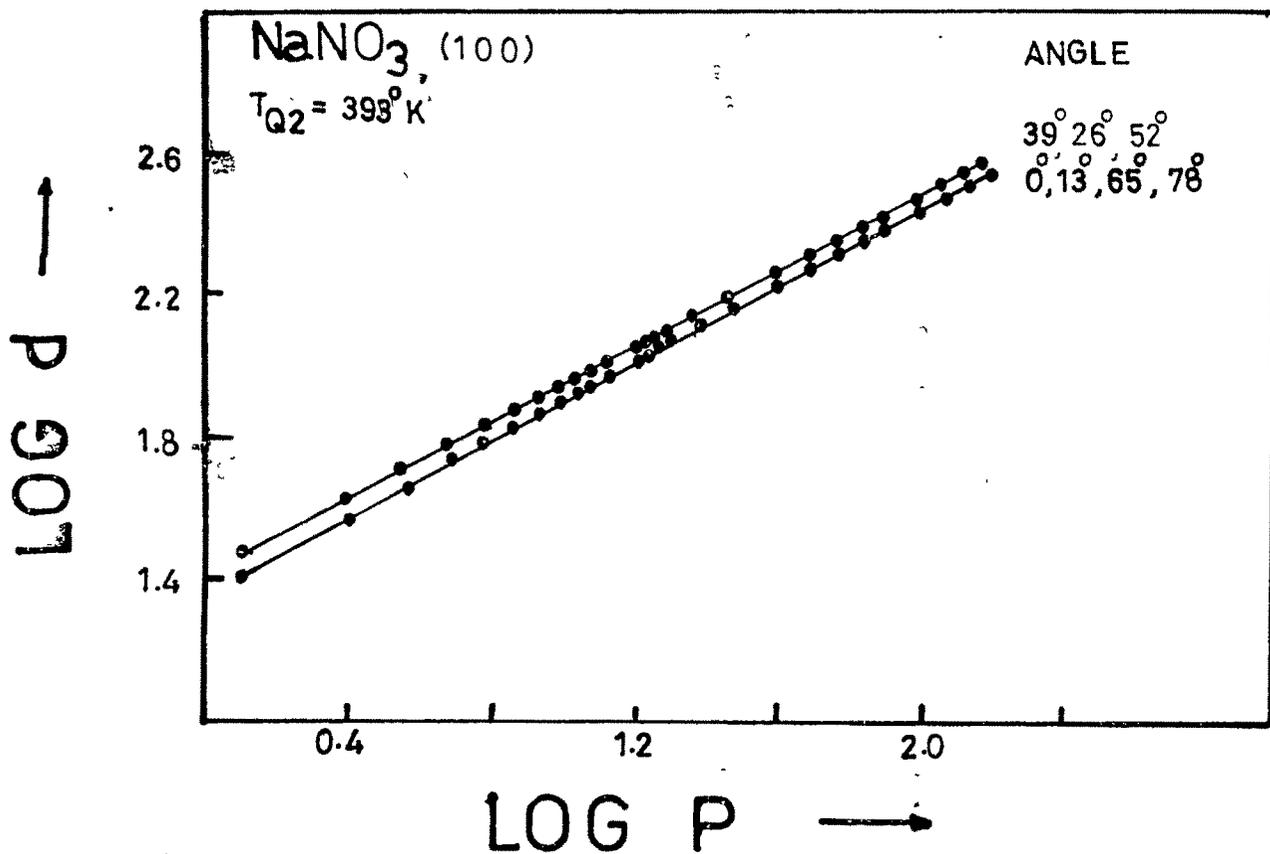
(iv) Quenching Temperature = 698°K					
Angle (A)	n_2 obs	n_2 mod	W_2	$b_2 \times 10^{-3}$	$a_2 \times 10^{-2}$
0	1.63	2.0978	8.115	7.9	4.73
7	1.66	2.0706	7.459	7.86	4.07
14	1.66	2.1027	7.617	7.84	4.07
21	1.61	2.1597	8.514	7.05	4.73
28	1.69	2.1946	7.191	7.74	3.5
35	1.66	2.2562	7.491	6.87	3.63
(v) Quenching Temperature = 773°K					
0	1.7	2.1046	7.114	8.97	3.8
7	1.666	2.1431	7.581	8.173	4.1
14	1.66	2.1509	7.653	7.84	4.07
21	1.61	2.1805	8.504	7.076	4.73
28	1.69	2.1113	7.204	7.726	3.5
35	1.66	2.1673	7.569	7.009	3.7



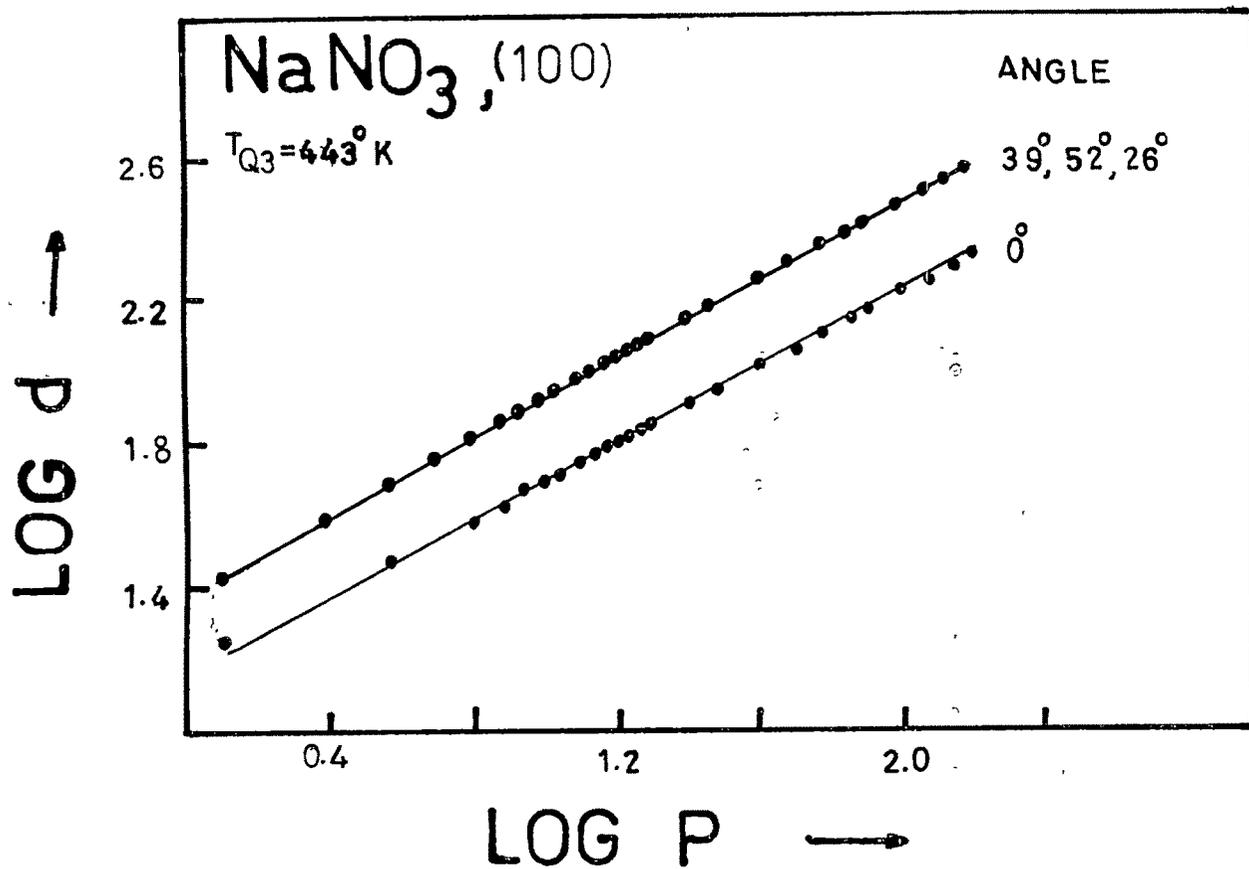
PLOT OF LOG d Vs LOG P
 FIG : 4.1(A) (i)



LOG P →
PLOT OF LOG d Vs LOG P
FIG:4.1(A)(ii)

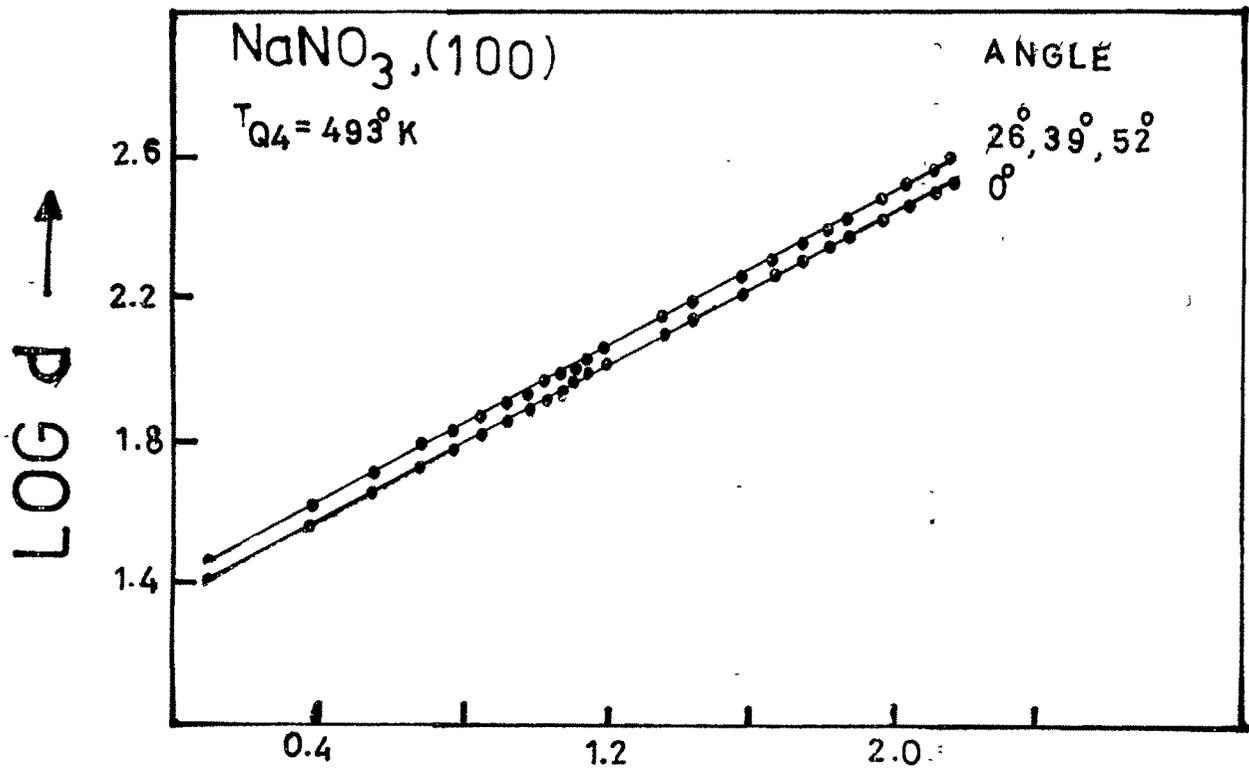


PLOT OF LOG d Vs LOG P
 FIG : 4.1(A) (iii)

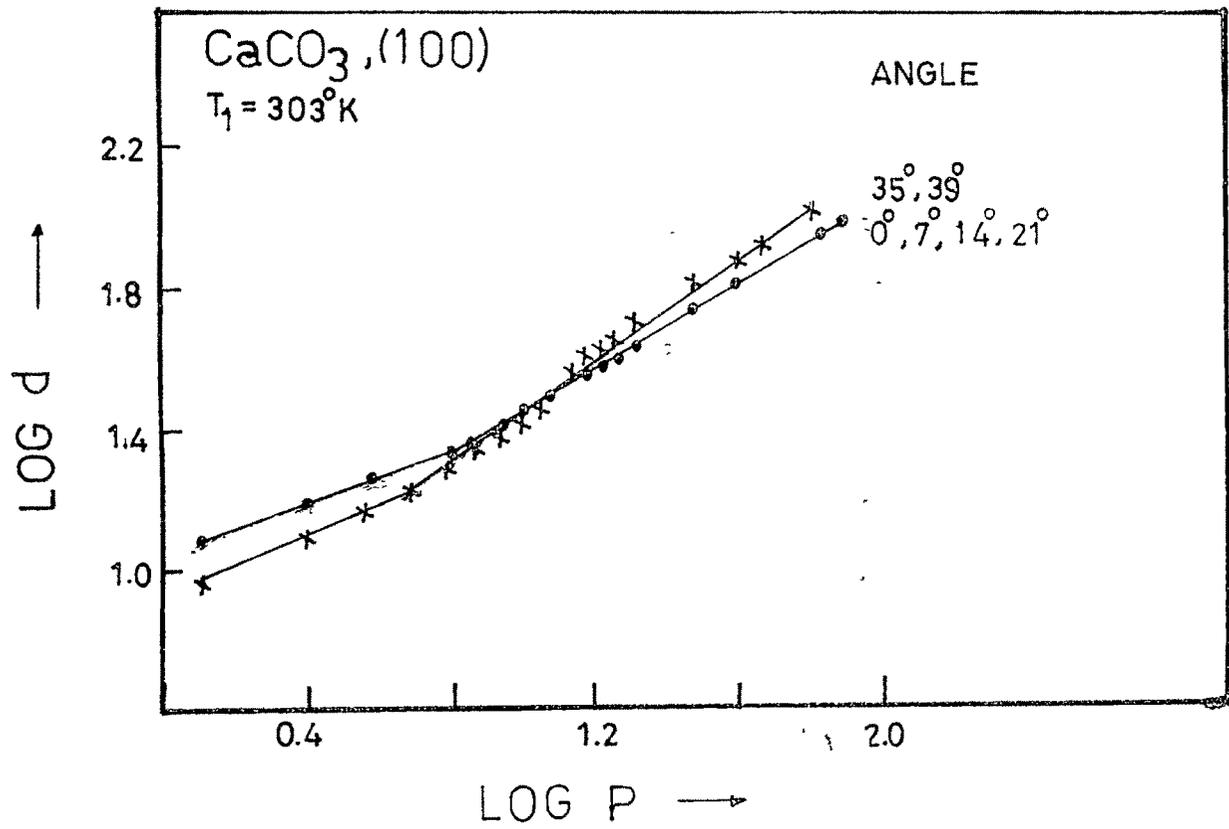


PLOT OF LOG d Vs LOG P

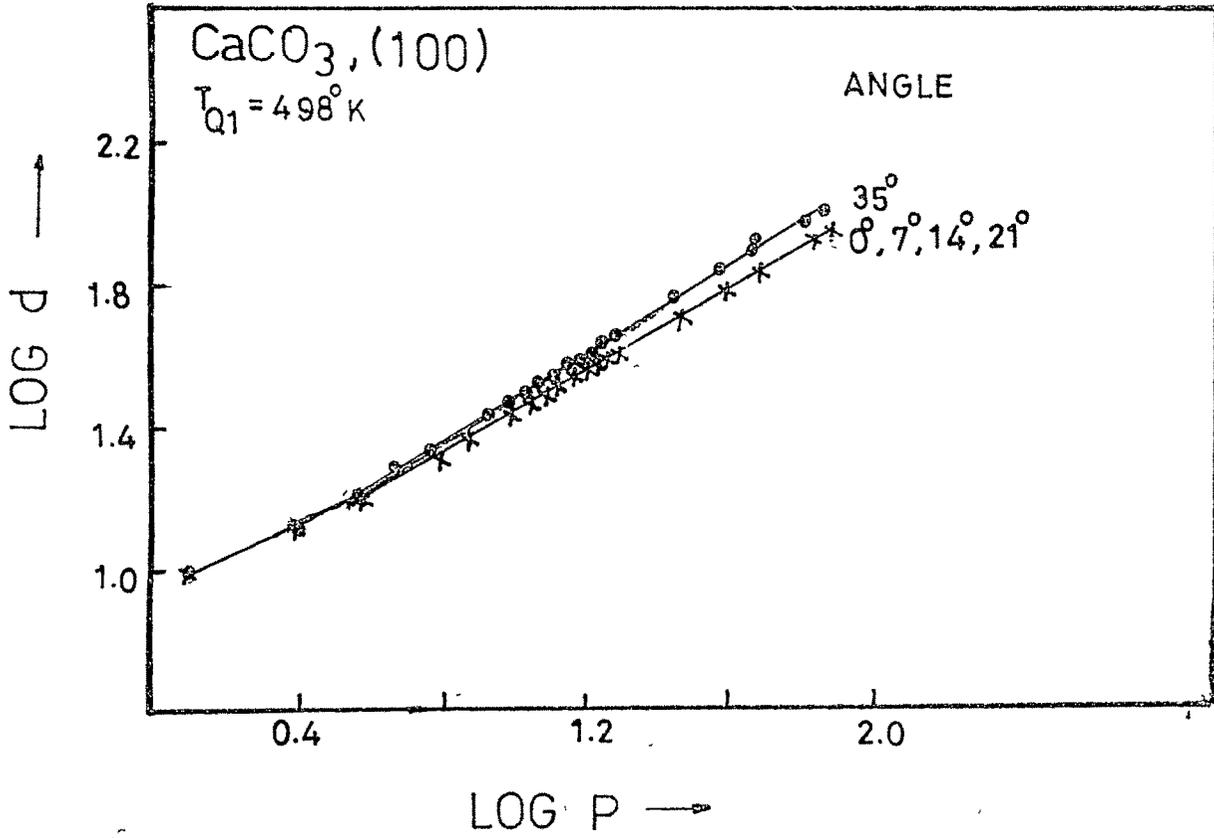
FIG : 4-1(A)(iv)



LOG P →
 PLOT OF LOG d Vs LOG P
 FIG : 4.1(A)(v)

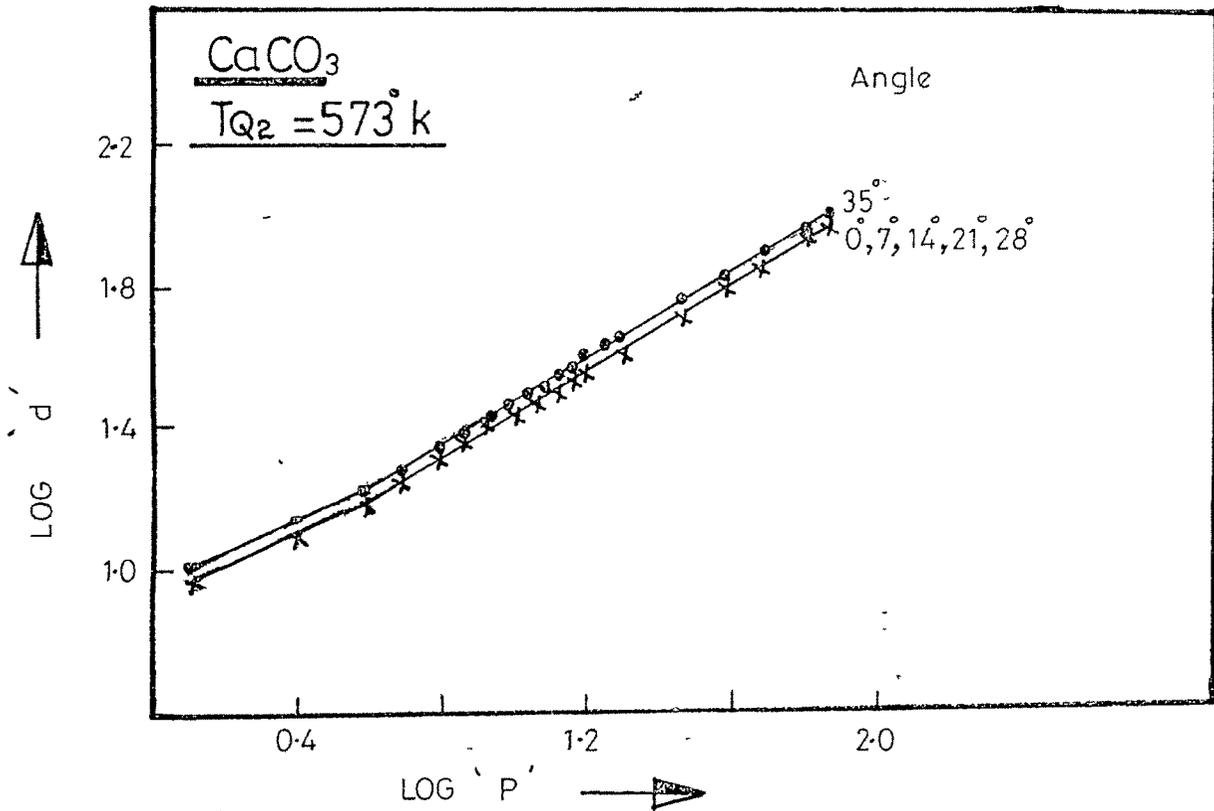


PLOT OF LOG d Vs LOG P
 FIG: 4.1(B)(i)



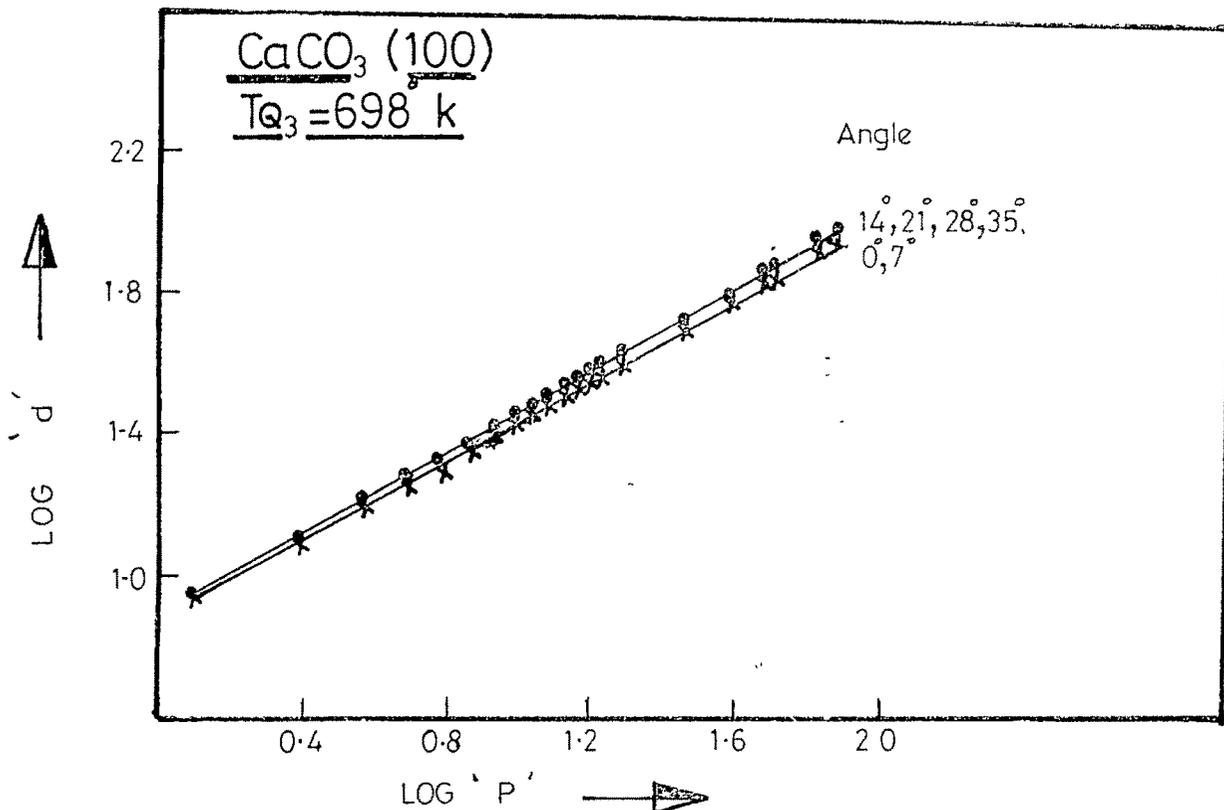
PLOT OF LOG d Vs LOG P

FIG : 4 1 (B) (ii)



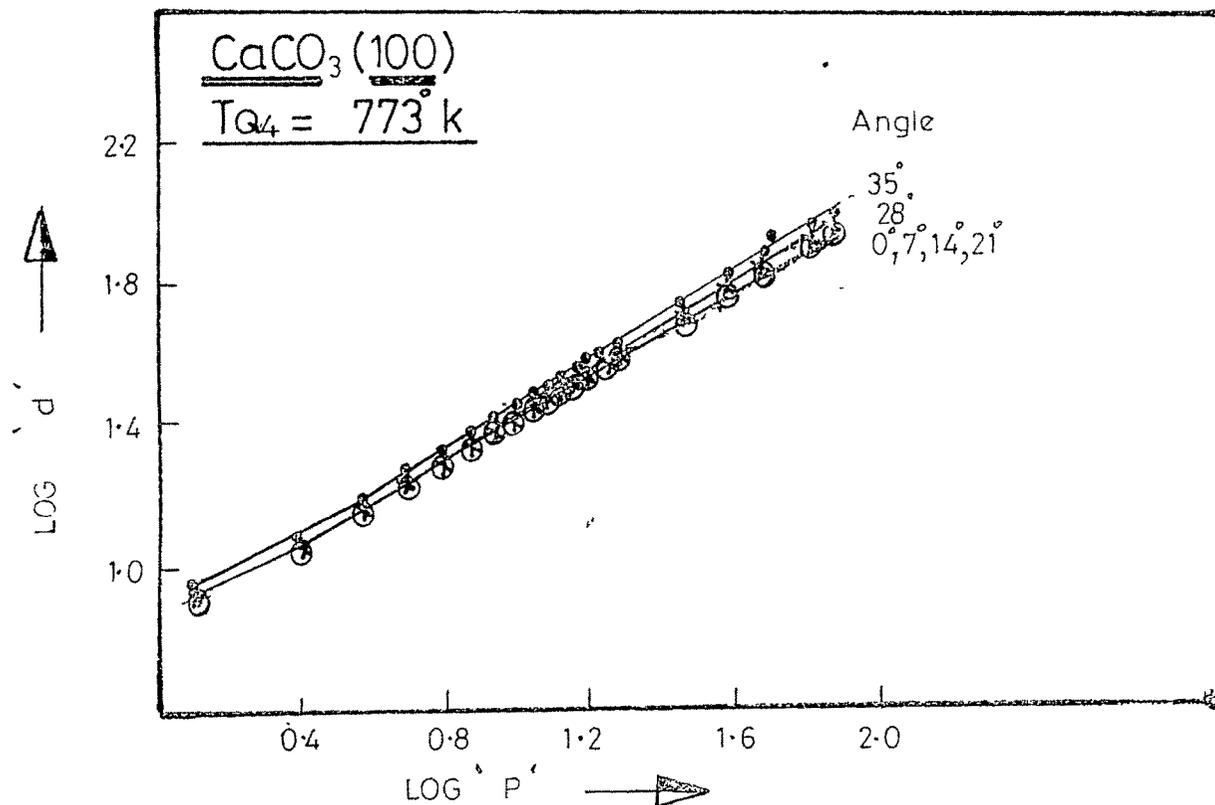
Plot of Log 'd' vs Log 'P'

Fig: 4.1 B (III)



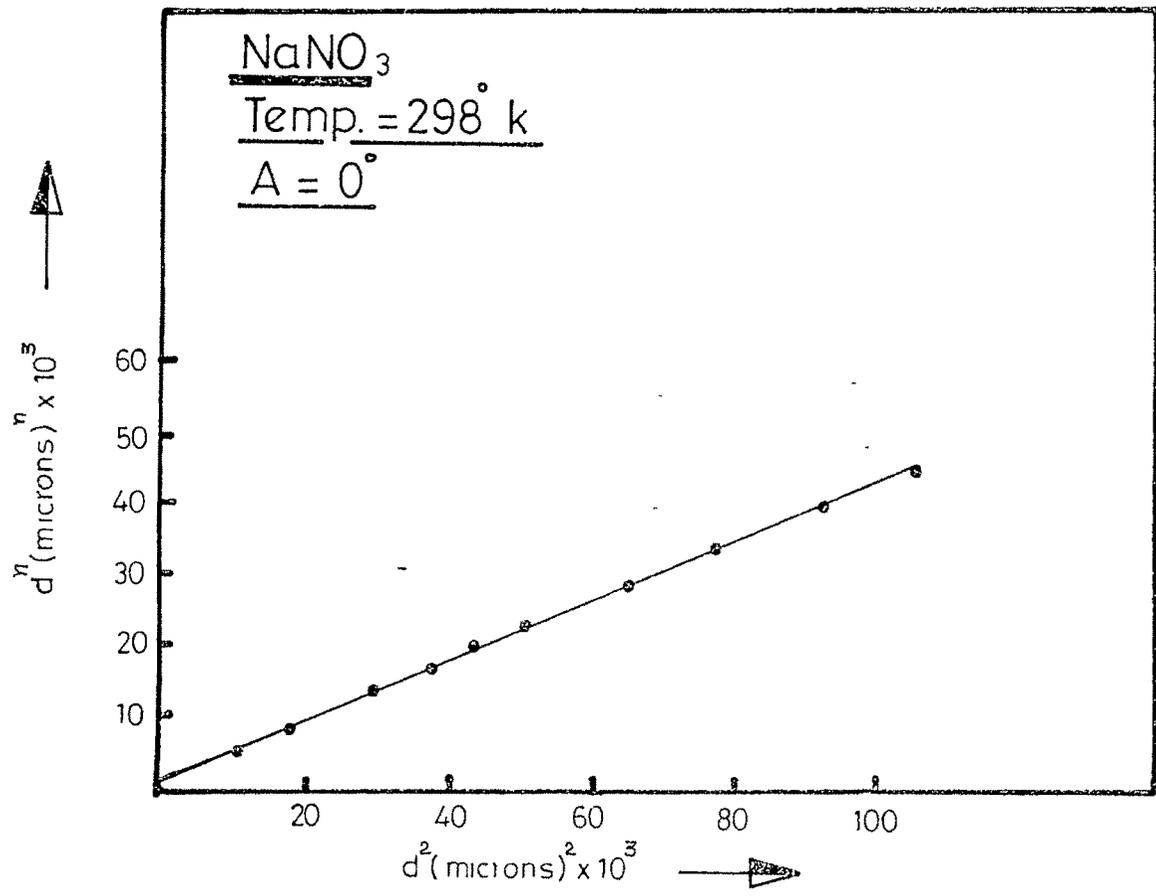
Plot of Log 'd' vs Log 'P'

Fig.: 4-1 B(IV)



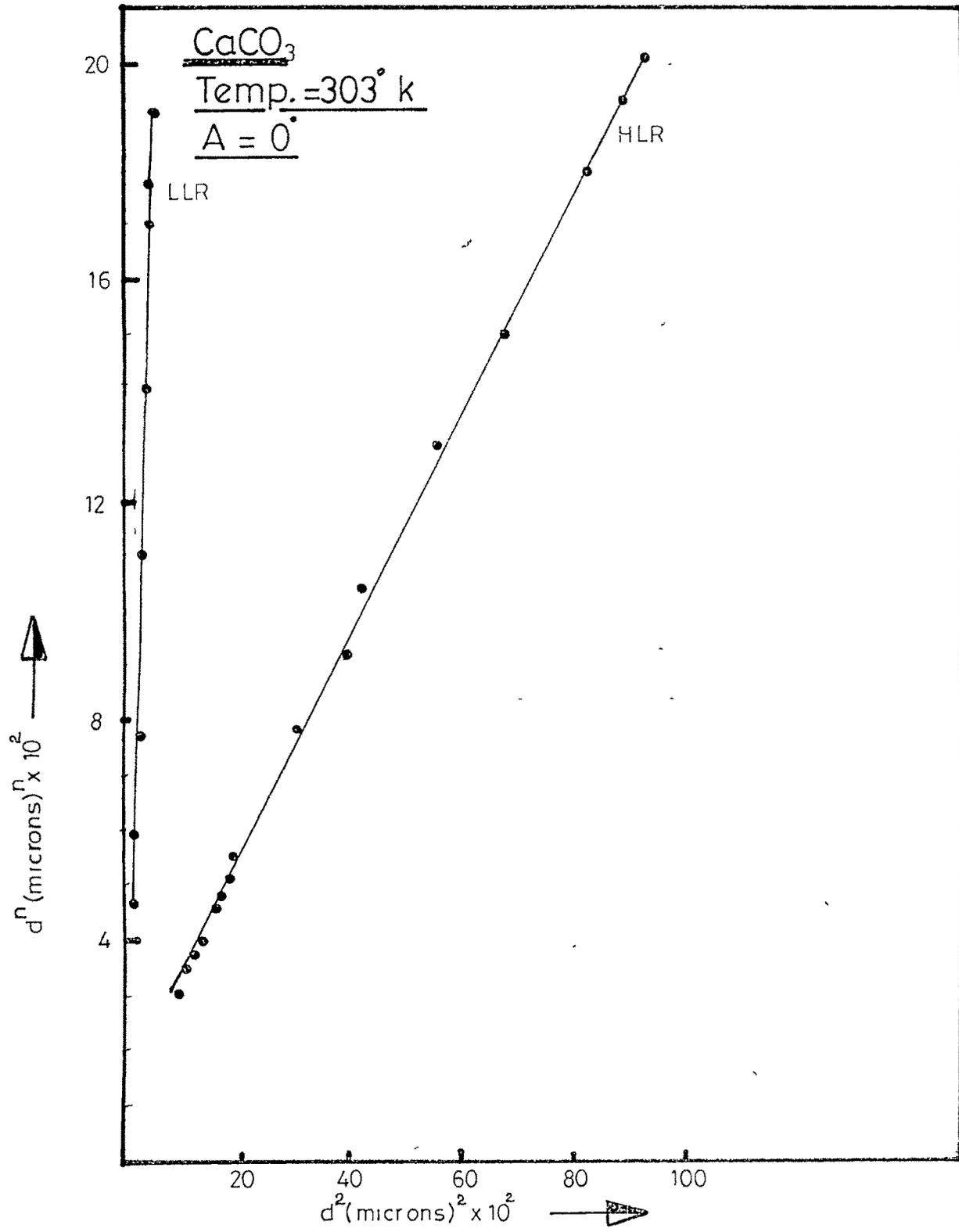
Plot of Log 'd' vs Log 'P'

Fig.: 4.1 B (V)



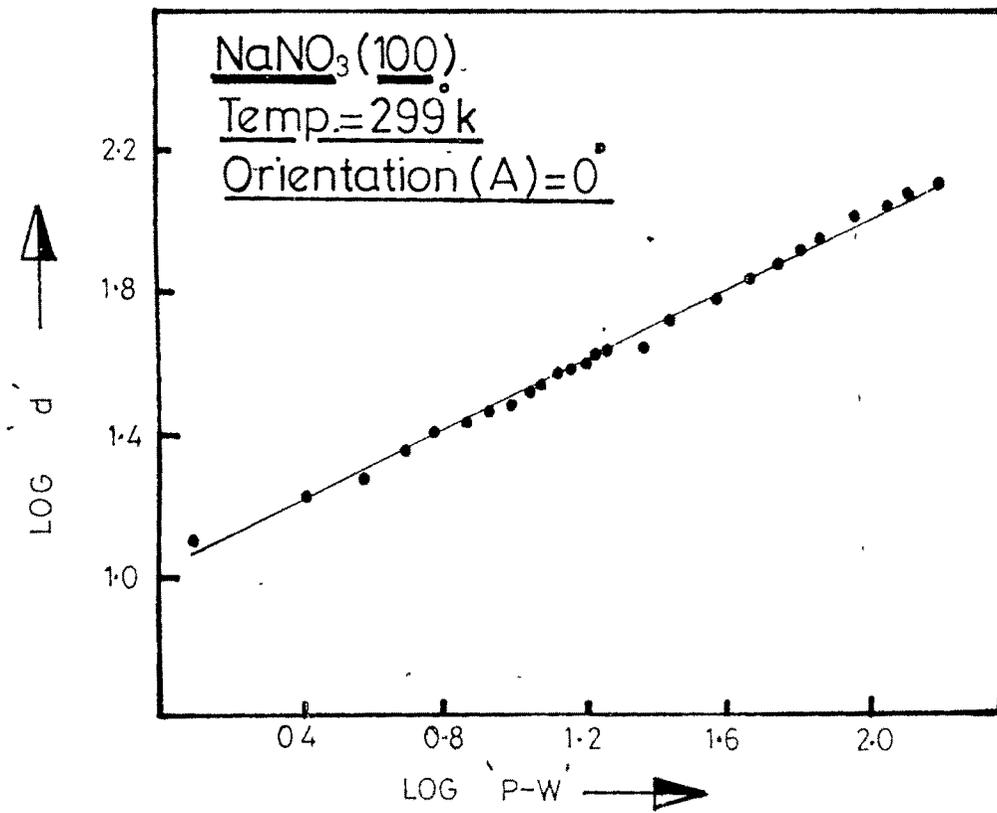
Plot of 'dⁿ' vs 'd²'

Fig: 4.2 (A)



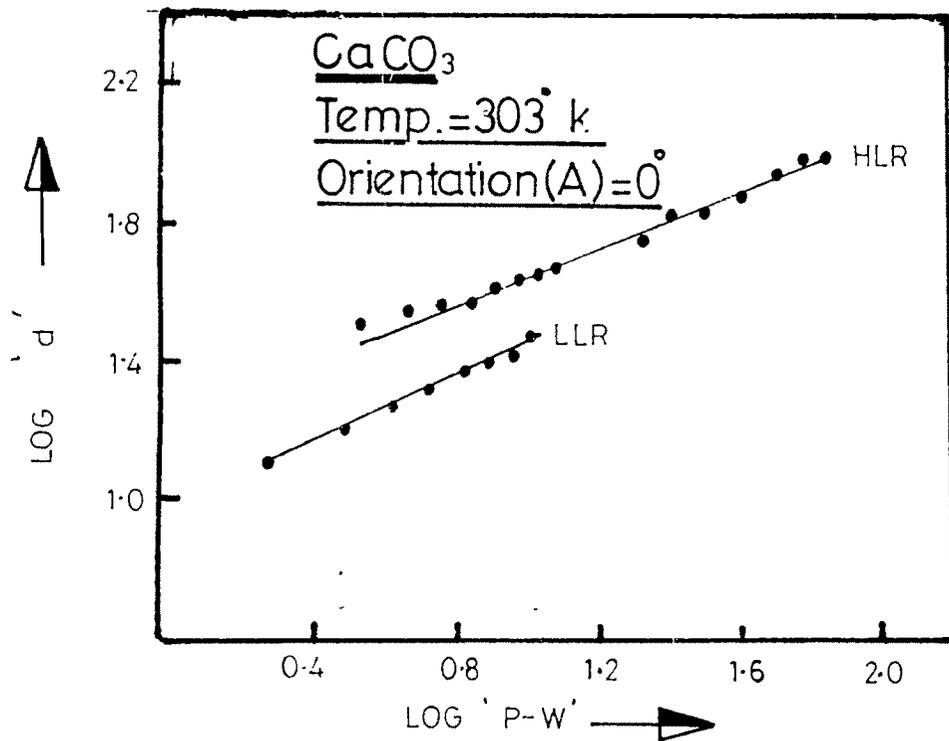
Plot of 'dⁿ' vs. 'd²'

Fig: 4.2(B)



Plot of Log 'd' vs Log 'P-W'

Fig: 4.3 (A)



Plot of Log 'd' vs Log 'P-W'

Fig: 4.3 (B)

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