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### *Crystal structure of some ring systems containing group III and group V elements*

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Crystal Structure of some ring systems containing group III  
and group V elements.

A thesis submitted for the degree of Doctor of Philosophy by  
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P R E F A C E

This thesis describes research in Chemical Crystallography carried out during three years spent in the Chemistry Department in Durham University.

I am indebted to my supervisor, Dr. H.M.M. Shearer for continual guidance and encouragement and for suggesting the problems. I would like to thank Prof. G.E. Coates and Dr. K. Wade and their research students for providing the compounds.

The Scientific Research Council kindly provided me with a maintenance grant.

S U M M A R Y

The work in the first part of this thesis describes the crystal structure analysis of the trans-ethylideneaminodimethylborane dimer  $(\text{MeHCNMe}_2)_2$ . The structure was solved from the three dimensional Patterson function with the aid of superposition methods, and the atomic parameters refined by  $F_o$  syntheses and least-squares calculations to a residual of 0.121 for the 645 observed reflections. The molecule was found to contain a planar four-membered boron-nitrogen ring system with a double bond attached directly to nitrogen and to be the trans isomer.

Part II describes the crystal structure analysis of the 2,2'-dimethylbutylidene-3-aminodimethylaluminium dimer,  $(\text{Bu}^t\text{MeCNAlMe}_2)_2$ . Evaluation of the three dimensional Patterson function gave the solution to the structure. Refinement of the atomic parameters showed the space group to be the centrosymmetric  $Cmca$  rather than  $Aba2$ . The final value for the residual was 0.114 for the 524 reflections observed. This structure was shown to be similar to  $(\text{MeHCNMe}_2)_2$  as it contains an aluminium-nitrogen four membered ring system with a double bond attached to nitrogen and to be the trans isomer.

The crystal structure analysis of dimethylphosphinatodimethylgallium,  $(\text{Me}_2\text{GaO}_2\text{PMe}_2)_2$ , is described in part III. Over the 726 reflections observed, the final value of R was 0.086. The dimer contains an eight membered ring system in which the gallium atoms are bridged by

(iv)

two phosphinate groups. The ring conformation is such that contacts across the ring and methyl contacts round the ring are comparable with the closest intermolecular contacts.

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STRUCTURE REFINEMENT

X-rays are scattered by the electrons in atoms. The atoms possess finite volume and phase differences arise between rays scattered from different parts of the atom. The differences increase with increasing scattering angle and the atomic scattering factor,  $f_0$ , falls off with  $\sin \theta$ . The atoms in a crystal lattice have finite amplitudes of oscillation. The frequency of these vibrations is less than the frequency of the X-rays so that, as the thermal motions of corresponding atoms are not in phase, the scattering is further reduced with increasing Bragg angle. The vibrations can be described as an ellipsoid of vibration. This can be represented as a tensor,  $\underline{U}$ , with six independent components. The amplitude  $U$ , for a reflection with Miller indices  $hkl$ , is given by,

$$U = U_{11}h^2a^{*2} + U_{22}k^2b^{*2} + U_{33}l^2c^{*2} + 2U_{23}klb^*c^* + 2U_{31}lhc^*a^* + 2U_{12}hka^*b^*$$

and the expression for the atomic scattering,  $f$ , by

$$f = f_0 \exp - 8\pi^2 U (\sin \theta / \lambda)^2$$

For an isotropic vibration this is expressed as  $f = f_0 \exp - B(\sin \theta / \lambda)^2$

where  $B$ , the Debye factor, is  $8\pi^2 U$ .

The resultant of waves scattered by the whole contents of the unit cell in a particular direction is the structure factor,  $F_{hkl}$

$$F_{hkl} = \sum_0^n f_j e^{2\pi i (hx_j/a + hy_j/b + lz_j/c)}$$



where the summation is over all the  $n$  atoms in the unit cell, atom  $j$  having coordinates  $x_j, y_j, z_j$ .

This complex quantity can be expressed as an amplitude,  $F_{hkl} = \sqrt{A^2 + B^2}$  together with a phase angle,  $\alpha$ , where  $\alpha_{hkl} = \tan^{-1} (B/A)$ .

$$A = \sum_0^n f_j \cos 2\pi (hx_j/a + ky_j/b + lz_j/c)$$

$$B = \sum_0^n f_j \sin 2\pi (hx_j/a + ky_j/b + lz_j/c)$$

The structure factor can also be represented by the expression

$$F_{hkl} = \frac{V}{abc} \int_0^a \int_0^b \int_0^c \rho(xyz) e^{2\pi i (hx/a + ky/b + lz/c)} dx dy dz.$$

Where  $\rho(xyz)$  is the electron density at the point  $xyz$  in the unit cell, the number of electrons in the volume  $dx dy dz$  being  $\rho(xyz) dx dy dz$ .

As  $\rho(xyz)$  is a periodic function it can be represented as a Fourier series.

$$\rho(xyz) = \sum_{-\infty}^{\infty} \sum_{-\infty}^{\infty} \sum_{-\infty}^{\infty} A_{pqr} e^{2\pi i (px/a + qy/b + rz/c)}$$

Substituting this in the expression for  $F_{hkl}$  and integrating, all terms are zero except those where  $p = -h, q = -k$  and  $r = -l$ .

Thus  $F_{hkl}/V = A (\bar{h} \bar{k} \bar{l})$

and  $\rho(xyz) = \frac{1}{V} \sum_{-\infty}^{\infty} \sum_{-\infty}^{\infty} \sum_{-\infty}^{\infty} F_{hkl} e^{-2\pi i (hx/a + ky/b + lz/c)}$

Fourier Methods.

$F_o$  synthesis.

Evaluation of the expression for the electron density using the observed values for the structure factors,  $F_o$ , combined with the phases of structure factors based on the postulated atomic parameters,  $F_c$ , gives a high concentration of electron density in the region of atomic sites. Re-estimates of the atomic coordinates from these peaks give a set of  $F_c$  in better agreement with the  $F_o$ 's hence leading to further refinement.

Not all the reflections can be observed experimentally and only a finite number of terms are available to include in the summation. This gives rise to termination of series effects where the peaks are surrounded by diffraction ripples which can cause the observed peaks to be displaced from their true positions.

If the structure is being solved by heavy atom methods, peaks due to the atoms not included in the calculation of structure factors appear in the  $F_o$  synthesis and hence their coordinates can be found.

Refinement by this method ends when the signs of the  $F_c$  for a centro-symmetric space group are no longer changing.

$F_o - F_c$  synthesis.

If, instead of  $F_o$ , the difference between the magnitude of the observed and calculated structure factors,  $(|F_o| - |F_c|)$ , are used as

coefficients in the Fourier series, the systematic errors due to the termination of series are eliminated. The resultant synthesis gives the difference between the observed electron density and that for the postulated model and indicates corrections to the positional and thermal parameters for each atom.

The coordinate corrections can be estimated from the first derivatives of  $\rho_o - \rho_c$ . The value of the electron density at a distance  $r$  from the centre of an atom can be approximated by the expression

$$\rho_o(r) = \rho_o(o) \exp(-pr^2).$$

Expanding this and ignoring all terms past the second gives

$$\rho_o(r) = \rho_o(o) (1 - pr^2).$$

If the error in  $r$  is  $\delta r$  then

$$\rho_o(r) - \rho_c(r) = \rho_o(o)(1 - p(r-\delta r)^2) - \rho_c(o)(1 - pr^2).$$

Assuming that the shapes of  $\rho_o$  and  $\rho_c$  are identical but are displaced then, if  $D_r = \rho_o(r) - \rho_c(r)$ ,  $\left(\frac{\delta D}{\delta r}\right)_{r=0} = -\rho_o(o)2p\delta r$ .

$$\text{Hence } \delta r = \left(\frac{\delta D}{\delta r}\right)_{r=0} / 2p\rho_o(o)$$

Values of  $p$  and  $\rho_o(o)$  can be found from the shape of the peak for each atom from an  $F_o$  synthesis.

Anisotropic corrections to the thermal parameters can be found from the curvatures of  $(\rho_o - \rho_c)$  and the correction to an isotropic temperature factor can be determined from the value of  $D$  at an atomic site. If isotropic temperature parameters have been used to calculate

the set of  $F_c$  then the principle axes of the ellipsoid of vibration are in the directions of principal curvature of D at the atomic site.

Schomaker (1957) derives the following equations giving the corrections to scaling and thermal parameters.

If  $h_1$ ,  $h_2$  and  $h_3$  are the components of  $2 \sin \theta/\lambda$  along the principal axes of the ellipsoid of vibration and T is the assumed isotropic temperature factor, then

$$\rho_o(r) = (1 + \Delta K) \int_0^{h_o} f_o T \exp((\Delta B_1 h_1^2 + \Delta B_2 h_2^2 + \Delta B_3 h_3^2)/4) \exp(-2\pi i h r) \cdot V \cdot dh.$$

where  $h_o$  is the limit of the observed reflections and the AB's are the changes in the temperature parameter and  $\Delta K$  the error in the scale factor.

He derives the following four equations:

$$D(o) + \rho_o(o) - \rho_c(o) = 4\pi I_2 \Delta K - \frac{\pi}{3} I_4 (\Delta B_1 + \Delta B_2 + \Delta B_3)$$

$$D_1''(o) = -\frac{16}{3} \pi^3 I_4 \Delta K + \frac{4}{15} \pi^3 I_6 (3\Delta B_1 + \Delta B_2 + \Delta B_3)$$

$$D_2''(o) = -\frac{16}{3} \pi^3 I_4 \Delta K + \frac{4}{15} \pi^3 I_6 (\Delta B_1 + 3\Delta B_2 + \Delta B_3)$$

$$D_3''(o) = -\frac{16}{3} \pi^3 I_4 \Delta K + \frac{4}{15} \pi^3 I_6 (\Delta B_1 + \Delta B_2 + 3\Delta B_3)$$

The  $D''(o)$  are the curvatures of  $\rho_o - \rho_c$  and  $I_2$ ,  $I_4$  and  $I_6$  are

integrals of the form  $I_n = \int_0^{h_o} h^n f_o T \cdot dh.$

These are analagous to the equations derived by Cruikshank (1956), which give the corrections to the thermal parameters referred to the reciprocal axes.

If the scaling is assumed correct and the first equation ignored, Schomakers equations simplify to those produced by Cochran (1951).

#### Method of Least-Squares

This method adjusts the scale and atomic parameters so that the sum of the weighted squares of the differences in magnitudes of the observed and calculated structure factors, R, is minimised.

$$R = \sum_{hkl} W ( |F_o| - |F_c| )^2 = \sum_{hkl} W \Delta^2$$

where

$$\Delta = |F_o| - |F_c|$$

For R to be a minimum  $\delta R / \delta p_j = 0$  where p are the parameters of  $F_c$  and j is one of the n atoms.

Cochran, 1948, has shown that the methods for determining corrections to the atomic parameters by least-squares refinement and the difference synthesis are formally equivalent and identical if the least squares weights, w, are equal to  $1/f_{hkl}$ .

The structure factors least-squares parameter corrections are computed by solving a set of normal equations derived as follows:

for R to be a minimum  $\frac{\delta R}{\delta p_j} = 0 = \sum \frac{W \Delta \delta |F_c|}{\delta p_j} \dots \dots \dots (1)$

Expanding  $\Delta$  as a function of its parameters using the first two terms only of the Taylor Series, where  $p$  represents a set of parameters and the set of errors in these, gives

$$\Delta(p + \epsilon) = \Delta(p) + \sum_{i=1}^n \epsilon_i \frac{\delta F_c}{\delta p_i}$$

This approximation is valid only for small parameter changes as  $F_c$  is not a linear function of these. As  $F_c$  is a linear function of the scale factor, the normal equations are valid for large scale changes if the changes in the other parameters are small.

As

$$\Delta(p + \epsilon) = 0, \quad \Delta(p) = \sum_{i=1}^n \epsilon_i \frac{\delta F_c}{\delta p_i}$$

Substituting this in equation (1) gives a set of  $n$  equations, the normal equations.

$$\sum_{i=1}^n \left\{ \sum_{hkl} W \left( \frac{\delta |F_c|}{\delta p_j} \cdot \frac{\delta |F_c|}{\delta p_i} \right) \right\} \epsilon_i = \sum_{hkl} W \Delta \frac{\delta |F_c|}{\delta p_j}$$

The partial derivatives of  $F_c$  with respect to the coordinates are evaluated as follows:  $|F_c| = A \cos \alpha + B \sin \alpha$

$$\frac{\delta |F_c|}{\delta p_j} = \left( \frac{\delta A}{\delta p_j} \right) \cos \alpha + \left( \frac{\delta B}{\delta p_j} \right) \sin \alpha + (-A \sin \alpha + B \cos \alpha) \left( \frac{\delta \alpha}{\delta p_j} \right)$$

where

$$-A_j \sin \alpha + B_j \cos \alpha = 0$$

$$A_j = f_j \cos 2\pi (hx/a + ky/b + lz/c)$$

and

$$B_j = f_j \sin 2\pi (hx/a + ky/b + lz/c)$$

then

$$\begin{aligned} \frac{\delta A}{\delta x_j} &= \frac{-2\pi h f_j \sin 2\pi (hx/a + ky/b + lz/c)}{a} \\ &= \frac{-2\pi h B_j}{a} \end{aligned}$$

and

$$\frac{\delta B_j}{\delta x_j} = \frac{2\pi h \cos 2\pi (hx/a + ky/b + lz/c)}{a} = \frac{2\pi h A_j}{a}$$

Hence

$$\frac{\delta |F|_c}{\delta p_j} = \frac{2\pi h}{a} (A_j \cos \alpha - B_j \sin \alpha)$$

The partial derivatives with respect to the thermal parameters can be found similarly. They are of the form.

$$\begin{aligned} \frac{\delta |F|_c}{\delta U_{11,j}} &= -2\pi^2 h^2 a^*{}^2 |F|_c \\ \text{as } \frac{\delta A}{\delta U_{11,j}} &= -2\pi^2 h^2 a^*{}^2 A_j \quad \text{and} \quad \frac{\delta B}{\delta U_{11,j}} = -2\pi^2 h^2 a^*{}^2 B_j \end{aligned}$$

The overall scale factor for the  $F_0$  is determined as the inverse scale factor for the  $F_c$  and  $\frac{\delta |F|_c}{\delta G} = \frac{|F|_c}{G}$  where the  $F_c$  include this

scale factor.

With the availability of larger, faster computers, it is possible to use the full matrix treatment to solve the normal equations directly in some cases. Usually some approximation is made. Use of the diagonal terms only of the matrix leads to very slow refinement as this neglects any interaction between parameters.

In the block diagonal approximation suggested by Cruikshank et.al., 1961, corrections to the coordinates and temperature parameters are found by calculating a series of  $3 \times 3$ ,  $6 \times 6$  and  $1 \times 1$  matrices together with their right hand sides. The  $3 \times 3$  matrix allows for the interactions between the coordinates of an atom due to the axes not being orthogonal and the  $6 \times 6$  matrix allows for the interactions between the anisotropic thermal parameters of an atom.

The effect of a change of overall scale factor on the temperature parameter corrections is found from a  $2 \times 2$  matrix.

These were the approximations made in the least-squares computer program used for the work described in this thesis. Other programs use a series of  $9 \times 9$  or  $4 \times 4$  matrices to allow for the interactions between all the parameters of an atom.

When using approximations of this kind it is found that fewer cycles of refinement are needed if the shifts obtained from the least squares equations are multiplied by a partial shift or "fudge" factor. In the block diagonal approximation used a partial shift

factor of 0.8 was applied to all the shifts.

For the parameters to have minimum e.s.d.'s each of the structure factors should be weighted so that  $w = k/\sigma_{F_{hkl}}^2$ . The e.s.d. in the parameter  $p_j$  is given by

$$\sigma^2(p_j) = (a^{-1})_{jj} w \Delta^2 / (m-n)$$

where  $(a^{-1})_{jj}$  is an element of the matrix inverse to the full matrix,  $a_{ij}$ , of the normal equations,  $m$  is the number of experimental observations and  $n$  the number of parameters. Rather than giving each reflection a weight of  $K/\Delta^2$ , a weighting function with only a few parameters is used and these are adjusted to give average values of  $w\Delta^2$  that are constant for reflections within ranges of value  $F_0$  and/or  $\sin\theta/\lambda$ .

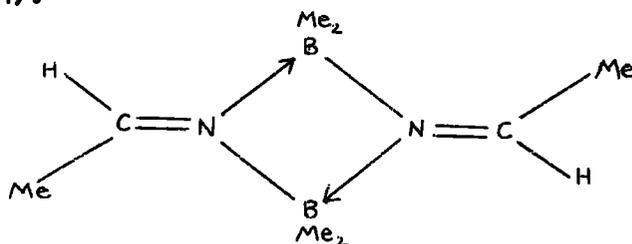
For the work in this thesis  $F_0$  syntheses were used to complete the structure determination by locating atoms whose coordinates could not be found by Patterson methods. Refinement of atomic parameters was carried out by structure factors least squares calculations. Difference syntheses were computed to check the least-squares results for unforeseen errors e.g. disordering and in an attempt to locate hydrogen atoms.

The Crystal Structure of trans-ethylideneaminodimethylborane dimer



Introduction

Hydroboration of methyl cyanide using dimethyl borohydride gives two products with the same chemical analysis and very similar infra-red spectra, one a liquid and the other a solid. Vapour density determinations and cryoscopic measurements in benzene indicate that the molecule contains two  $\text{Me}_2\text{BNCHMe}$  units, and the i.r. spectra shows bands that could correspond to a carbon-nitrogen double bond stretching frequency. The similarity of these two compounds suggest that they are cis and trans isomers with the following structure for the trans compound. (Lloyd and Wade, 1964).



As yet no complete structure analysis has been carried out for a compound containing a boron-nitrogen four membered ring with a double bond attached directly to it. The crystal structure analysis confirms that, in the crystalline state, this compound has the structure suggested and is the trans isomer.

Experimental

Crystals.

Crystals elongated in the direction of the 'c' axis were found to

form on the sides of a flask containing  $(\text{Me}_2\text{BNCHMe})_2$  crystals left standing at the pressure of their own vapour. The crystals were air sensitive but could be cut and mounted on glass fibres in air and were found to be satisfactorily protected by a coating of shellac.

Crystal data.

The unit cell dimensions were obtained from photographs of the hko and hol nets taken with Cu K $\alpha$  radiation and of the okl and hol nets using Mo K $\alpha$  radiation and the precession method. The greatest error in these is probably that in centering the crystal and is thought to be of the order of 0.3%. The dimensions given are the mean values obtained using the different radiations, the greatest difference in the corresponding values being 0.3%.

Monoclinic.  $a = 6.55\text{\AA}$ ,  $b = 11.92\text{\AA}$ ,  $c = 7.89\text{\AA}$ ,  $\beta = 105^\circ 23'$

$\lambda(\text{Mo K}\alpha) = 0.7107\text{\AA}$ ,  $\lambda(\text{Cu K}\alpha) = 1.5418\text{\AA}$

$V = 592.73\text{\AA}^3$ ,  $Z = 4 \text{ Me}_2\text{BNCHMe units}$ ,  $F(000) = 184 \text{ electrons}$

$D_m = 0.93 \text{ gm cm}^{-3}$ ,  $D_x = 0.929 \text{ gm cm}^{-3}$

Absorption  $\mu(\text{Cu K}\alpha) = 2.2 \text{ cm}^{-1}$ ,  $\mu(\text{Mo K}\alpha) = 0.65 \text{ cm}^{-1}$

Observed reflections:

hol when  $h = 2n$

oko when  $k = 2n$

hkl no conditions.

This uniquely determines the space group as  $P2_1/a$ ,  $(C_{2h}^5)$ .

The density for four  $\text{Me}_2\text{BNCHMe}$  units per unit cell of  $0.929 \text{ gm cm}^{-3}$  calculated using the above cell dimensions is the same as the value of  $0.93 \text{ gm cm}^{-3}$  obtained by differential flotation of the crystals in a methyl cyanide water mixture. Each of the four asymmetric units of the space group is occupied by one  $\text{Me}_2\text{BNCHMe}$  unit. If the compound is dimeric in the crystalline state, then each dimer must possess a centre of symmetry and the methyl carbons on the carbons attached to nitrogen must be trans.

#### Collection of Intensities.

Partial three dimensional data was recorded photographically using Zr-filtered Mo radiation and the precession method for the  $0kl=2kl$  nets and Ni-filtered Cu radiation and the equi-inclination Weissenberg method for the  $hko=hk5$  nets.

The intensities were estimated visually by comparison with a graduated scale, the elongated reflections only on the Weissenberg nets being used.

Length corrections (Phillips, 1956) were applied to these reflection on the nets  $hkl=hk3$  at the same time as the usual Lorentz and polarisation corrections. For the nets  $hk4$  and  $hk5$  the length of spots with the same  $\sin \theta$  values were found to vary across the film so estimates of the lengths were obtained by direct measurements.

No correction for absorption was made.

The structure factors were correlated using factors calculated from the common reflections by a modified Rollett least-squares method. They numbered 475 of which 174 appeared on more than one net.

### Structure Determination

The structure was solved by calculation of the three-dimensional Patterson function. The atomic parameters were refined by  $F_o$  and  $F_o - F_c$  syntheses and finally by least squares calculations.

The three dimensional Patterson function was calculated, the expression

$$P(uvw) = \frac{4}{V} \sum_0^h \sum_0^k \sum_0^l [w_{hkl} |F_{hkl}|^2 \cos 2\pi(hu + lw) + w_{\bar{h}k\bar{l}} |F_{\bar{h}k\bar{l}}|^2 \cos 2\pi(-hu + l\bar{w})] \cos 2\pi kv$$

being evaluated at intervals in  $u$  of  $0.262\text{\AA}$ , in  $v$  of  $0.263\text{\AA}$  and in  $w$  of  $0.298\text{\AA}$ .

The expression used for  $w_{hkl}$  was  $1/\{f \exp(-2.5 \sin^2 \theta / \lambda^2)\}^2$  where  $f$  is the theoretical value for the scattering for the  $\sin \theta$  value for each  $F_{hkl}$ .

A statistical analysis of the intensities of the  $hko$  reflections (Wilson, 1942) gave an apparently low estimate of the overall temperature factor of  $2.8\text{\AA}^2$  for the atoms in the molecule. The expression used for  $w_{hkl}$  gives a set of coefficients intermediate to those from point atoms

at rest and point atoms.

The Patterson function was solved by choosing a sharply defined peak  $4.8\text{\AA}$  from the origin as arising from the single weight vector due to  $C3' - C3$  and superimposing this on the origin. (see fig. I). This three-dimensional superposition gave regions of positive overlap in positions consistent with all six atoms in the asymmetric unit, but for  $C4$  there was a choice of two peaks, one of which was eliminated by further superpositions. The appearance of this spurious peak was probably due to the boron-nitrogen vector orientated similarly to the  $C3 - C4$  vector.

The coordinates obtained from the superposition were as follows and gave interatomic distances and angles consistent with the proposed dimeric structure.

Atom	x	y	z	$\text{\AA}$
N	0.92	0.60	0.79	
C1	-0.92	1.79	-1.58	
C2	0.92	0.60	-2.10	
C3	1.44	1.79	1.18	
C4	2.10	1.79	2.63	
B	0.13	0.60	-0.92	

A set of structure factors was calculated using these coordinates. The value of the residual, R, was 0.59 where

$$R = \frac{\sum |F_o| - |F_c|}{\sum |F_o|}$$

### Structure Refinement

Refinement was carried out at first from a three dimensional  $F_o$  synthesis computed at the same intervals as the Patterson function using the signs of the calculated structure factors with their observed magnitudes.

The expression used was

$$p(xyz) = \frac{4}{V} \sum_0^h \sum_0^k \sum_0^l \left[ F_{hkl}^{h+k=2n} \cos 2\pi(hx + lz) + F_{\bar{h}k\bar{l}} \cos 2\pi(hx - lz) \right] \cos 2\pi ky$$

$$\sum_0^h \sum_0^k \sum_0^l \left[ F_{hkl}^{h+k=2n+1} \sin 2\pi(hx + lz) + F_{\bar{h}k\bar{l}} \sin 2\pi(hx - lz) \right] \sin 2\pi ky$$

This gave well defined peaks in positions corresponding to five of the atomic sites, and with heights consistent with their atomic number. The carbon peak heights were between 4 and 5 e  $\text{\AA}^{-3}$ . The sixth peak, corresponding to C2, was much more smeared out along  $\underline{b}$ . The y-coordinate of C2 was adjusted until calculated structure factors gave a residual of 0.47. Two further cycles of refinement caused the residual to fall to 0.39 and then to 0.31. At this stage the coordinate shifts were of the order of 0.1 $\text{\AA}$ .

Refinement was continued by calculating an  $F_o - F_c$  synthesis.

The shifts in the coordinates were derived by means of the expression (see Introduction).

$$\delta r = \frac{d(\rho_o - \rho_c)}{dr} \frac{1}{2\rho_o(o)p}$$

with the atomic positions being moved in the direction of maximum gradient. Values of  $\rho_o(o)$  and  $p$  were obtained by plotting  $\log \rho_o$  against  $r^2$  for C2 and N.

Temperature factor corrections for the atoms were calculated, assuming (wrongly) the scaling to be correct, from the values of the electron density at the atomic sites. The simplified expression  $\rho_o - \rho_c = -\pi I_4 \Delta B$  and the suggested value for  $I_4$  (Schomaker, 1957) were used. Where  $\rho_o - \rho_c$  is negative at the atomic sites the temperature factors are too low.

Structure factors calculated using these corrections to the coordinates and temperature factors gave a residual of 0.29. As  $\sum |F_o|$  and  $\sum |F_c|$  for these structure factors were still very different the scale and temperature factors were corrected as follows.

Structure factors for the hko and okl nets were used to plot values of  $\ln(\sum |F_o| / \sum |F_c|)$  against  $\sin^2 \theta$  for ranges of  $\sin \theta$ . From the intercept and slope of this line,  $K$ , the scale factor, and the change in  $B$  can be measured.

$$KF_o = F_c \exp(-\Delta B \sin^2 \theta / \lambda^2)$$

$$\ln(\sum |F_o| / \sum |F_c|) = \ln(1/K) - \Delta B \sin^2 \theta / \lambda^2$$

The values of B used were found to be too high and K too low. Altering the scale and temperature factors in this way improved the residual from 0.29 to 0.265.

A second difference map was computed which resulted in a residual of 0.215. At this stage the coordinate shifts were of the order of 0.02Å.

As a least-squares computer program was now available, refinement was continued isotropically for all six atoms to a residual of 0.177, the average shift after five cycles being 0.002Å. All six atoms were then refined anisotropically to a residual of 0.139.

#### Hydrogen atoms.

At this stage in the refinement a difference map was computed which showed peaks of height about 0.25 e.Å<sup>-3</sup> that could all be explained as being due to the hydrogen atoms and all the hydrogen atoms could be accounted for in this way. The mean C-H distance for the methyl hydrogens ranged from 0.83 to 1.1Å with a mean value of 1.03Å. The C-C-H angles ranged from 102° to 131° with a mean value of 112°. The single hydrogen, H7, was 1.21Å from C4.

Structure factors calculated including all ten hydrogen atoms in these positions gave, after one further cycle of refinement of the atoms other than hydrogen a residual of 0.1204, the final value.

The final cycle of refinement.

No. of planes = 646,  $\sum |F_o| = 3681.45$ ,  $\sum |F_c| = 3639.38$ ,

$R = 0.1207$ ,  $R' = 0.0313$ .

In the final cycles refinement the weighting scheme used was  $w = 1/(a + |F_o| + c(F_o)^2)$ .

$w$  appears in the quantity  $R'$ , which is that minimised in the least-squares calculations.

$$R' = \frac{\sum w (|F_o| - |F_c|)^2}{\sum w |F_o|^2}$$

In the last cycle of refinement values of  $a$  of 3.2 and  $c$  of 0.3 were used. The final shifts in the coordinates ranged from 0.03 to 0.15 of the corresponding e.s.d., the average value being 0.004Å. The average shift in temperature factors, for this cycle was 0.0002Å<sup>2</sup>. These shifts varied from 0 to 0.12 of the corresponding e.s.d.

The final values of the atomic coordinates are shown in table I and the thermal parameters in table II. The unobserved planes were not included in the refinement, but none of these were found to be significantly greater than their minimum observable value. The final values of the structure factors are listed in table V.

The scattering curves quoted in International Tables for X-ray Crystallography Volume III, page 202, were used.

Table I.  $(\text{Me}_2\text{BNCHMe}_2)_2$ Atomic Coordinates and their e.s.d.'s

Atom	x	y	z	$\sigma(x)$	$\sigma(y)$	$\sigma(z)$	$\text{\AA}$
N	0.7066	0.7515	0.5872	0.0036	0.0036	0.0041	
C1	-0.7789	1.5803	-1.8933	0.0074	0.0058	0.0071	
C2	1.4288	-0.1259	-1.6144	0.0063	0.0070	0.0075	
C3	1.5535	1.6238	1.2468	0.0052	0.0052	0.0060	
C4	1.9978	1.7607	2.7625	0.0065	0.0065	0.0072	
B	0.1745	0.4231	-1.0208	0.0056	0.0053	0.0064	
H1	2.1000	2.0000	0.4000				
H2	-0.5400	2.4000	-2.3000				
H3	-1.4500	1.8000	-1.3000				
H4	-1.3500	1.3000	-2.8500				
H5	1.3000	1.5000	3.4000				
H6	3.0000	1.5000	3.2000				
H7	1.9100	2.5300	3.0240				
H8	1.9100	0.5960	-1.5780				
H9	1.0920	-0.5960	-2.3670				
H10	1.9100	-0.8940	-0.9200				

Table II.  $(\text{Me}_2\text{BNCHMe}_2)_2$

Thermal parameters in  $\text{\AA}^2$  and their e.s.d.'s in  $10^3 \text{\AA}^2$  in brackets.

Atom	$U_{11}$	$U_{22}$	$U_{33}$	$U_{12}$	$U_{23}$	$U_{13}$
N1	0.0358(2)	0.0455(2)	0.0313(3)	-0.0025(1)	-0.0039(3)	0.0074(2)
C1	0.0895(5)	0.0609(3)	0.0672(5)	0.0035(3)	0.0213(3)	-0.0081(4)
C2	0.0678(4)	0.1002(5)	0.0748(5)	-0.0115(4)	-0.0189(4)	0.0399(4)
C3	0.0505(3)	0.0605(3)	0.0517(4)	-0.0038(2)	-0.0128(3)	0.0060(3)
C4	0.0615(3)	0.0857(4)	0.0683(5)	-0.0099(3)	-0.0252(3)	-0.0001(3)
B	0.0446(3)	0.0472(3)	0.0422(4)	-0.0040(2)	0.0064(2)	0.0103(3)

The isotropic temperature factor used for all the hydrogen atoms had the value 0.1106.

Table III.  $(\text{Me}_2\text{BNCHMe})_2$

Bond distances and angles.

B-C1	1.602 $\text{\AA}$	0.008 $\text{\AA}$
B-C2	1.620	0.008
B-N	1.588	0.006
B-N'	1.596	0.006
N-C3	1.272	0.006
C3-C4	1.468	0.007
B-N mean	1.592	0.004
B-C mean	1.611	0.006
B-N-B'	93.6 $^\circ$	0.3 $^\circ$
N-B-N'	86.4	
C1-B-C2	116.9	0.4
N-C3-C4	125.2	0.5
B-N-C3	131.4	0.4
B'-N-C3	134.7	0.4

### Description of the Structure

As expected from the chemical evidence, the molecule is dimeric and contains a four-membered boron-nitrogen ring with a double bond attached to nitrogen. It is the trans isomer. The interatomic distances and angles together with their estimated standard deviations are shown in Table III and also in Fig. I. The lengths of the chemically equivalent bonds B-N and B-N' and also B-C1 and B-C2 do not differ significantly from one another and their mean values are illustrated in the figure and are included in the table.

The ring bonds are formally single and the average B-N distance of  $1.592 \pm 0.004\text{\AA}$  is the same as that of  $1.591 \pm 0.006\text{\AA}$  in  $(\text{BCl}_2\text{NMe}_2)_2$  (Hess, 1963) which also contains a four-membered boron-nitrogen ring. This close agreement arises in spite of the nitrogen atoms being formally  $sp^2$  hybridised in the present work and  $sp^3$  hybridised in the other case. In both instances the bond angles in the rings are nearly  $90^\circ$  and the atomic orbitals involved in the ring formation must depart considerably from their formal hybrid states. Similar lengths are found in other compounds. The B-N distance in  $(\text{CH}_3)_2\text{NBF}_3$  (Geller and Hoard, 1951) is  $1.58\text{\AA}$  and in the  $[\text{BH}_2(\text{NH}_3)_2]^+$  ion (Nordman, 1959) it is  $1.58 \pm 0.02\text{\AA}$ .

The carbon-nitrogen double bond, N-C<sub>3</sub>, has a length of  $1.272\text{\AA}$ , the same as in  $(\text{Bu}^t\text{MeCNAlMe}_2)_2$ . This value is also found for dimethylglyoxime (Merritt and Lanterman, 1952). The mean B-C distance of

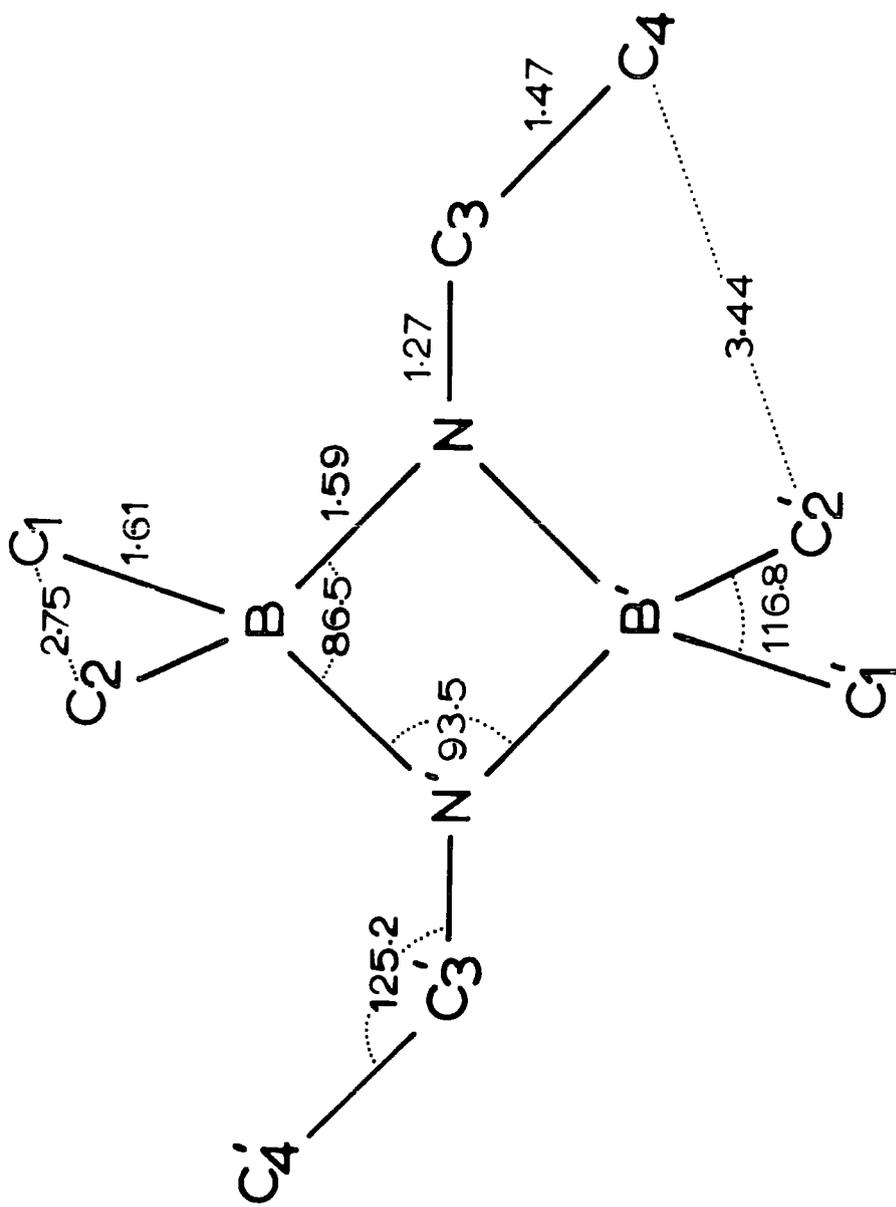


FIG. I.  $(\text{Me}_2\text{BNCHMe})_2$

$1.611 \pm 0.006\text{\AA}$  is the same as that in tetramethyl diborane (Hedberg and Schomaker, 1951).

However the C3-C4 distance of  $1.468 \pm 0.007\text{\AA}$  is much shorter than that expected for a bond involving atoms in  $sp^2$  and  $sp^3$  hybrid states. Pauling (1960) estimates the shortening for a C-C single bond adjacent to a C=C double bond as of the order of  $0.02\text{\AA}$ . No comparable shortening is found in  $(\text{Bu}^t\text{MeCNAlMe}_2)_2$  and in dimethylglyoxime the corresponding distance is  $1.53\text{\AA}$ . On the basis of the significance tests proposed by Cruickshank (1953), the difference between the above value and that of  $1.53 \pm 0.01\text{\AA}$  is highly significant. The molecular librations will lead to an apparent shortening in the bond lengths and the effect would be expected to be greatest for this terminal bond. However only a part of the shortening can be explained in this way.

The ring angle at nitrogen is greater than  $90^\circ$ . This might be expected from its formal  $sp^2$  hybrid nature and its greater electronegativity than boron. However in  $(\text{BCl}_2\text{NMe}_2)_2$  where all the ring atoms are formally  $sp^3$  hybridised, the angle at boron is  $93.1^\circ$  compared with  $86.4^\circ$  in the present work. With the reduction in the ring angle at boron from the tetrahedral value, the angle Cl-B-C2 is increased to  $116.8^\circ$  and leads to a C1-C2 distance of  $2.75\text{\AA}$ .

The B'-N-C3 angle of  $134.7^\circ$  is greater than B-N-C3 which is  $131.7^\circ$ . This distortion increases the distances between C4 and the

methyl carbons on B<sup>0</sup> to 3.44 and 3.45<sup>0</sup>Å. Similarly the increase in the angle N-C3-C4 to 125.2<sup>0</sup>, greater than the trigonal value, increases the non-bonding contacts involving C4.

The equation of the mean plane through B, N, C3 and the atoms related by the centre of symmetry is

$$0.769x' - 0.633y + 0.076z' = 0$$

where the atoms are referred to orthogonal axes parallel to a, b and c\*.

The distances of the atoms from this plane are as follows:

N	0.009 <sup>0</sup> Å
C1	-1.353
C2	1.391
C3	0.004
C4	0.061
B	0.000

C4 is therefore at a distance of 0.06<sup>0</sup>Å from the mean plane.

The equation of the mean plane through B, C1, C2 and the atoms related by the centre of symmetry is

$$0.489x' + 0.695y + 0.527z' = 0$$

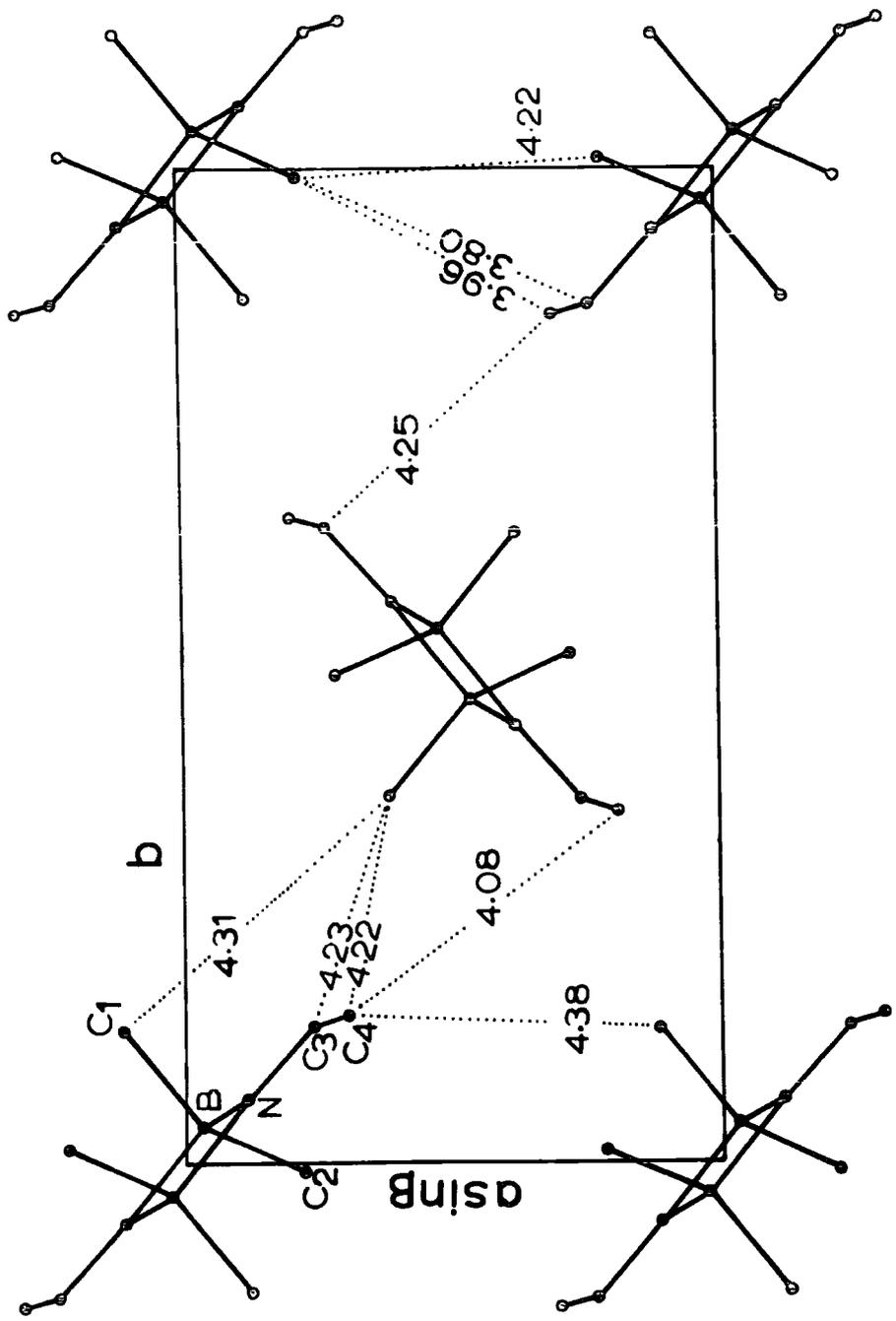
where the atoms are referred to axes as above. The distances of the atoms from this plane are:

B	-0.006 <sup>0</sup> Å
C1	0.002
C2	0.002

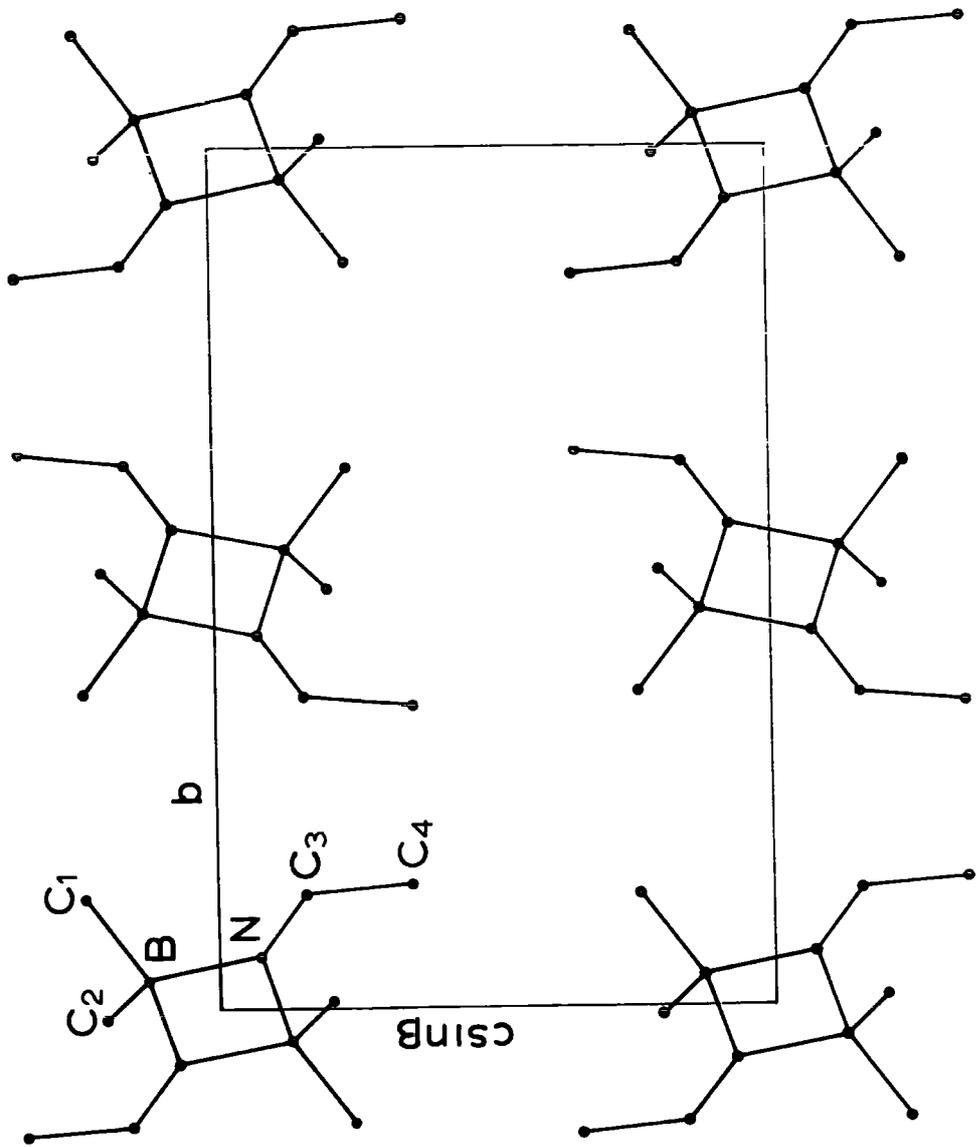
and the atoms are co-planar. The angle between the two mean planes is  $89^\circ$ .

The temperature parameters are generally greater for atoms furthest from the molecular centre and are smallest for the boron and nitrogen atoms. In addition the values appear smaller for nitrogen than for boron which is consistent with some increased concentration of electrons at nitrogen.

The intermolecular contacts of less than  $4.4\text{\AA}$  are listed in Table IV where the second atom is situated at the position indicated in the Table. The two contacts of less than  $4\text{\AA}$  are from C2 to C3 and C4 of the next molecule along a. Figs. II and III show the molecular packing.



(Me<sub>2</sub>BNCHMe)<sub>2</sub> 001 projection



$(\text{Me}_2\text{BNCHMe})_2$  100 projection

Table IV.  $(\text{Me}_2\text{BNCHMe})_2$

Non bonding contacts.

Intramolecular contacts.

C1	C2		2.745
C2'	C4		3.454
C1'	C4		3.442

Intermolecular contacts.

C2	C3	$1-x, \bar{y}, \bar{z}$	3.80A <sup>0</sup>
C2	C4	$1-x, \bar{y}, \bar{z}$	3.961
C4	C4	$x-\frac{1}{2}, \frac{1}{2}-y, z$	4.08
C4	C2	$x, y, 1+z$	4.16
C2	C2	$1-x, \bar{y}, \bar{z}$	4.221
C2	C4	$x-\frac{1}{2}, y-\frac{1}{2}, \bar{z}$	4.22
C2	C3	$x-\frac{1}{2}, y-\frac{1}{2}, \bar{z}$	4.23
C3	C3	$x-\frac{1}{2}, \frac{1}{2}-y, z$	4.25
C4	C1	$1+x, y, 1+z$	4.27
C1	C1	$\frac{1}{2}+x, \frac{1}{2}-y, z$	4.32
C3	C4	$x-\frac{1}{2}, 1-y, z$	4.38

TABLE V.  $(\text{Me}_2\text{BNCHMe}_2)_2$ .

Observed and calculated structure factors.

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
0	0	1	246	383	0	6	5	60	53
0	0	2	281	-336	0	6	6	56	59
0	0	3	144	-151	0	7	1	21	-17
0	0	4	128	-140	0	7	2	40	39
0	0	5	22	-10	0	7	3	36	49
0	0	6	<48	-15	0	7	4	47	-43
0	0	7	50	-53	0	7	5	60	-50
0	1	1	126	-139	0	8	0	56	55
0	1	2	19	7	0	8	1	62	-62
0	1	3	205	-220	0	8	2	117	-102
0	1	4	57	-47	0	8	3	54	-48
0	1	5	82	83	0	8	4	34	32
0	1	6	<48	-14	0	8	5	79	73
0	1	7	36	-38	0	9	1	<15	9
0	2	0	338	417	0	9	2	48	43
0	2	1	261	316	0	9	3	<15	9
0	2	2	25	-27	0	9	4	35	27
0	2	3	121	-143	0	9	5	60	50
0	2	4	41	-35	0	10	0	101	-101
0	2	5	23	-26	0	10	1	44	-47
0	2	6	34	-45	0	10	2	<14	-4
0	3	1	72	-89	0	10	3	<17	8
0	3	2	96	-101	0	10	4	43	47
0	3	3	168	-176	0	10	5	21	25
0	3	4	62	-68	0	11	1	41	39
0	3	5	<12	3	0	11	2	28	27
0	3	6	39	-47	0	11	3	39	39
0	3	7	36	-33	0	11	4	49	46
0	3	8	<51	9	0	12	0	49	-43
0	3	9	36	32	0	12	1	19	-17
0	4	0	227	-251	0	12	2	18	16
0	4	1	81	73	0	12	3	27	26
0	4	2	72	65	0	12	4	13	15
0	4	3	58	-51	0	13	1	<11	10
0	4	4	33	20	0	13	2	23	25
0	4	5	25	-14	0	13	3	36	41
0	5	1	23	27	0	13	4	11	12
0	5	2	55	-66	1	1	-6	63	-55
0	5	3	45	45	1	1	-5	60	-72
0	5	4	61	-56	1	1	-4	67	79
0	5	5	159	-158	1	1	-3	81	79
0	5	6	56	-58	1	1	-2	73	-65
0	5	7	<51	14	1	1	-1	379	426
0	5	8	43	31	1	1	0	319	438
0	5	9	43	40	1	1	1	136	137
0	6	0	115	114	1	1	2	13	-11
0	6	1	51	-45	1	1	3	205	-212
0	6	2	135	-139	1	1	4	83	-114
0	6	3	58	-51	1	1	5	60	-15
0	6	4	<15	-10	1	1	6	44	-59

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
1	2	-6	42	-38	1	6	-5	103	110
1	2	-5	52	54	1	6	-4	29	-45
1	2	-4	212	221	1	6	-3	60	-56
1	2	-3	91	95	1	6	-2	67	-57
1	2	-2	17	-10	1	6	-1	<11	16
1	2	-1	247	-239	1	6	0	19	28
1	2	0	257	-299	1	6	1	81	-84
1	2	1	102	101	1	6	2	<11	-2
1	2	2	151	-172	1	6	3	<15	-11
1	2	3	101	-112	1	6	4	90	-85
1	2	4	94	99	1	6	5	28	-23
1	2	5	<13	1	1	7	-5	33	-24
1	2	6	45	-57	1	7	-4	<16	15
1	3	-6	37	-24	1	7	-3	73	-34
1	3	-5	35	33	1	7	-2	109	-113
1	3	-4	<11	1	1	7	-1	34	31
1	3	-3	81	78	1	7	0	35	-32
1	3	-2	39	33	1	7	1	104	-105
1	3	-1	385	-415	1	7	2	36	-41
1	3	0	125	132	1	7	3	<16	-15
1	3	1	480	525	1	7	4	70	76
1	3	2	108	110	1	7	5	83	96
1	3	3	61	-68	1	8	-5	40	45
1	3	4	174	-175	1	8	-4	49	46
1	3	5	83	-96	1	8	-3	45	-39
1	3	6	50	33	1	8	-2	37	-41
1	4	-6	106	116	1	8	-1	40	-44
1	4	-5	89	60	1	8	0	42	-41
1	4	-4	49	56	1	8	1	53	53
1	4	-3	62	59	1	8	2	36	33
1	4	-2	64	-62	1	8	3	<17	-2
1	4	-1	38	-45	1	8	4	47	40
1	4	0	15	21	1	9	-3	18	-17
1	4	1	159	-160	1	9	-2	62	-64
1	4	2	82	-80	1	9	-1	62	-67
1	4	3	23	-22	1	9	0	42	-32
1	4	4	84	-87	1	9	1	27	-22
1	4	5	38	-35	1	9	2	21	-15
1	5	-4	28	18	1	9	3	31	35
1	5	-3	13	-7	1	9	4	60	57
1	5	-2	90	-95	1	9	5	29	26
1	5	-1	189	-186	1	10	-5	23	-22
1	5	0	21	-19	1	10	-4	16	11
1	5	1	137	137	1	10	-3	<17	-8
1	5	2	52	63	1	10	-2	45	-44
1	5	3	55	-50	1	10	-1	42	-36
1	5	4	72	-82	1	10	0	26	20
1	5	5	17	22	1	10	1	58	63
1	5	6	51	52	1	10	2	36	36
1	6	-6	111	121	1	10	3	44	40

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
1	10	4	50	42	2	1	5	35	-35
1	11	-5	18	20	2	2	-5	61	-44
1	11	-4	29	24	2	2	-4	<10	5
1	11	-3	29	24	2	2	-3	168	162
1	11	-2	<13	-11	2	2	-2	145	136
1	11	0	48	-44	2	2	-1	44	20
1	11	1	31	25	2	2	0	32	32
1	11	2	30	30	2	2	1	67	50
1	12	-4	41	-40	2	2	2	57	49
1	12	-3	23	-30	2	2	3	81	-77
1	12	-2	23	-23	2	2	4	145	-120
1	12	-1	<15	11	2	2	5	81	-82
1	12	0	51	42	2	3	-6	57	62
1	12	1	27	25	2	3	-5	80	134
1	12	2	39	33	2	3	-4	91	117
1	12	3	30	30	2	3	-3	<11	-9
1	13	-4	19	22	2	3	-2	218	-237
1	13	-3	23	24	2	3	-1	290	-274
1	13	-2	11	12	2	3	0	74	-71
1	13	-1	<13	3	2	3	1	71	-51
1	13	0	11	-12	2	3	2	73	-59
1	14	-3	21	-23	2	3	3	<13	18
1	14	-2	<9	-2	2	4	-5	73	-78
1	14	-1	14	13	2	4	-4	58	-71
1	14	0	9	9	2	4	-3	61	62
1	14	2	15	15	2	4	-2	81	-75
1	15	-1	16	21	2	4	-1	99	-85
2	0	-6	70	-64	2	4	0	127	128
2	0	-5	25	15	2	4	1	150	131
2	0	-4	104	96	2	4	2	77	84
2	0	-3	111	112	2	4	3	91	-91
2	0	-2	403	411	2	4	4	129	-133
2	0	-1	174	146	2	4	5	18	23
2	0	0	281	-336	2	5	-6	60	82
2	0	1	50	-54	2	5	-5	28	19
2	0	2	29	-20	2	5	-4	43	40
2	0	3	<16	4	2	5	-3	29	-24
2	0	4	30	-33	2	5	-2	45	-40
2	0	5	169	-177	2	5	-1	45	-35
2	0	6	65	-76	2	5	0	217	-219
2	1	-5	121	113	2	5	1	135	-129
2	1	-4	54	62	2	5	2	34	35
2	1	-3	<9	10	2	5	3	40	-22
2	1	-2	192	-177	2	5	4	<16	1
2	1	-1	345	-314	2	5	5	47	47
2	1	0	120	130	2	6	-5	40	-33
2	1	1	85	68	2	6	-4	46	-31
2	1	2	96	-106	2	6	-3	40	-50
2	1	3	63	60	2	6	-2	<12	13
2	1	4	14	16	2	6	-1	93	-77

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2	6	1	45	34	2	11	2	45	43
2	6	2	73	58	2	12	-3	22	22
2	6	3	67	43	2	12	-1	20	-21
2	6	4	57	68	2	12	0	12	-13
2	7	-5	50	52	2	12	3	21	-19
2	7	-3	<16	-18	2	13	-5	22	-21
2	7	-2	38	-35	2	13	-4	17	-17
2	7	-1	82	-76	2	13	-3	16	2
2	7	0	56	-51	2	13	-2	21	21
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2	7	2	24	31	2	13	0	<37	5
2	7	3	20	21	2	13	1	<12	13
2	8	-5	30	-28	2	13	2	17	21
2	8	-4	<17	-19	2	14	-3	22	26
2	8	-3	41	-37	2	14	-2	<7	28
2	8	-2	<13	-10	2	14	-1	<10	4
2	8	-1	45	-25	2	14	0	23	-23
2	8	0	71	-83	2	14	1	17	-21
2	8	1	30	-33	3	1	-5	97	51
2	8	2	40	49	3	1	-4	60	-41
2	8	3	101	111	3	1	-3	21	6
2	8	4	60	67	3	1	-2	124	116
2	9	-5	53	53	3	1	-1	52	39
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2	9	-3	<17	-13	3	1	1	96	-90
2	9	-2	77	-73	3	1	2	31	-27
2	9	-1	78	-75	3	1	3	31	23
2	9	0	61	54	3	1	4	104	-104
2	9	1	80	79	3	1	5	111	-105
2	9	2	30	34	3	2	-5	54	35
2	9	3	48	42	3	2	-4	20	19
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2	10	-4	16	-12	3	2	0	78	78
2	10	-3	<17	8	3	2	1	101	-99
2	10	-2	44	-44	3	2	2	20	-13
2	10	-1	43	-38	3	2	3	18	11
2	10	0	<45	3	3	2	4	<16	0
2	10	1	<16	3	3	2	5	46	43
2	10	2	32	35	3	3	-5	70	-64
2	10	3	18	19	3	3	-4	40	-41
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2	10	5	26	28	3	3	-2	79	71
2	11	-4	16	16	3	3	-1	158	154
2	11	-3	<17	-3	3	3	0	27	-23
2	11	-2	22	-16	3	3	1	59	-47
2	11	-1	<16	11	3	3	2	51	-48
2	11	0	38	29	3	3	3	106	-97

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3	4	-5	57	48	3	9	-5	19	-20
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3	4	0	170	-187	3	9	0	18	-16
3	4	1	24	-12	3	9	1	<16	7
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3	4	3	61	48	3	9	3	41	35
3	4	4	73	71	3	10	-5	17	21
3	4	5	23	22	3	10	-4	21	20
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3	5	-4	93	-76	3	10	-2	17	-14
3	5	-3	49	-41	3	10	-1	23	20
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3	5	-1	50	38	3	10	1	26	21
3	5	0	33	32	3	10	2	13	15
3	5	1	21	9	3	11	-5	22	-24
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3	6	-4	26	18	3	11	0	<43	-8
3	6	-3	49	44	3	11	1	<15	-7
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3	6	1	<14	7	3	12	-2	33	35
3	6	2	60	58	3	12	-1	<13	-1
3	6	3	67	67	3	12	0	11	-9
3	6	4	48	44	3	12	1	22	18
3	7	-4	80	-84	3	12	2	13	15
3	7	-3	40	-39	3	13	-3	19	24
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3	7	-1	45	-34	3	13	-1	<11	-10
3	7	0	<45	9	3	13	0	13	-13
3	7	1	27	17	3	13	1	<10	-22
3	7	2	83	83	3	13	2	16	-18
3	7	3	118	122	4	0	-5	93	88
3	7	4	<17	0	4	0	-4	47	-57
3	7	5	45	-40	4	0	-3	153	-139
3	8	-5	17	18	4	0	-2	122	-127
3	8	-4	29	18	4	0	-1	75	58
3	8	-3	<17	-8	4	0	0	<37	21
3	8	-2	60	-58	4	0	1	87	-67
3	8	-1	24	-20	4	0	2	<13	2
3	8	0	13	15	4	0	3	78	-73
3	8	1	<16	1	4	0	4	99	-97

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
4	1	-5	19	-17	4	6	-5	21	-19
4	1	-4	33	-14	4	6	-4	37	-40
4	1	-3	111	-97	4	6	-3	49	-52
4	1	-2	11	-5	4	6	-2	28	-30
4	1	-1	86	73	4	6	-1	70	70
4	1	0	44	-51	4	6	0	64	73
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4	1	2	<13	-10	4	6	2	44	45
4	1	3	<12	6	4	6	3	<17	17
4	1	4	60	61	4	6	4	15	-18
4	1	5	25	22	4	7	-5	19	15
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4	2	-1	<13	5	4	7	0	39	-41
4	2	0	<38	9	4	7	1	<16	17
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4	4	0	22	29	4	9	3	<14	5
4	4	1	<15	11	4	9	4	22	24
4	4	2	61	-60	4	10	-5	16	1
4	4	3	20	29	4	10	-4	<15	4
4	4	4	59	58	4	10	-3	28	4
4	4	5	18	-15	4	10	-2	26	24
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4	5	1	42	36	4	11	-4	16	18
4	5	2	72	75	4	11	-3	22	26
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4	5	4	15	16	4	12	-4	17	17

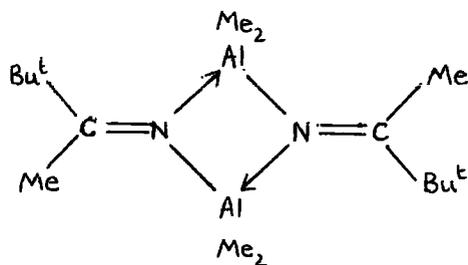
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4	12	-2	<10	6	5	5	0	45	50
4	12	-1	<11	-2	5	5	1	44	39
4	12	0	<32	-9	5	5	2	13	18
4	12	1	18	-23	5	5	3	<16	-2
4	13	-3	19	25	5	5	4	17	-14
4	13	-2	<7	9	5	6	-3	53	-48
4	13	-1	<8	-8	5	6	-2	73	-79
4	13	0	6	0	5	6	-1	25	-21
5	1	-5	37	39	5	6	0	21	23
5	1	-4	<16	-5	5	6	1	41	43
5	1	-3	90	-85	5	6	2	39	38
5	1	-2	81	-74	5	7	-2	46	41
5	1	-1	47	-36	5	7	-1	50	53
5	1	0	26	-26	5	7	0	26	27
5	1	1	<16	24	5	7	1	40	40
5	1	2	18	-11	5	8	-1	19	-24
5	1	3	50	-40	5	8	0	20	-21
5	2	-4	51	-49	5	8	1	14	-6
5	2	-3	44	-28	5	8	2	<12	-6
5	2	-2	30	32	5	8	3	25	27
5	2	-1	40	-39	5	9	-3	24	20
5	2	0	41	-43	5	9	-2	21	19
5	2	1	<16	24	5	9	-1	21	20
5	2	2	26	24	5	9	0	23	28
5	2	3	67	95	5	9	1	13	12
5	2	4	53	52	5	10	-4	28	24
5	3	-5	64	61	5	10	-3	17	19
5	3	-4	42	36	5	10	-2	34	17
5	3	-3	29	-25	5	10	0	20	-23
5	3	-2	119	-124	5	10	1	24	-28
5	3	-1	69	-71	5	11	-4	17	21
5	3	0	47	55	5	11	0	7	8
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5	3	2	<14	10	6	0	-5	27	-21
5	3	3	39	29	6	0	-4	27	-25
5	3	4	20	-16	6	0	-3	<17	0
5	4	-4	27	-32	6	0	-2	44	-41
5	4	-3	62	-65	6	0	-1	111	-114
5	4	-2	75	-78	6	0	0	29	-36
5	4	-1	25	-21	6	1	-3	19	14
5	4	0	<44	10	6	1	-2	25	-23
5	4	1	30	32	6	1	-1	25	-21
5	4	2	64	67	6	2	-3	35	-32
5	4	3	30	42	6	2	-2	69	-70
5	4	4	25	23	6	2	-1	45	-51
5	5	-5	30	25	6	2	0	<45	-9
5	5	-4	35	30	6	2	1	33	28
5	5	-3	21	-15	6	2	2	41	38
5	5	-2	45	-40	6	3	-2	26	-23

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
6	3	-1	<16	-14	6	10	-1	13	16
6	3	0	<45	12	7	1	-5	26	-28
6	3	1	35	32	7	1	-4	28	-32
6	3	2	58	60	7	1	-3	19	-21
6	4	-4	15	16	7	1	-2	39	-43
6	4	-3	35	-27	7	1	-1	34	-36
6	4	-2	48	-48	7	2	-1	22	19
6	4	-1	<16	8	7	2	0	8	11
6	4	0	13	18	7	3	-5	17	-18
6	4	1	29	28	7	3	-4	37	-37
6	4	2	29	29	7	3	-3	26	-30
6	5	-3	29	-31	7	3	-2	15	12
6	5	-2	<13	-2	7	4	-3	23	21
6	5	-1	<15	14	7	4	-2	18	17
6	5	0	12	15	7	4	-1	<13	4
6	5	1	38	38	7	4	0	10	14
6	6	-4	19	21	7	5	-3	13	8
6	6	-3	42	41	7	5	-2	18	17
6	6	-2	24	28	7	6	-4	14	14
6	6	-1	<16	-7	7	6	-3	22	25
6	6	0	<43	9	7	6	-2	10	13
6	6	1	21	18	7	7	-4	22	27
6	7	-2	16	-17	7	7	-3	31	38
6	8	-4	20	25	8	0	-4	26	-27
6	8	-3	43	52	8	0	-3	41	-50
6	8	-2	31	37	8	0	-2	26	-27
6	9	-5	25	28	8	0	-1	12	11
6	9	-4	26	28	8	1	-2	19	20
6	9	-3	<12	15	8	2	-4	26	-28
6	9	-2	17	-18	8	2	-3	21	-24
6	9	-1	24	-30	8	4	-3	18	1
6	9	0	15	-21					

The Crystal Structure of 2,2' dimethylbutylidene-3-aminodimethyl-  
aluminium dimer  $(\text{Bu}^t\text{MeCNAlMe}_2)_2$ .

Introduction.

Trialkylaluminiums react with alkyl cyanides forming adducts which rearrange on heating, giving products thought to contain a nitrogen-aluminium four-membered ring system. Unlike the analogous boron compounds only one product is formed in most cases and this is thought to be exclusively the trans isomer (Wade and Jennings, 1965). These compounds are much more readily hydrolysed than the corresponding ethylideneaminoboranes, but for the compounds in which there is most crowding of the groups round the aluminium the hydrolysis is very slow and  $(\text{Bu}^t\text{MeCNAlMe}_2)_2$  is hydrolysed very slowly indeed. This compound is also unusual in that it does not undergo further rearrangement and is not further attacked by trimethylaluminium.  $(\text{Bu}^t\text{MeCNAlMe}_2)_2$  was studied for comparison with  $(\text{MeCHNBMe})_2$  and also to see whether the packing in the crystal would account for its unusual lack of reactivity compared with other aluminium compounds in the series.



Experimental

Plate-like crystals were grown by vacuum sublimation, cut to

suitable shapes and mounted in sealed glass capillary tubes, the walls of which were about 0.06 mm. thick. These operations were carried out in a glove box in an atmosphere of oxygen free nitrogen.

Crystal data.

The unit cell dimensions were measured from photographs of the hol and okl nets photographed using Zr- filtered Mo radiation and the precession camera. The statistical errors in the cell dimensions measured from the photographs are 0.004Å in a, 0.006Å in b and 0.003Å in c. The actual error is probably about 0.5% of each dimension and 10' in  $\beta$ .

Orthorhombic  $a = 11.2\text{\AA}$ ,  $b = 14.86\text{\AA}$ ,  $c = 12.54\text{\AA}$ ,  $V = 2085\text{\AA}^3$   
 $Z = 8$  Bu<sup>t</sup>MeCNAI<sub>2</sub>Me<sub>2</sub> formula units.  $D_x = 0.935 \text{ gm.cm}^{-3}$ .  $\mu(\lambda = 0.7107) = 1.186 \text{ cm}^{-1}$ .  $\mu(\lambda = 1.5418) = 10.5 \text{ cm}^{-1}$ .

Reflections observed:-

hkl when  $h + k = 2n$

hko when  $h = 2n$  ( $k = 2n$ )

hol when  $l = 2n$  ( $h = 2n$ )

okl when ( $k = 2n$ )

These are consistent with the centrosymmetric space group Cmca

(International Tables for X-ray Crystallography, Vol. 1, No. 64) or with the non-centrosymmetric C2ca (Aba<sub>2</sub>, No. 41 if the directions of a and c are interchanged). The density calculated on the basis of eight Bu<sup>t</sup>MeCNAI<sub>2</sub>Me<sub>2</sub> units per unit cell is  $0.935 \text{ gm.cm}^{-3}$ , in agreement with

the experimental value of between 0.91 and 0.96 gm.cm<sup>-3</sup>.

If the space group is C2ca then the molecule must possess a two-fold axis lying along a. For the trans isomer this must be perpendicular to the plane of the ring. For the space group to be Cmca the molecule must possess, in addition, a mirror plane perpendicular to this two-fold axis. For the trans isomer to fulfill the symmetry requirements of this space group, the plane containing the ring atoms must coincide with the mirror plane and all of the atoms will lie in this plane, except the atoms of the two methyl attached to aluminium and also the atoms of two of the methyl groups forming part of the t-butyl group which will be related by the mirror plane.

#### Collection of Intensities.

As the absorption coefficient for this compound for Mo radiation is 1.186 cm<sup>-1</sup> and the crystals were fairly small, no absorption correction was made to any of the data as Mo radiation was used throughout.

The hk0-hk6 nets were recorded using the equi-inclination angle Weissenberg technique and a needle shaped crystal of cross section 0.3 x 0.3 mm<sup>2</sup>. A crystal shaped like a triangular plate mounted along its longest side and of height 0.6 mm. and thickness 0.4 mm. and the precession camera were used to record the nets okl-3kl, hol-h6l and some diagonal nets.

The intensities of these reflections were estimated visually

using a graduated scale. After the usual Lorentz, polarisation and length corrections (Phillips, 1956) had been applied, the structure factors on the twenty four nets were correlated by a least-squares method. 646 independent reflections were recorded, 161 of these appeared on only two nets and a further 185 on at least three.

### The Patterson Function

The expression

$$P(uvw) = \frac{c}{V} \sum_0^{\infty} \sum_0^{\infty} \sum_0^{\infty} w_{hkl}^2 |F_{hkl}|^2 \cos 2\pi hu \cos 2\pi kv \cos 2\pi lw$$

was used to compute the three-dimensional Patterson function, the structure factors being weighted by means of the function  $\exp \{ 12 \sin^2 \theta / \lambda^2 \}$ . This function was allowed a maximum value of 100 so as not to give too large a weight to the weak high-order reflections.

The Patterson section  $P(0vw)$  showed a large number of pronounced peaks, in agreement with the expected arrangement of the molecules in the cell. An examination of the aluminium-aluminium vectors allowed coordinates to be assigned to the aluminium atom. The x-coordinate of zero is compatible with either space group and can arise from this atom being situated in the mirror plane in the centro-symmetric space group or from the arbitrary position of the origin in the a-axis direction in the non-centrosymmetric one. Direct inspection of the Patterson function, together with the use of superposition methods, revealed the

positions of all the atoms except those of the methyl carbons in the t-butyl group. With the omission of these atoms, the molecule was found to be essentially centrosymmetric and structure factors were calculated for these atoms, assuming a centrosymmetrical model. The residual R was 0.38.

An  $F_o$  synthesis was then evaluated at the same intervals as the Patterson function using the expression appropriate to the centrosymmetrical case, namely that for  $Cmca$ . This is

$$\rho(xyz) = \frac{8}{V} \left\{ \sum_0 \sum_0 \sum_0^{k+l+2n} F_{hkl} \cos 2\pi x \cos 2\pi y \cos 2\pi z \right. \\ \left. - \sum_0 \sum_0 \sum_0^{k+l=2n+1} F_{\bar{h}kl} \cos 2\pi x \sin 2\pi y \sin 2\pi z \right\}$$

The electron density map showed peaks at positions corresponding to all the atoms whose positions had previously been determined. In addition, peaks corresponding to the methyl carbon atoms in the t-butyl group were also present. These peaks were very drawn out and, in one direction, fell to half their maximum value over a distance of about  $2\text{\AA}$ . The compound was now established as the trans isomer.

The inability to recognise peaks in the Patterson function arising

from vectors involving the methyl carbon atoms in the t-butyl group did not permit a choice of space group to be made at that time. Calculation of the electron density in the centrosymmetrical space group resulted in their being a mirror plane at  $x = 0$ . Atoms, which are not related in pairs by the mirror plane, will give rise to peaks of electron density, above and below this plane, of weight one-half. The peaks which were smeared out in the  $F_0$  synthesis were thought to have arisen in this way from the overlap of peaks of lesser height. On this basis, coordinates were now given to the methyl carbon atoms in the t-butyl group. The positions of these atoms were not related by a mirror plane and the centre of symmetry in the structure was now removed, permitting systematic methods of refinement to be applied.

#### Refinement

The atomic parameters of the non-centrosymmetrical model in the space group  $Aba2$  were refined by least-squares methods. With isotropic temperature factors the residual fell to 0.175 and with anisotropic temperature parameters to a value of 0.117. At this stage the temperature factors of two of the methyl carbons in the t-butyl group were very much larger than those of the third and were not consistent with the vibration of the group as a whole. The carbon-carbon distances in the t-butyl group ranged from 1.45 to 1.55Å with quoted e.s.d.'s of about 0.03 and the carbon-carbon angles varied considerably amongst themselves. In addition, the molecule showed marked deviations from planarity in a

not very systematic manner. At this stage, a difference map showed two peaks of height  $0.5e\text{\AA}^{-3}$  close to two of the t-butyl methyl carbons and in positions related by the plane of the molecule, although these atoms had shown no tendency to move to positions related in this way during the refinement.

For these reasons it was thought that the space group might be the centrosymmetric  $Cmca$  and atomic coordinates were chosen in accordance with the required molecular symmetry. Of the three methyl carbon atoms in the t-butyl group, one now lay in the mirror plane at  $x = 0$  with one above and one below this plane and related by it. The refinement of this model gave thermal parameters more easy to understand and more consistent bond distances and angles. The least-squares refinement was carried out with isotropic thermal parameters until a residual of  $0.184$  was obtained. Further refinement with anisotropic thermal parameters resulted in the final value of the residual being  $0.114$ , calculated on the  $524$  observed reflections. A difference synthesis now showed no major features and in particular there were no marked positive or negative regions in the plane of the t-butyl methyl carbons.

It would appear that these atoms are undergoing very large vibrations, apparently as a rigid body, about the bond  $C3-C4$  to the rest of the molecule rather than rotating freely about this bond. The space group was now established as  $Cmca$ .

The Final Cycle of Refinement.

No. of planes = 524,  $|F_o| = 13052$ ,  $|F_c| = 12684$ ,  $R = 0.114$ ,  
 $R^1 = 0.0351$ .

In the final cycles of refinement the weighting scheme  $W = 1/(a + |F_o| + c|F_o|^2)$  was used.  $a$  and  $c$  had the values 12 and 0.08 in the last cycle. The real part of the correction for dispersion was applied to the scattering factors for aluminium. The unobserved reflections were given zero weight in the refinement. The final coordinates and their e.s.d.'s are listed in Table VI and the final thermal parameters in Table VII. The average coordinate shift in the final cycle of refinement was  $0.0010\text{\AA}$ , the shifts ranging up to 0.25 of the corresponding e.s.d. The average shift in thermal parameters was  $0.0015\text{\AA}$ , the shifts varying from 0 to 0.35 of the corresponding e.s.d. The final values of the structure factors are listed in Table X.

The scattering factors used were those quoted in International Tables for X-ray Crystallography, Vol. 1, page 202.

Table VI.  $(\text{Bu}^t\text{MeCNA1Me}_2)_2$ . Atomic Coordinates and their standard

Atom	<u>deviations</u>						Å
	x	y	z	$\sigma_x$	$\sigma_y$	$\sigma_z$	
A1	0	1.260	0.671	0	0.004	0.004	
N	0	-0.600	1.172	0	0.011	0.010	
C1	1.761	2.163	1.028	0.015	0.012	0.013	
C2	1.267	-1.317	4.322	0.028	0.025	0.019	
C3	0	-1.340	2.207	0	0.017	0.016	
C4	0	-0.827	3.664	0	0.016	0.013	
C5	0	-2.879	2.109	0	0.018	0.016	
C6	0	0.678	3.735	0	0.024	0.021	

Table VII.  $(\text{Bu}^t\text{MeCNAlMe}_2)_2$

Thermal parameters in  $\text{\AA}^2$  and their e.s.d.'s in  $10^3 \text{\AA}^2$  in brackets.

Atom	$U_{11}$	$U_{22}$	$U_{33}$	$U_{12}$	$U_{23}$	$U_{13}$
A1	0.067(3)	0.034(2)	0.035(2)	0	0.005(2)	0
N	0.065(8)	0.037(6)	0.019(4)	0	0.010(4)	0
C1	0.082(9)	0.069(7)	0.072(8)	-0.025(7)	-0.008(6)	0.0004(7)
C2	0.209(23)	0.195(22)	0.093(11)	0.105(14)	-0.047(13)	-0.077(14)
C3	0.090(13)	0.058(10)	0.058(10)	0	0.017(9)	0
C4	0.062(10)	0.069(9)	0.026(6)	0	0.003(7)	0
C5	0.175(23)	0.046(9)	0.049(9)	0	0.010(8)	0
C6	0.232(32)	0.079(13)	0.053(10)	0	-0.025(11)	0

### Description of the Structure

As expected, the molecule is a dimer and contains a four-membered ring system with a double bond attached to nitrogen. It is the trans isomer.

The bond lengths and angles are listed in Table VIII. The values for the chemically equivalent bonds Al-N and Al-N' (where N' refers to the atom related by the centre at 000) do not differ significantly from one another and their mean value is also quoted. The molecular dimensions are shown in fig. IV.

A value of 1.96Å (Pauling, 1960) is obtained for the length of an aluminium-nitrogen single bond for atoms in  $sp^3$  hybrid states. As the nitrogen is formally  $sp^2$  hybridised, a value of about 1.94Å might be expected. Both these values agree with the mean Al-N distance of  $1.942 \pm 0.008\text{Å}$ .

The Al-C1 distance of  $2.01 \pm 0.014\text{Å}$  is in good agreement with the value of 1.99Å found for the terminal aluminium-carbon bond in trimethylaluminium (Rundle, 1953). This distance is considerably greater than that of a boron-carbon bond and the separation between C1 and the atom related by the mirror plane is increased to 3.52Å, compared with 2.74Å in the boron compound examined previously. This distance is now greater than most of the other intramolecular non-bonding contacts.

The length of the carbon-nitrogen double bond N-C3 is 1.272Å, almost identical with that of the corresponding bond in  $(\text{MeHCNMe})_2$  and of the

Table VIII.      (Bu<sup>t</sup>MeCNA1Me<sub>2</sub>)<sub>2</sub>.      Bond lengths and angles.

Al-N	1.927Å	0.011Å
Al-N'	1.958	0.011
Al-C1	2.010	0.014
N-C3	1.272	0.020
C3-C5	1.543	0.025
C3-C4	1.545	0.022
C4-C2	1.509	0.027
C4-C6	1.506	0.029
Al-N (mean)	1.942	0.008
N-Al-N'	85.4°	0.5°
Al-N-Al'	94.6	0.5
C1-Al-C''	122.2	0.6
Al-N-C3	140.5	0.8
Al'-N-C3	125.0	0.8
N-C3-C4	125.3	1.0
N-C3-C5	120.5	1.1
C4-C3-C5	113.0	1.3
C3-C4-C2	107.6	1.1
C3-C4-C6	112.0	1.4
C2-C4-C6	107.7	1.2
C2-C4-C2''	114.2	1.6

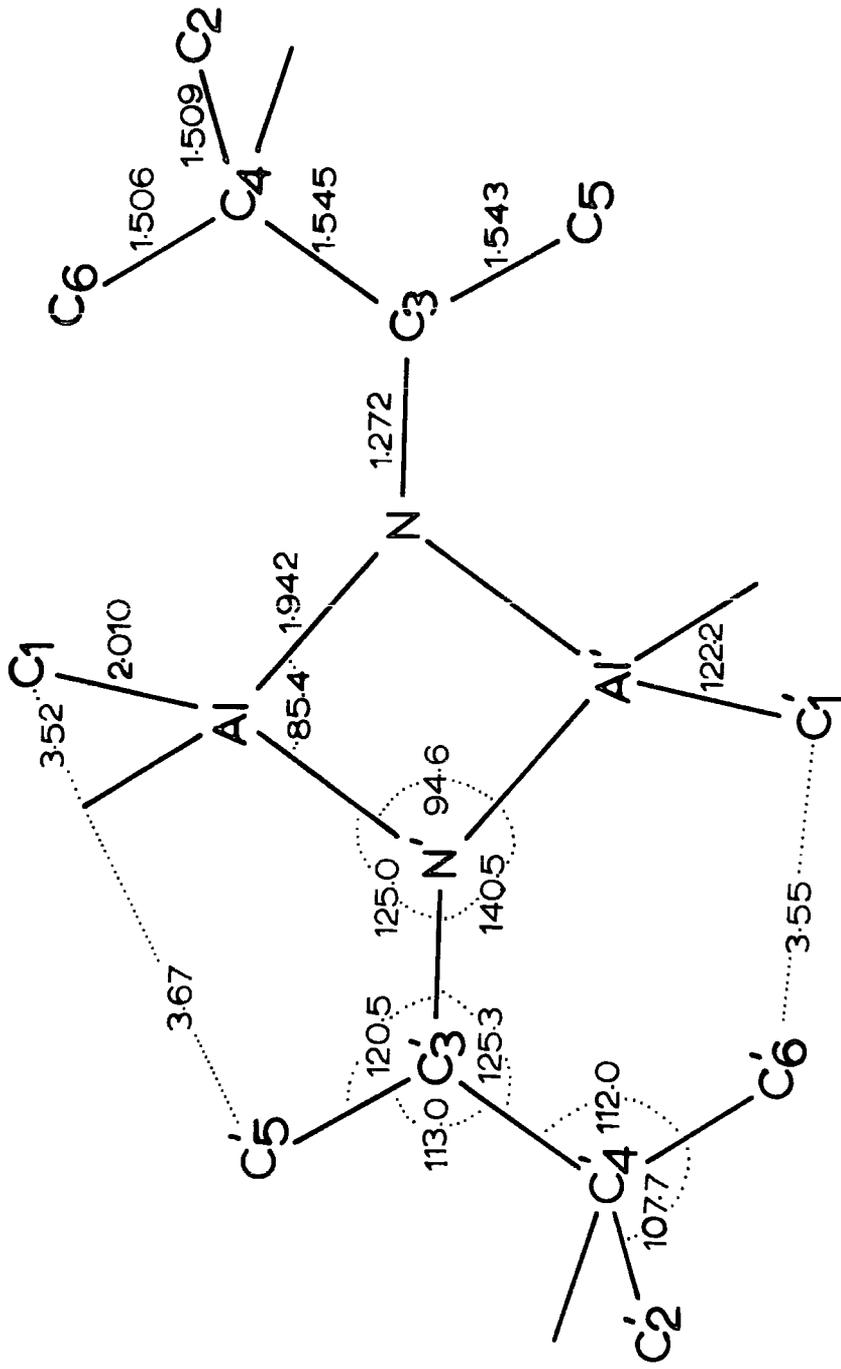
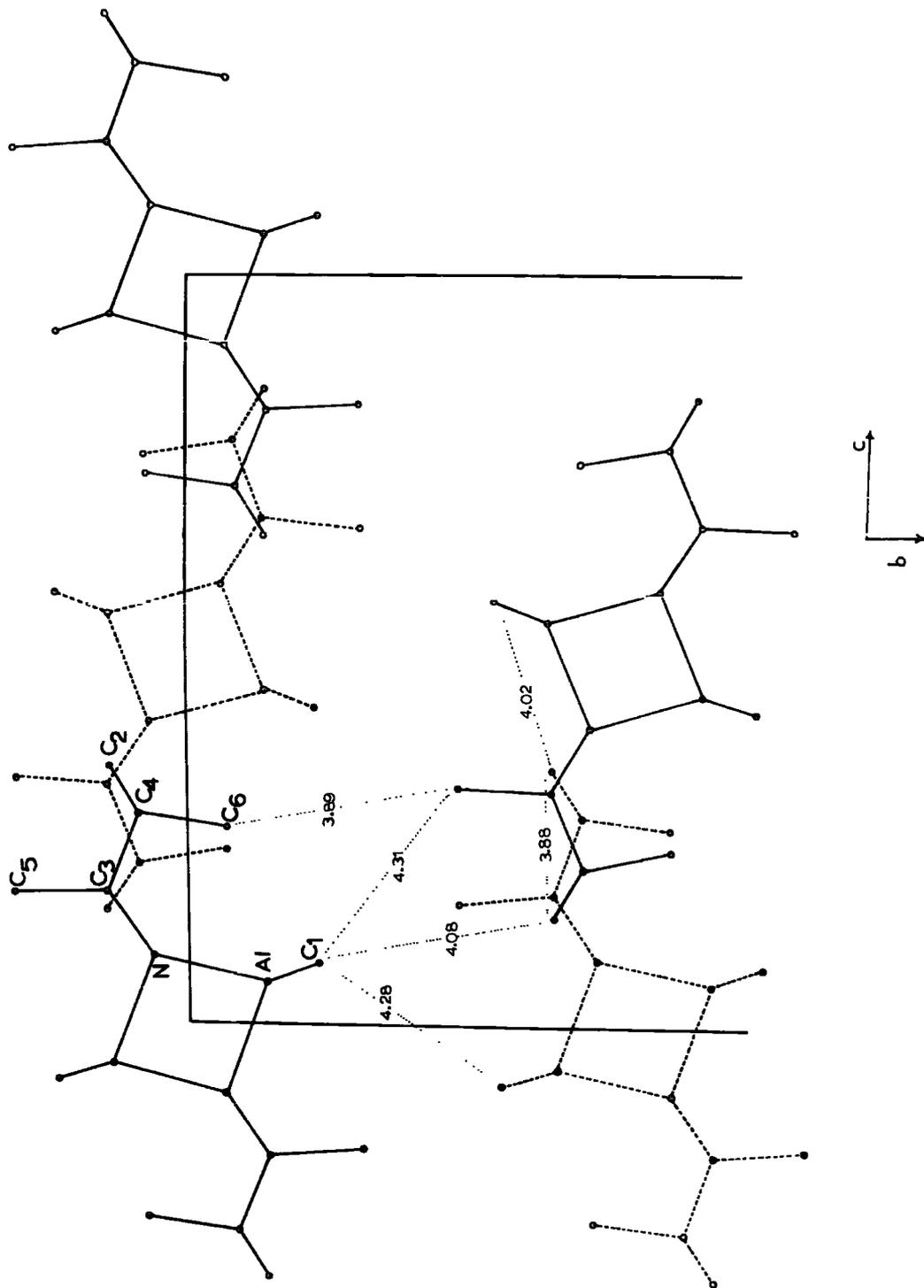


FIG. IV. Molecular Geometry.

$(\text{Bu}^t\text{MeCNAlMe}_2)_2$



$(\text{Bu}^t\text{-MeCNAIMe}_2)_2$  100 projection

FIG. VI. Molecular packing in the unit cell.

double bond in dimethylglyoxime.

Neither of the carbon-carbon bonds adjacent to the double bond is shortened as in the boron compound. Their lengths of  $1.545 \pm 0.022\text{\AA}$  for C3-C4 and  $1.543 \pm 0.025\text{\AA}$  for C3-C5 do not differ significantly from the value of about  $1.52\text{\AA}$ , expected for a bond between carbon atoms in  $sp^2$  and  $sp^3$  hybrid states.

In the t-butyl group, the distances involving the methyl carbons are  $1.509 \pm 0.027\text{\AA}$  for C2-C4 and  $1.506 \pm 0.029\text{\AA}$  for C4-C6 and neither is significantly shorter than the standard value of  $1.5445\text{\AA}$  for diamond. However the space group symmetry requires that the thermal vibration tensor components  $U_{12}$  and  $U_{13}$  for C6 have zero value and this atom has its major axis of vibration parallel to a. The correction for thermal oscillation effects (Cruickshank, 1956a) for the bond C4-C6 is  $0.017\text{\AA}$  giving a corrected length for this bond of  $1.523\text{\AA}$ . An increase in length of similar magnitude is expected for C2-C4.

As in the boron compound previously examined the ring angle at nitrogen is greater than  $90^\circ$ , presumably because of its formal  $sp^2$  hybrid state and the greater electronegativity of nitrogen compared with aluminium. This angle at  $94.6^\circ$  is greater than in the earlier case, since aluminium forms longer bonds than boron and the bond angle at aluminium would be expected to deform more readily than the one at nitrogen. Corresponding to this reduction in the ring angle at aluminium, the angle C1-Al-C1" (where the C1" refers to the atom related by the mirror plane

at  $x = 0$ ) is increased to  $122.2^\circ$ , considerably greater than the tetrahedral value.

The values other angles seem best discussed in conjunction with the lengths of the non-bonding contacts which arise within the molecule. These together with the intermolecular contacts are listed in Table IX. The arrangement results in pairs of methyl carbons, related by the mirror plane, and methyl carbons lying on the mirror plane being situated round the circumference of the molecule and giving rise to maximum non-bonding contacts.

The distortion of the aluminium-nitrogen-carbon angles to  $140^\circ$  for Al-N-C3 and  $125^\circ$  for Al'-N-C3 increases the C1-C6 separation to  $3.55\text{\AA}$  making it comparable to the C1-C5 separation of  $3.67\text{\AA}$  and to corresponding intramolecular contacts in  $(\text{Me}_2\text{BNCHMe})_2$  of  $3.45$  and  $3.44\text{\AA}$ . The value of  $112^\circ$  for the angle C3-C4-C6 is not significantly greater than the tetrahedral value of  $109^\circ 28'$ , but the N-C3-C4 angle of  $125^\circ$ , slightly greater than the trigonal value, will help to increase the C1-C6 separation. The value of  $3.67$  for the distance C1-C5 is in spite of the angle N-C3-C5 of  $121^\circ$  being nearly trigonal and Al'-N-C3 being  $125^\circ$ .

The angle C5-C3-C4 is only  $113^\circ$  which is much less than trigonal and the value for C2-C4-C3 of  $108^\circ$  is not significantly different to tetrahedral. As a result of the molecular geometry the separation between C2 and C5 at  $2.99\text{\AA}$  is much shorter than other contacts between methyl groups not bonded to the same atom. In hexamethyl benzene

(Robertson, 1939) the methyl contacts round the ring are  $2.92 \text{ \AA}$ .

In the t-butyl group the angle C2-C4-C6 is  $108^\circ$  and close to tetrahedral whereas C2-C4-C2'' where this angle is in a plane perpendicular to the plane of the molecule is  $114^\circ$ . The separation between C2 and C6 is  $2.44$  and that between C2 and C2'' is  $2.53 \text{ \AA}$ .

All the atoms except C1 and C2 are fixed on the mirror plane by the requirements of the space group symmetry. The best line through N, C3 and the atoms related by the centre of symmetry is

$$x = 0, y = -0.587z$$

N is  $0.55 \text{ \AA}$  from this and C3 -  $0.038 \text{ \AA}$  and the four atoms are not co-linear. The equation of the mean plane through Al, C1 and the atoms related by the centre of symmetry is

$$0.0719x - 0.4088y + 0.90872z = 0$$

where x, y and z are parallel to the crystal axes. The angle between the normal to this plane and the mirror plane is  $7^\circ$ .

The intermolecular contacts are listed in Table IX. The only contacts of less than  $4 \text{ \AA}$  are between C2 and C2' of the next molecule at  $(\frac{1}{2}, 0, \frac{1}{2})$  and C5 with C6 of the molecule at  $(\frac{1}{2}, \frac{1}{2}, 0)$ .

The molecular packing is shown in fig. V<sub>h</sub>.

The lack of reactivity of this compound compared with similar compounds of aluminium is explained by the molecular structure. The aluminium has two nitrogens and four methyl groups around it in a very distorted tetrahedral arrangement. In addition it has two methyl groups as

more distant neighbours at 3.21 and 3.12Å and another aluminium atom at a distance of 2.8Å.

Table IX. (Bu<sup>t</sup>MeCNAlMe<sub>2</sub>)<sub>2</sub>. Non-bonding contacts.

Intramolecular contacts.

C5'-C1	3.67 <sup>8</sup> Å
C1-C6	3.55
Al-C6	3.12
N-C6	2.86
Al-C5'	3.21
N-C5'	2.46
C6-C2	2.44
C2-C2''	2.53
C1-C1''	3.52
C2-C5	2.99

Intermolecular contacts.

C2-C2	$\frac{1}{2} - x, y, \frac{1}{2} - z$	3.878 <sup>8</sup> Å
C5-C6	$0, y - \frac{1}{2}, \frac{1}{2} - z$	3.891
C1-C2	$\frac{1}{2} - x, \bar{y}, z - \frac{1}{2}$	4.022
C1-C2	$x, \frac{1}{2} + y, \frac{1}{2} - z$	4.083
C1-C1	$\frac{1}{2} - x, \frac{1}{2} - y, \bar{z}$	4.262
C1-C5	$0, \frac{1}{2} + y, \frac{1}{2} - z$	4.313
C2-C3	$\frac{1}{2}, y, \frac{1}{2} - z$	4.341
C1-C2	$\frac{1}{2} - x, y, \frac{1}{2} - z$	4.424

TABLE X.       $(\text{Bu}^t\text{MeCNAlMe}_2)_2$ .

Observed and calculated structure factors.

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
0	0	2	209	-137	0	8	0	771	-658
0	0	4	934	-762	0	8	1	195	-195
0	0	6	248	-156	0	8	2	212	167
0	0	8	844	-894	0	8	3	372	360
0	0	10	143	-101	0	8	4	<61	-117
0	2	0	1751	1617	0	8	5	598	554
0	2	1	737	687	0	8	6	158	-99
0	2	2	323	-227	0	8	7	<83	10
0	2	3	1075	-983	0	8	8	250	275
0	2	4	<117	31	0	8	10	<107	23
0	2	5	1350	-1341	0	8	11	<107	0
0	2	6	231	-148	0	8	12	<107	74
0	2	7	<109	16	0	8	13	117	-118
0	2	8	326	-316	0	10	0	<83	2
0	2	9	<134	51	0	10	1	<107	-52
0	2	10	114	86	0	10	2	117	81
0	2	11	143	108	0	10	3	353	380
0	2	12	173	-139	0	10	4	<114	7
0	2	13	202	243	0	10	5	377	380
0	2	14	<124	11	0	10	6	221	263
0	2	15	156	132	0	10	7	<114	24
0	4	0	1080	-1085	0	10	8	<107	-76
0	4	1	306	472	0	10	9	<107	89
0	4	2	450	-462	0	10	10	309	-334
0	4	3	<141	35	0	10	11	<107	-47
0	4	4	255	233	0	10	12	<107	-11
0	4	5	445	-460	0	10	13	122	-94
0	4	6	105	121	0	12	0	180	195
0	4	7	382	-424	0	12	1	122	119
0	4	8	250	260	0	12	2	246	259
0	4	9	212	-246	0	12	3	97	116
0	4	10	297	292	0	12	4	141	125
0	4	11	129	123	0	12	5	<102	-76
0	4	12	<161	-1	0	12	6	<102	-8
0	4	13	192	210	0	12	7	<109	-9
0	4	14	<161	-42	0	12	8	216	-194
0	4	15	136	199	0	12	9	<112	-3
0	6	0	1070	-870	0	12	10	260	-277
0	6	1	535	424	0	14	0	109	71
0	6	2	<88	48	0	14	1	114	-122
0	6	3	642	518	0	14	2	114	110
0	6	4	190	-167	0	14	3	231	-249
0	6	5	221	160	0	14	4	<129	69
0	6	6	122	-114	0	14	5	226	-231
0	6	7	180	-146	0	14	6	<129	-46
0	6	8	340	363	0	14	7	122	-112
0	6	9	224	-255	0	16	0	148	-169
0	6	10	306	322	0	16	1	109	-60
0	6	11	<109	-42	0	16	2	134	-137
0	6	12	207	191	0	16	3	231	-220

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
0	16	4	<122	36	1	7	3	229	-247
0	16	5	156	-189	1	7	4	382	322
0	18	0	182	-199	1	7	5	<150	30
0	18	1	<122	-4	1	7	6	105	96
0	18	2	190	-109	1	7	7	<124	64
1	1	1	1131	1145	1	7	8	<112	6
1	1	2	406	-285	1	7	9	336	376
1	1	3	907	781	1	7	10	<105	-99
1	1	4	849	-736	1	7	11	131	113
1	1	5	788	-789	1	9	1	<105	-65
1	1	6	199	-206	1	9	2	187	225
1	1	7	336	-350	1	9	3	148	-131
1	1	8	<122	2	1	9	4	574	526
1	1	9	460	-418	1	9	5	282	286
1	1	10	<151	-49	1	9	6	272	273
1	1	11	<136	17	1	9	7	90	-74
1	1	12	197	173	1	9	8	<134	24
1	1	13	<139	-4	1	9	9	<134	4
1	1	14	146	130	1	9	10	<143	34
1	1	15	134	-113	1	9	11	<143	-73
1	3	1	464	-316	1	9	12	119	-102
1	3	2	669	-636	1	11	1	248	262
1	3	3	491	434	1	11	2	258	271
1	3	4	109	-456	1	11	3	<122	-7
1	3	5	474	-422	1	11	4	100	104
1	3	6	426	-452	1	11	5	321	293
1	3	7	197	158	1	11	6	119	130
1	3	8	297	-359	1	11	7	175	-173
1	3	9	131	138	1	11	8	<122	39
1	3	10	<134	-7	1	11	9	272	-261
1	3	11	<139	-10	1	11	10	<122	-48
1	3	12	331	313	1	11	11	146	-158
1	3	13	<139	1	1	13	1	182	180
1	3	14	195	209	1	13	2	<131	-60
1	5	1	263	-345	1	13	3	122	158
1	5	2	457	303	1	13	4	231	-220
1	5	3	640	-554	1	13	5	<131	68
1	5	4	110	157	1	13	6	<134	-86
1	5	5	<90	-14	1	13	7	182	-153
1	5	6	348	-302	1	13	8	<134	-48
1	5	7	464	392	1	13	9	146	-139
1	5	8	311	-330	1	15	1	<122	-55
1	5	9	360	316	1	15	2	182	-203
1	5	10	<134	-99	1	15	3	<122	-15
1	5	11	151	172	1	15	4	241	-266
1	5	12	173	158	1	15	5	<122	60
1	5	13	109	103	1	15	6	146	-145
1	5	14	134	156	1	17	1	178	-204
1	7	1	396	-355	2	0	0	2562	2722
1	7	2	598	563	2	0	2	438	-284

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
2	0	4	163	-75	2	8	0	824	-726
2	0	6	<107	20	2	8	1	<83	71
2	0	8	596	-620	2	8	2	<88	-2
2	0	10	117	-109	2	8	3	640	625
2	0	12	180	-154	2	8	4	<95	-42
2	2	0	1362	1306	2	8	5	554	570
2	2	1	632	635	2	8	6	<105	85
2	2	2	151	93	2	8	7	<112	-17
2	2	3	150	-157	2	8	8	265	265
2	2	4	<71	53	2	10	0	219	223
2	2	5	749	-685	2	10	1	<95	49
2	2	6	336	-368	2	10	2	190	195
2	2	7	243	-260	2	10	3	413	434
2	2	8	326	-298	2	10	4	<105	-53
2	2	9	153	-188	2	10	5	345	342
2	2	10	<136	108	2	10	6	<112	82
2	2	11	109	91	2	10	7	<112	20
2	2	12	131	-129	2	10	8	141	-149
2	2	13	204	240	2	10	9	<112	48
2	2	14	<122	26	2	10	10	238	-271
2	2	15	129	160	2	12	0	185	185
2	4	0	<109	-70	2	12	1	<107	29
2	4	1	204	-56	2	12	2	243	254
2	4	2	122	-139	2	12	3	<80	-47
2	4	3	309	-310	2	12	4	129	115
2	4	4	<124	-125	2	12	5	146	-139
2	4	5	343	-377	2	12	6	<119	-34
2	4	6	131	-137	2	12	7	<119	40
2	4	7	409	-444	2	12	8	209	-177
2	4	8	122	146	2	12	9	<119	61
2	4	9	143	-159	2	12	10	226	-240
2	4	10	304	298	2	14	0	<97	-47
2	4	11	185	202	2	14	1	117	-116
2	4	12	122	94	2	14	2	<117	51
2	4	13	175	168	2	14	3	195	-222
2	4	14	<131	-6	2	14	4	212	112
2	4	15	161	168	2	14	5	185	-201
2	6	0	1021	-940	2	16	0	114	-133
2	6	1	156	154	2	16	1	<117	-29
2	6	2	336	-345	2	16	2	129	-113
2	6	3	122	136	2	16	3	129	-145
2	6	4	170	-140	2	16	4	<117	27
2	6	5	<92	27	2	16	5	153	-150
2	6	6	209	20	2	18	0	156	-149
2	6	7	80	-74	3	1	1	691	732
2	6	8	370	406	3	1	2	893	647
2	6	9	<131	-104	3	1	3	<117	84
2	6	10	248	239	3	1	4	302	-284
2	6	11	<119	5	3	1	5	224	-233
2	6	12	136	155	3	1	6	212	-229

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
3	1	7	<131	13	3	9	9	<134	-10
3	1	8	92	-88	3	9	10	<134	-30
3	1	9	433	-475	3	9	11	<134	-65
3	1	10	175	-185	3	9	12	92	-84
3	1	11	136	-48	3	11	1	384	396
3	1	12	<136	121	3	11	2	90	111
3	1	13	<146	-14	3	11	3	<112	-30
3	1	14	156	171	3	11	4	<88	24
3	3	1	625	446	3	11	5	141	141
3	3	2	338	221	3	11	6	<124	93
3	3	3	328	306	3	11	7	117	-206
3	3	4	399	-507	3	11	8	<124	63
3	3	5	671	-654	3	11	9	253	-245
3	3	6	445	-498	3	13	1	105	73
3	3	7	114	-152	3	13	2	122	-114
3	3	8	212	-219	3	13	3	122	114
3	3	9	100	86	3	13	4	253	-263
3	3	10	136	-120	3	13	5	129	136
3	3	11	114	108	3	15	1	<105	-83
3	3	12	260	248	3	15	2	107	-100
3	3	14	212	247	3	15	3	<105	-2
3	5	1	409	-439	3	15	4	185	-183
3	5	2	97	-133	3	15	5	<97	82
3	5	3	178	-190	3	15	6	136	-121
3	5	4	275	-392	3	17	1	141	-132
3	5	5	165	-103	4	0	0	1228	1169
3	5	6	302	-295	4	0	2	<51	9
3	5	7	216	201	4	0	4	265	242
3	5	8	<173	-43	4	0	6	107	-148
3	5	9	377	374	4	0	8	464	-486
3	5	10	<117	-6	4	0	10	<153	-28
3	5	11	161	181	4	0	12	173	-178
3	5	12	161	151	4	2	0	803	806
3	7	1	795	-792	4	2	1	178	178
3	7	2	406	394	4	2	2	195	197
3	7	3	<85	-75	4	2	3	163	-154
3	7	4	379	405	4	2	4	80	85
3	7	5	236	223	4	2	5	272	-279
3	7	6	107	138	4	2	6	311	-380
3	7	7	219	203	4	2	7	263	-306
3	7	8	<97	-50	4	2	8	268	-255
3	7	9	336	396	4	2	9	233	-262
3	9	1	<92	-53	4	2	10	107	112
3	9	2	345	347	4	2	11	119	131
3	9	3	75	-90	4	2	12	112	-106
3	9	4	761	724	4	2	13	204	203
3	9	5	161	155	4	4	0	173	175
3	9	6	260	262	4	4	1	265	-205
3	9	7	88	-105	4	4	2	122	-135
3	9	8	114	-128	4	4	3	530	-408/

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
4	4	4	<263	-242	4	12	7	<117	39
4	4	5	248	-232	4	12	8	163	-141
4	4	6	100	-60	4	12	9	<117	60
4	4	7	355	-373	4	12	10	168	-198
4	4	8	126	137	4	14	0	<100	-46
4	4	9	143	-160	4	14	1	<100	-93
4	4	10	243	210	4	14	2	<100	34
4	4	11	216	228	4	14	3	156	-157
4	4	12	<165	101	4	14	4	<97	100
4	4	13	168	134	4	14	5	190	-153
4	6	0	657	-665	5	1	1	931	807
4	6	1	302	166	5	1	2	105	99
4	6	2	365	-401	5	1	3	88	74
4	6	3	<85	88	5	1	4	396	-408
4	6	4	170	-177	5	1	5	370	-363
4	6	5	<85	-8	5	1	6	243	-247
4	6	6	287	309	5	1	7	105	-82
4	6	7	<114	-52	5	1	8	<117	44
4	6	8	357	373	5	1	9	309	-353
4	6	9	<136	-72	5	1	10	<117	-42
4	6	10	136	147	5	1	11	<117	-37
4	6	11	<148	17	5	1	12	126	81
4	6	12	117	131	5	3	1	<73	-47
4	8	0	464	-520	5	3	2	<75	-21
4	8	1	146	217	5	3	3	204	204
4	8	2	<97	-36	5	3	4	460	-475
4	8	3	552	592	5	3	5	250	-242
4	8	4	80	-39	5	3	6	457	-480
4	8	5	409	418	5	3	7	<129	11
4	8	6	100	91	5	3	8	<122	-93
4	8	7	<97	9	5	3	9	<122	78
4	8	8	190	196	5	3	10	<122	-27
4	10	0	212	189	5	3	11	<122	40
4	10	1	<88	66	5	3	12	182	163
4	10	2	231	202	5	3	13	<122	4
4	10	3	377	334	5	3	1	143	193
4	10	4	<88	-22	5	5	1	503	-471
4	10	5	277	244	5	5	2	112	83
4	10	6	<97	-3	5	5	3	78	-88
4	10	7	<97	47	5	5	4	<102	-6
4	10	8	<97	-146	5	5	5	<102	4
4	10	9	<97	49	5	5	6	268	-251
4	10	10	265	-196	5	5	7	163	144
4	12	0	139	112	5	5	8	124	-136
4	12	1	<97	-17	5	5	9	297	300
4	12	2	178	198	5	5	10	<161	-71
4	12	3	73	-70	5	5	11	163	151
4	12	4	105	121	5	5	12	107	104
4	12	5	126	-112	5	5	13	<146	24
4	12	6	<117	-17	5	5	14	124	130

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
5	7	1	365	-359	6	4	0	270	-271
5	7	2	209	220	6	4	1	131	103
5	7	3	119	-98	6	4	2	209	-243
5	7	4	321	382	6	4	3	163	-158
5	7	5	<146	42	6	4	4	<107	-51
5	7	6	126	107	6	4	5	214	-188
5	7	7	80	48	6	4	6	92	136
5	7	8	<146	-71	6	4	7	216	-226
5	7	9	255	286	6	4	8	221	201
5	9	1	<113	41	6	4	9	178	-206
5	9	2	129	123	6	4	10	109	114
5	9	3	102	-111	6	4	11	109	120
5	9	4	409	426	6	4	12	<107	7
5	9	5	112	131	6	4	13	129	132
5	9	6	192	209	6	6	0	316	-342
5	11	1	238	207	6	6	1	229	271
5	11	2	112	137	6	6	2	129	-144
5	11	3	<109	-19	6	6	3	209	240
5	11	4	151	51	6	6	4	170	-173
5	11	5	136	180	6	6	5	<97	48
5	11	6	<112	84	6	6	6	119	30
5	11	7	<112	-87	6	6	7	126	-80
5	11	8	<112	36	6	6	8	250	251
5	11	9	197	-197	6	6	9	112	-140
5	13	1	<112	102	6	6	10	134	146
5	13	2	<109	-10	6	8	0	253	-294
5	13	3	<109	100	6	8	1	<100	61
5	13	4	163	-165	6	8	2	<100	31
5	15	1	<73	-36	6	8	3	229	244
5	15	2	95	-112	6	8	4	<100	-55
5	15	3	<109	11	6	8	5	238	233
6	0	0	1311	1293	6	8	6	<100	-33
6	0	2	231	252	6	8	7	<100	49
6	0	4	<73	-28	6	8	8	105	128
6	0	6	282	-301	6	10	0	<100	-43
6	0	8	484	-498	6	10	1	<100	2
6	2	0	486	490	6	10	2	<100	69
6	2	1	<73	-37	6	10	3	385	207
6	2	2	<73	-37	6	10	4	<100	64
6	2	3	574	-536	6	10	5	185	197
6	2	4	<78	50	6	10	6	<90	97
6	2	5	404	-404	6	10	7	<90	47
6	2	6	122	-132	6	10	8	<90	-90
6	2	7	<129	-74	6	10	9	<90	48
6	2	8	216	-184	6	10	10	161	-166
6	2	9	<129	-81	6	12	0	<105	115
6	2	10	<129	52	6	12	1	<105	21
6	2	11	151	135	6	12	2	102	141
6	2	12	<129	-68	6	12	3	134	65
6	2	13	165	151	6	12	4	<100	88

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
6	12	5	<100	-16	7	7	6	<90	59
6	12	6	<100	2	7	7	7	<90	37
6	12	7	<100	-18	7	7	8	<90	-11
6	12	8	153	-123	7	7	9	151	169
6	12	9	<100	-9	7	9	1	<73	-28
6	12	10	151	-163	7	9	2	<73	110
6	14	0	<100	67	7	9	3	<75	-78
6	14	1	<100	-79	7	9	4	209	234
6	14	2	<100	57	7	9	5	119	127
6	14	3	129	-137	7	9	6	124	141
6	18	0	141	-119	7	11	1	105	120
6	18	1	<100	-7	7	11	2	136	157
6	18	2	95	-75	7	11	3	<70	26
7	1	1	433	502	7	11	4	92	77
7	1	2	126	-125	7	11	5	129	121
7	1	3	170	177	7	11	6	<70	62
7	1	4	263	-266	7	11	7	70	-67
7	1	5	280	-292	7	11	8	<70	0
7	1	6	165	-176	7	11	9	143	-133
7	1	7	158	-154	7	13	1	<100	109
7	1	8	<146	21	7	13	2	<117	-17
7	1	9	175	-189	7	13	3	<70	83
7	3	1	143	-113	7	13	4	107	-125
7	3	2	161	-170	7	15	1	<100	-45
7	3	3	112	95	7	15	2	117	-112
7	3	4	88	-240	7	15	3	<90	3
7	3	5	<92	-65	7	15	4	146	-165
7	3	6	326	-331	8	0	0	679	649
7	3	7	<102	54	8	0	2	126	105
7	3	8	<100	-100	8	0	4	<100	-3
7	3	9	<100	51	8	0	6	<100	-72
7	3	10	<100	12	8	0	8	282	-263
7	3	11	<100	16	8	2	0	326	338
7	3	12	148	129	8	2	1	<117	87
7	5	1	270	-257	8	2	2	<107	56
7	5	2	58	61	8	2	3	209	-195
7	5	3	122	-135	8	2	4	<100	-3
7	5	4	<163	105	8	2	5	285	-254
7	5	5	150	12	8	2	6	<124	-80
7	5	6	156	-174	8	2	7	124	-79
7	5	7	126	115	8	2	8	143	-115
7	5	8	148	-153	8	4	0	119	-100
7	5	9	173	178	8	4	1	88	90
7	5	10	<120	-72	8	4	2	88	-71
7	5	11	109	118	8	4	3	146	-137
7	7	1	146	-149	8	4	4	<120	-55
7	7	2	119	113	8	4	5	221	-191
7	7	3	129	-143	8	4	6	<141	-29
7	7	4	229	216	8	4	7	122	-129
7	7	5	<90	3	8	4	8	131	104

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
8	6	0	287	-330	9	5	9	146	118
8	6	1	97	97	9	7	1	192	-206
8	6	2	112	-113	9	7	2	85	101
8	6	3	<112	48	9	7	3	85	-91
8	6	4	<100	-58	9	7	4	<140	144
8	6	5	<100	13	9	7	5	<140	76
8	6	6	<120	20	9	7	6	<140	27
8	6	7	<120	-39	9	7	7	112	101
8	6	8	178	180	9	9	1	<140	3
8	6	9	<120	-57	9	9	2	136	165
8	6	10	129	120	9	9	3	<140	-21
8	8	0	226	-260	9	9	4	231	220
8	8	1	<120	46	9	11	1	114	124
8	8	2	<120	-35	10	0	0	233	280
8	8	3	197	202	10	0	2	<140	53
8	8	4	<120	2	10	0	4	<140	28
8	8	5	209	211	10	0	6	<140	-24
8	10	0	<130	50	10	0	8	114	-116
8	10	1	<130	27	10	2	0	231	211
8	10	2	<130	67	10	2	1	<134	56
8	10	3	163	187	10	2	2	<134	57
8	10	4	<130	16	10	2	3	<134	-56
8	10	5	158	162	10	2	4	<134	-9
8	12	0	114	135	10	2	5	141	-119
8	12	1	<130	-10	10	4	0	<71	-25
8	12	2	112	104	10	4	1	<120	20
9	1	1	212	195	10	4	2	<120	-25
9	1	2	<139	14	10	4	3	136	-129
9	1	3	178	115	10	4	4	<141	-41
9	1	4	<140	-43	10	4	5	146	-125
9	1	5	<140	-84	10	6	0	219	-245
9	1	6	97	-93	10	6	1	<131	37
9	1	7	<148	-66	10	6	2	114	-107
9	1	8	<150	-59	10	6	3	<130	2
9	1	9	<150	-120	10	6	4	<130	-13
9	1	10	163	-33	10	6	5	<130	20
9	3	1	85	89	10	6	6	<130	64
9	3	2	<140	-73	10	6	8	105	116
9	3	3	<140	29	10	8	0	236	-129
9	3	4	170	-105	10	8	1	<130	64
9	3	5	122	-126	10	8	2	<130	-29
9	3	6	180	-191	10	8	3	158	166
9	5	1	168	-132	10	8	4	<130	-10
9	5	2	95	-83	10	8	5	153	150
9	5	3	95	-104	11	1	1	141	141
9	5	4	<140	-63	11	3	1	<130	26
9	5	5	<140	-18	11	3	2	<130	-55
9	5	6	100	-117	11	3	3	<130	10
9	5	7	<140	84	11	3	4	85	-89
9	5	8	<180	-21	11	7	1	105	-93

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
11	7	2	<130	73	12	0	0	204	210
11	7	3	130	-43	12	2	0	102	99
11	7	4	105	110	12	2	1	<130	-2
11	9	1	<130	13	12	2	2	<130	21
11	9	2	<130	60	12	2	3	129	-92
11	9	3	<130	-11	13	1	1	105	87
11	9	4	146	107					

Dimethylphosphinatodimethylgallium dimer (Me<sub>2</sub>GaO<sub>2</sub>PMe<sub>2</sub>)<sub>2</sub>.

Introduction.

Phosphinic acids react with a variety of metals. Some of these compounds have been shown to be polymeric and others dimeric. In all known cases the metal atoms are linked by two bridging phosphinate groups.

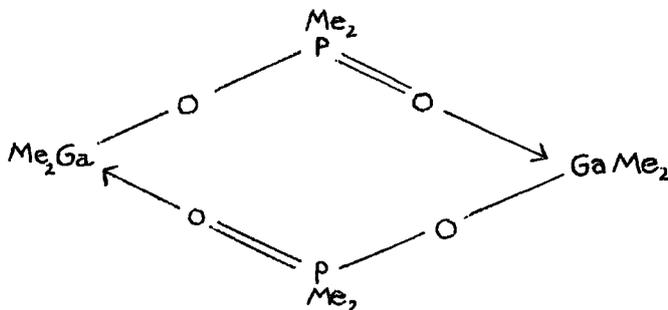
Cobalt and zinc phosphinates are thought to have a polymeric structure (Coates, 1962).

Recent work (Danielsen, 1963) has shown that Mn(CH<sub>3</sub>COOC<sub>2</sub>H<sub>5</sub>)<sub>2</sub>(O<sub>2</sub>PCl<sub>2</sub>)<sub>2</sub> n is polymeric with two phosphinate bridges between the metal atoms.

Wilkes, 1965, has shown that the molecule

(CH<sub>3</sub>OCHOCH<sub>3</sub>)<sub>2</sub>Cr(OP(C<sub>6</sub>H<sub>5</sub>)<sub>2</sub>O)<sub>2</sub>Cr(CH<sub>3</sub>OCHOCH<sub>3</sub>)<sub>2</sub> contains an eight membered chromium phosphinate ring system.

Trimethylaluminium and trimethylgallium react with phosphinic acids giving products whose infrared spectra and molecular weights suggest that they are dimeric with phosphinate bridges. (Coates, 1964). A crystal structure analysis of dimethylgallium dimethylphosphate has confirmed that the dimer contains an eight membered phosphinate ring system.



### Experimental

The crystals are extremely soluble in organic solvents. Sublimation in vacuo gives needle-shaped crystals elongated along b. Crystals of  $0.1 \times 0.1 \text{ mm}^2$  cross-section were sealed in thin walled lithium borate capillary tubes. The substance is air sensitive but crystals mounted in the air were sufficiently stable for data collection purposes.

### Crystal data.

The unit cell dimensions were measured from photographs of the zero nets using the precession method and Zr-filtered Mo radiation.

The calculated statistical standard deviations in the cell dimensions are  $0.003\text{\AA}$  in a,  $0.014\text{\AA}$  in b and  $0.003\text{\AA}$  in c, but the actual errors are thought to be about 0.005 of the unit cell lengths and  $20'$  in  $\beta$ .

Monoclinic  $a = 15.23\text{\AA}$ ,  $b = 6.78\text{\AA}$ ,  $c = 16.31\text{\AA}$ ,  $\beta = 105^\circ 23'$ .

Absorption  $\mu(\text{Mo K}\alpha) = 36.28 \text{ cm}^{-1}$ ,  $\mu(\text{Cu K}\alpha) = 61.34 \text{ cm}^{-1}$ .

$D_x = 1.55 \text{ gm. cm}^{-3}$ ,  $z = 8$ ,  $V = 1652\text{\AA}^3$ .

Observed reflections:-

$hkl$  when  $h + k = 2n$ .

$hol$  when  $l = 2n$ , ( $h = 2n$ ).

$oko$  when ( $k = 2n$ ).

These are consistent with the two space groups Cc and C2/c (Numbers 9 and 15 in International Tables for X-ray Crystallography, Vol. 1).

The calculated density, assuming eight  $\text{Me}_2\text{GaO}_2\text{PMe}_2$  units per unit cell, is  $1.55 \text{ gm. cm}^{-3}$ . The density of the crystals is found to lie between that of water and carbon tetrachloride ( $1.6 \text{ gm. cm}^{-3}$ ). If the space group is  $C2/c$  then the dimer must possess a twofold axis or be centrosymmetric.

### Collection of Intensities

Zr-filtered Mo radiation was used to record photographically the nets  $h0l - h6l$  using the equiinclination angle Weissenberg technique and the  $okl - 2kl$  and the  $hko - hk2$  nets using the precession method.

The intensities were estimated visually using a calibrated scale. The usual Lorentz and polarisation corrections were applied to the data. The length correction, (Phillips, 1956) was made to the data from the upper level Weissenberg photographs. No correction for absorption was made.

The structure factors were correlated using a least squares method. They were 726 in number, 188 appearing on more than one net.

### Structure Determination

#### The Patterson function

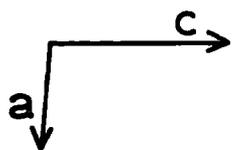
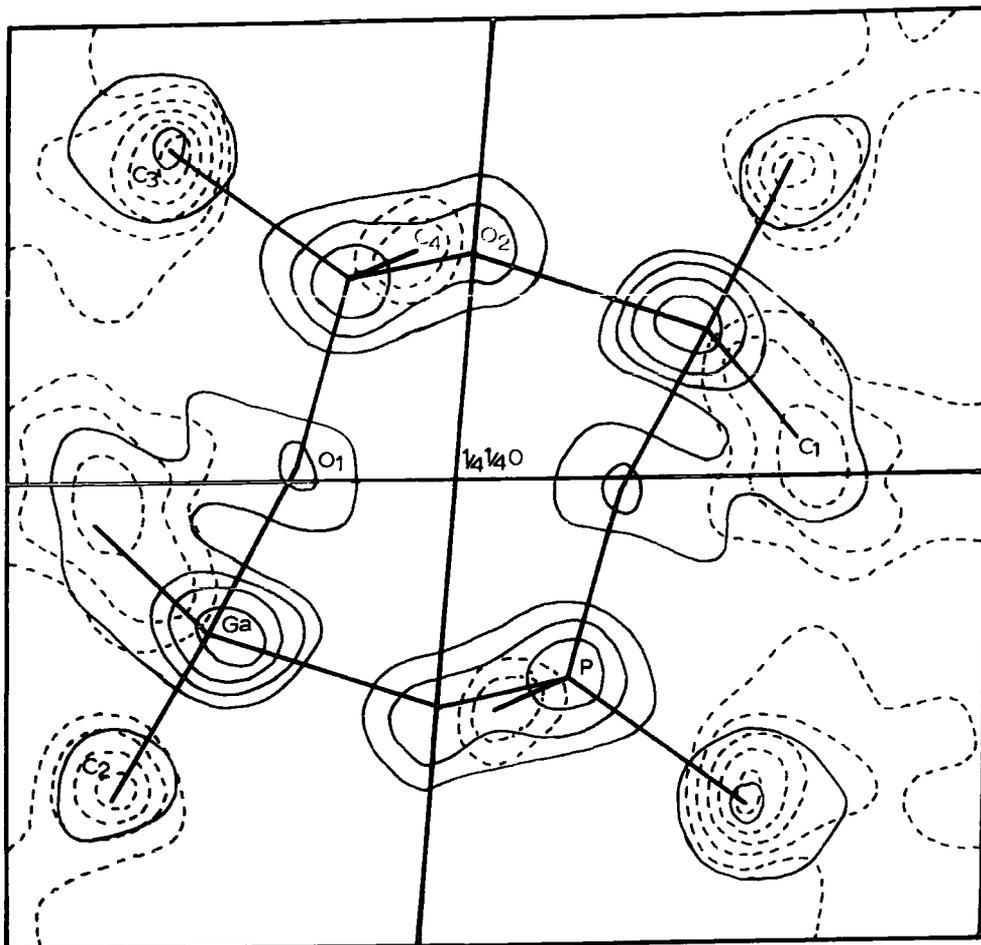
The expression evaluated was

$$P(uvw) = \frac{4}{Vc} \sum_0^\infty \sum_0^\infty \sum_0^\infty \left\{ W_{hkl} |F_{hkl}|^2 \cos 2\pi(hu + lw) + W_{\bar{h}kl} |F_{\bar{h}kl}|^2 \cos 2\pi(-hu + lw) \right\} \cos 2\pi kv$$

in intervals in  $u$  of  $0.2538\text{\AA}$ , in  $v$  of  $0.2718\text{\AA}$  and  $0.2823\text{\AA}$  in  $w$ . The coefficients were sharpened by weighting them using the expression  $\exp(2B\sin^2\theta/\lambda^2)$  with  $B$  taking the value of 6. The maximum value this expression was allowed to take was 100 to reduce the weighting for the weak high order reflections.

While the data collection was in progress, the Patterson function was computed in projection along the three crystal axes and showed the space group to be  $C2/c$ . In the  $010$  projection, three peaks of similar height appeared, two of which arise from double-weight phosphorus-gallium vectors and the third from the gallium-gallium single weight vector. The situation was resolved since an estimate of the gallium  $z$ -coordinate, with respect to the cell origin, was obtained from the projection along  $a$ . In the  $010$  projection a single application of superposition methods, based on the gallium-gallium single-weight peak, revealed a centrosymmetric eight-membered ring. Structure factors, based on the ring atoms alone, gave a residual of 0.32 after one cycle of least-squares refinement. A difference map then revealed the positions of the methyl carbon atoms in this projection (Fig. VII).

The space group  $C2/c$  possesses centres of symmetry at  $0,0,0$ , and  $\frac{1}{4},\frac{1}{4},0$  and two-fold axes. Examination of the Patterson function suggested that the molecule is grouped around the centre of symmetry at  $\frac{1}{4},\frac{1}{4},0$ . The  $hko$  structure factors, calculated on the gallium and phosphorus atoms alone, gave a residual of 0.42.



$(\text{Me}_2\text{GaO}_2\text{PMe}_2)_2$  010 projection

—  $F_0$  synthesis

---  $F_0 - F_c$  synthesis

( $F_c$ 's based on the ring atoms only)

As a check on the two dimensional results the three dimensional Patterson function was evaluated. This allowed atomic coordinates to be assigned to the gallium and phosphorus atoms.  $R(hkl)$  was 0.27.

### Fo synthesis

A three dimensional Fo synthesis was computed at the same intervals as the Patterson function using the signs of structure factors based on the phosphorus and gallium atoms only. This showed peaks corresponding to all the atoms other than hydrogen and allowed coordinates to be assigned to them. The reliability index was now 0.12.

The expression evaluated was

$$\rho(xyz) = \frac{4}{Vc} \left( \sum_0^{\infty} \sum_0^{\infty} \sum_0^{\infty} (F_{hkl} \cos 2\pi(hx + lz) + F_{\bar{h}kl} \cos 2\pi(hx + lz)) \cos 2\pi ky \right. \\ \left. - \sum_0^{\infty} \sum_0^{\infty} \sum_0^{\infty} (F_{hkl} \sin 2\pi(hx + lz) + F_{\bar{h}kl} \sin 2\pi(hx + lz)) \sin 2\pi ky \right)$$

### Structure refinement

The atomic parameters of all eight atoms were refined by one cycle of least squares calculations using isotropic thermal parameters to a residual of 0.116. Introduction of anisotropic thermal parameters for all the atoms reduced the residual to 0.085, its final value, over the 726 reflections.

An  $F_o - F_c$  synthesis computed at this stage showed only one pronounced feature, a peak of height  $1 \text{ e.A.}^{-3}$  near the site of the

gallium atom. Many of the other peaks were close to carbon atoms, but could not readily be explained as due to hydrogen atoms.

Structure factors for the unobserved reflections were not included in the refinement. None of these were found to be significantly greater than their minimum observable value.

The scattering curves used were those in International Tables for X-ray Crystallography, Vol. III, p. 202, to which the real part of the correction for dispersion (ibid, p.213) was applied for gallium and phosphorus, but not the imaginary part.

The final cycle of refinement

No. of planes = 726,  $\sum |F_o| = 39,977$ ,  $\sum |F_c| = 39,102$ ,  
R = 0.0856, R' = 0.0188.

The values of the constants A and C in the expression used for the weighting w, where  $w = 1/(A + |F_o| + C|F_o|^2)$ , were 80 and 0.1 in the final cycle. At this stage the average coordinate shift was 0.0028<sup>o</sup> the shifts varying up to 0.35 of the corresponding e.s.d. The average shift in thermal parameters was 0.0023<sup>o2</sup>, the shifts ranging up to 0.50 of the corresponding e.s.d.

The coordinates and thermal parameters are listed in Tables XI and XII and the final values of the structure factors in Table XV.

Table XI.  $(\text{Me}_2\text{GaO}_2\text{PMe}_2)_2$ . Atomic Coordinates and their standard  
deviations.

Atom	x	y	z $\text{\AA}$	$\sigma_x$	$\sigma_y$	$\sigma_z$	$\text{\AA}$
Ga	5.017	1.495	-1.820	0.002	0.002	0.002	
P	5.406	3.086	0.957	0.004	0.005	0.005	
O1	3.670	0.262	-1.287	0.011	0.015	0.012	
O2	1.875	1.310	0.064	0.011	0.013	0.012	
C1	3.466	0.330	2.736	0.023	0.025	0.023	
C2	6.421	0.351	-2.524	0.022	0.028	0.023	
C3	1.143	0.615	-2.505	0.023	0.025	0.019	
C4	1.830	-1.366	-0.370	0.024	0.023	0.025	

Table XII.  $(\text{Me}_2\text{GaO}_2\text{PMe}_2)_2$ . Thermal parameters in  $\text{\AA}^2$  with e.s.d.'s in  
 $10^3 \text{\AA}^2$  in brackets.

Atom	$U_{11}$	$U_{22}$	$U_{33}$	$U_{12}$	$U_{23}$	$U_{13}$
Ga	0.048(1)	0.064(1)	0.050(1)	0.001(1)	-0.006(1)	0.013(1)
P	0.039(2)	0.057(3)	0.054(2)	0.004(2)	-0.010(5)	0.006(2)
O1	0.042(7)	0.082(10)	0.072(8)	0.004(7)	-0.008(7)	0.019(6)
O2	0.043(6)	0.074(9)	0.047(6)	0.004(6)	-0.006(6)	-0.004(5)
C1	0.085(15)	0.072(16)	0.095(16)	0.005(13)	0.027(13)	0.004(12)
C2	0.064(13)	0.103(20)	0.081(15)	0.064(13)	-0.018(14)	0.004(11)
C3	0.079(15)	0.104(18)	0.053(11)	0.014(13)	0.013(12)	-0.016(10)
C4	0.075(14)	0.068(16)	0.101(17)	0.006(12)	-0.005(13)	0.019(12)

Description of the Structure.

The molecular dimensions are listed in Table XIII and are shown in Fig. VIII. The lengths of the two phosphorus-oxygen bonds, P'-O<sub>1</sub> and P'-O<sub>2</sub>, are  $1.522 \pm 0.012$  and  $1.492 \pm 0.013 \text{ \AA}$  respectively and do not differ significantly from one another. Their mean value is also quoted in Table XIII. Similarly the mean values of Ga-O<sub>1</sub> and Ga-O<sub>2</sub>, of Ga-C<sub>1</sub>' and Ga-C<sub>2</sub>', of P'-C<sub>3</sub> and P'-C<sub>4</sub> and also of the angles Ga-O<sub>1</sub>-P' and Ga'-O<sub>2</sub>-P' are also listed. However the variations in the four carbon-phosphorus-oxygen angles and in the four oxygen-gallium-carbon angles are significant.

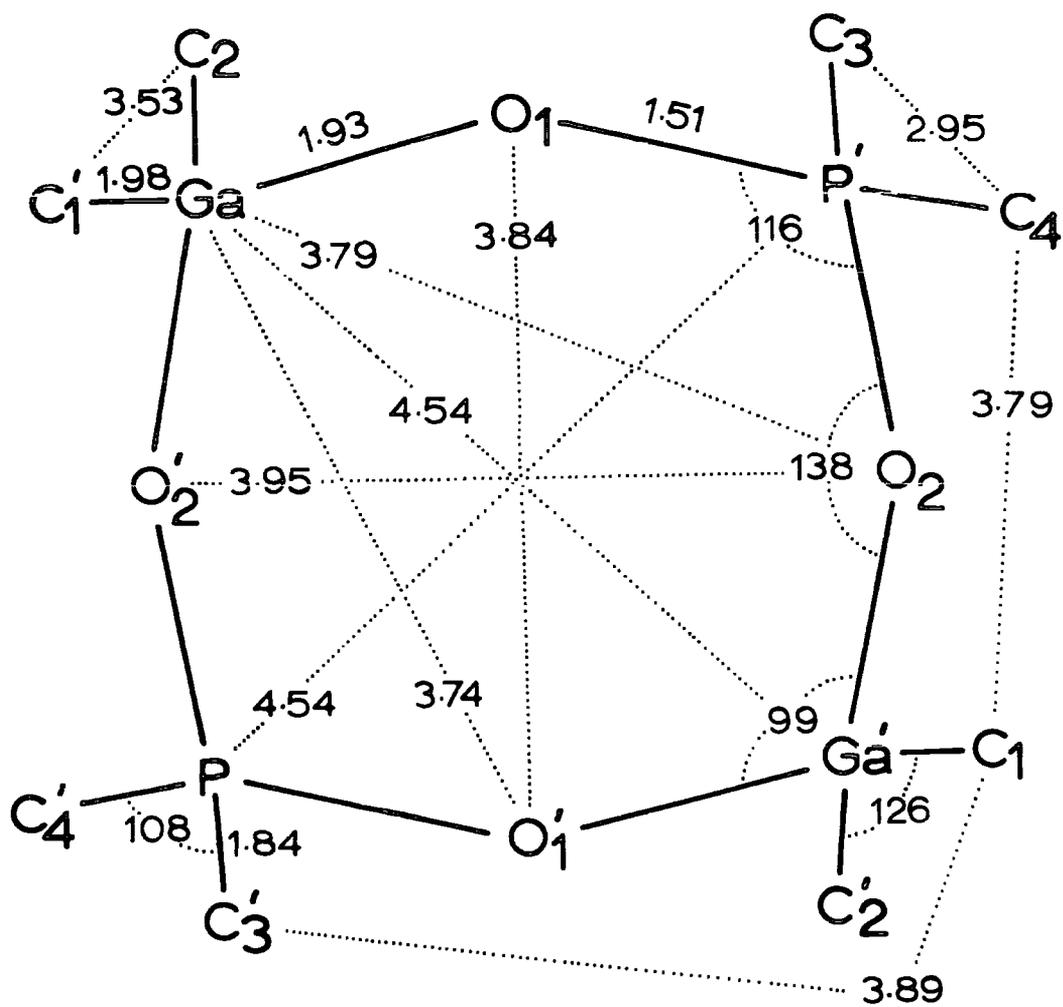
The mean gallium-oxygen distance of  $1.934 \pm 0.009 \text{ \AA}$  is not significantly shorter than that of  $1.96 \pm 0.03 \text{ \AA}$  in (Me<sub>2</sub>GaOH)<sub>4</sub> (Smith and Hoard, 1959). For a single covalent bond, a length of  $1.92 \text{ \AA}$  (Pauling, 1960) is expected.

The mean phosphorus-oxygen length of  $1.505 \pm 0.008 \text{ \AA}$  is the same as the average value of that in the chromium(III)phosphinate, (CH<sub>3</sub>COCHCOCH<sub>3</sub>)<sub>2</sub>Cr(OP(C<sub>6</sub>H<sub>5</sub>)<sub>2</sub>O)<sub>2</sub>Cr(CH<sub>3</sub>COCHCOCH<sub>3</sub>)<sub>2</sub> (Wilkes and Jacobson, 1965). The expected value for a phosphorus-oxygen single bond is  $1.71 \text{ \AA}$  (Schomaker and Stevenson, 1941) so that, in the present case, there is considerable shortening due to dπ - pπ bonding.

The average gallium-carbon distance of  $1.980 \pm 0.016 \text{ \AA}$  is the same as that in (Me<sub>2</sub>GaOH)<sub>4</sub>. Similarly the mean phosphorus-carbon length of

Table XIII. (Me<sub>2</sub>GaO<sub>2</sub>PMe<sub>2</sub>)<sub>2</sub>. Intramolecular distances and angles.

<u>Bonding</u>		<u>e.s.d.</u>		
Ga-O1	1.932 $\text{\AA}$	0.013 $\text{\AA}$		
Ga-O2'	1.936	0.011		
P'-O1	1.522	0.012		
P'-O2	1.492	0.013		
Ga-C1'	1.978	0.024		
Ga-C2	1.982	0.024		
P'-C3	1.837	0.020		
P'-C4	1.815	0.024		
Ga-O mean	1.934	0.009		
Ga-C mean	1.980	0.016		
P-O mean	1.505	0.008		
P-C mean	1.826	0.016		
C1'-Ga-C2	126.1 $^{\circ}$	0.9 $^{\circ}$		
O1-Ga-O2'	99.3	0.5		
O2-P'-O1	115.9	0.7		
C3-P'-C4	107.8	1.1		
O1-Ga-C1	110.0	0.8		
O1-Ga-C2	105.0	0.9		
O2'-Ga-C1	107.5	0.8		
O2'-Ga-C2	105.7	0.7		
Ga-O1-P'	138.1	0.9	Ga-O-P mean	137.7 $^{\circ}$
Ga'-O2-P'	137.4	0.8	O-Ga-C mean	107.0
			C-P-O mean	108.1
C3-P'-O1	108.9	0.8		
C3-P'-O2	108.2	0.8		
C4-P'-O1	106.0	1.0		
C4-P'-O2	109.5	0.9		



$(\text{Me}_2\text{GaO}_2\text{PMe}_2)_2$

$1.826 \pm 0.016\text{\AA}$  is very similar to the value of  $1.84 \pm 0.02\text{\AA}$  found in trimethylphosphine (Lide and Mann, 1958).

The  $O_1\text{-Ga-O}_2'$  angle of  $99.3^\circ$  is much less than the tetrahedral value and is the same as in  $(\text{Me}_2\text{GaOH})_4$ . Resulting from this, the angle  $C_1'\text{-Ga-C}_2$  is increased to  $126.1^\circ$ , giving a separation  $C_1'\text{-C}_2$  of  $3.52\text{\AA}$ . However the ring angle  $O_1\text{-P}'\text{-O}_2$ , at  $115.9^\circ$ , is greater than tetrahedral and the angle  $C_3\text{-P}'\text{-C}_4$  of  $107.8^\circ$  gives a  $C_3\text{-C}_4$  separation of  $2.95\text{\AA}$ .

The mean angle at oxygen of  $137.7^\circ$  is similar to the value of  $133^\circ$  in  $(\text{Me}_2\text{GaOH})_4$  and comparable values have been reported for other phosphinates. In the chromium(III) phosphinate, the angles at oxygen range from  $141$  to  $161^\circ$  and in the polymeric  $(\text{Mn}(\text{PO}_2\text{Cl}_2)_2(\text{CH}_3\text{COOC}_2\text{H}_5)_2)_n$  the angles are  $141$  and  $173^\circ$ . In the former case the effect is attributed to the non-bonding contacts involving atoms of the phenyl groups.

The non-bonding contacts of less than  $4.4\text{\AA}$  are listed in Table XIV. There are two carbon-carbon contacts around the ring of less than  $4\text{\AA}$ , the separations  $C_1 - C_4$  and  $C_1 - C_3'$  being  $3.79$  and  $3.89\text{\AA}$  respectively. These distances are normal and are similar to the shorter contacts of  $3.74$  and  $3.79\text{\AA}$  across the ring and it would appear that the ring conformation and the distortions at the ring angles is chiefly determined by the nature of these contacts. The shortest intermolecular contact of  $3.45\text{\AA}$  between  $O_1$  and an atom related to  $C_4$  and at the equivalent position  $\frac{1}{2}\text{-x}$ ,  $y\text{-}\frac{1}{2}$ ,  $\bar{z}$ , is less than any of the intramolecular contacts already described. A perspective view of the atoms in the

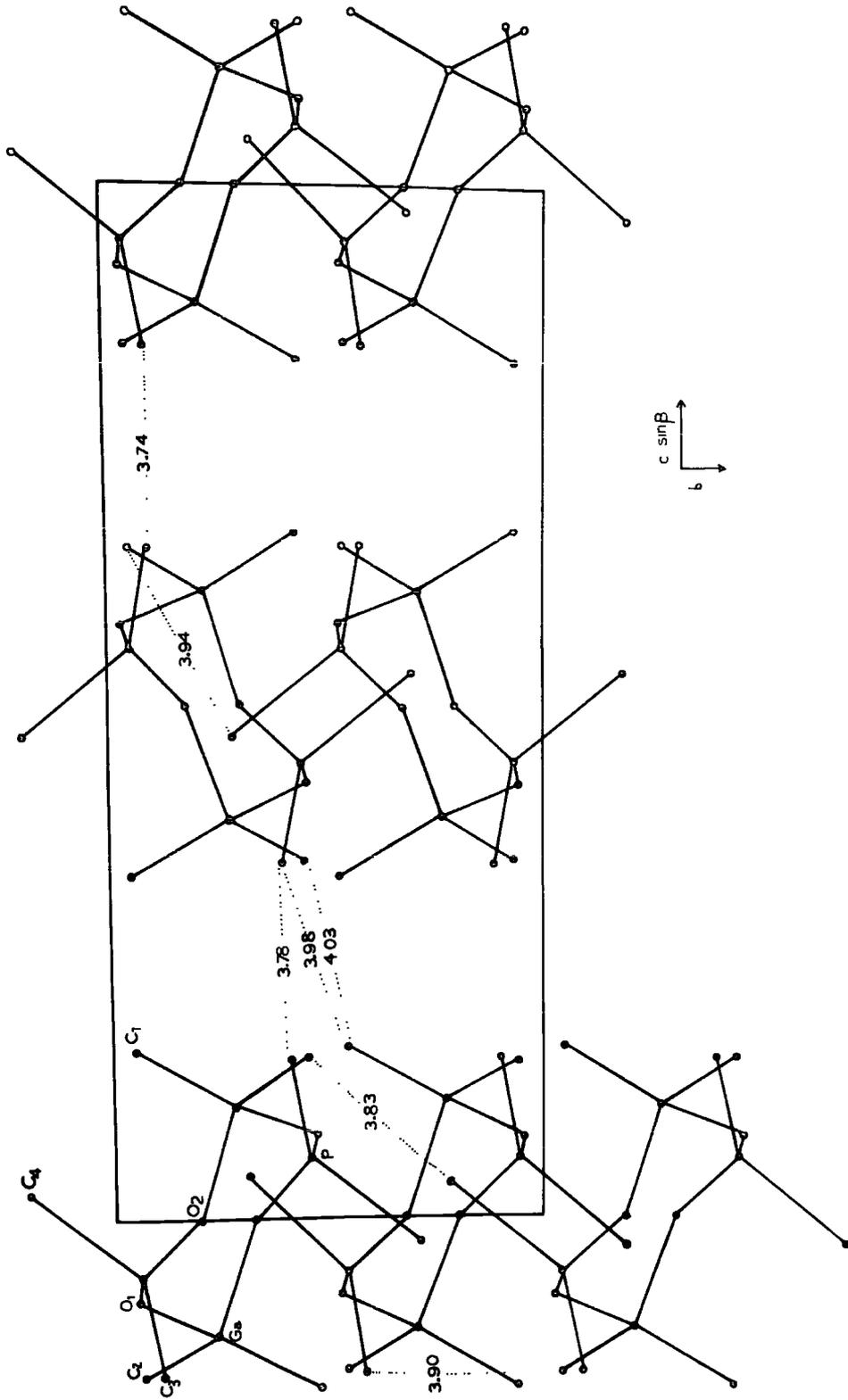
Table XIV. (Me<sub>2</sub>GaO<sub>2</sub>PMe<sub>2</sub>)<sub>2</sub>. Non-bonding Contacts.

Intermolecular Contacts

Ga	C4	$\frac{1}{2}-x, y-\frac{1}{2}, \bar{z}$	4.182
P	C4	$x, 1+y, z$	4.381
O1	C4	$\frac{1}{2}-x, y-\frac{1}{2}, \bar{z}$	3.45
C3	C3	$\bar{x}, y, -\frac{1}{2}-z$	3.74
G2	C4	$\frac{1}{2}-x, -\frac{1}{2}-y, \bar{z}$	3.83
C2	C3	$x+\frac{1}{2}, y-\frac{1}{2}, z$	3.90
C2	C4	$x+\frac{1}{2}, y+\frac{1}{2}, z$	3.94
C1	C3	$x, \bar{y}, \frac{1}{2}+z$	3.981
C4	C4	$\frac{1}{2}-x, y-\frac{1}{2}, \bar{z}$	4.02
C1	C2	$x, \bar{y}, \frac{1}{2}-z$	4.027
C2	C2	$1-x, y, -\frac{1}{2}-z$	4.07
C1	C4	$\frac{1}{2}-x, y-\frac{1}{2}, \bar{z}$	4.169
C2	C3	$x-\frac{1}{2}, y+\frac{1}{2}, z$	4.34
C3	C4	$\bar{x}, \bar{y}, \bar{z}$	4.36

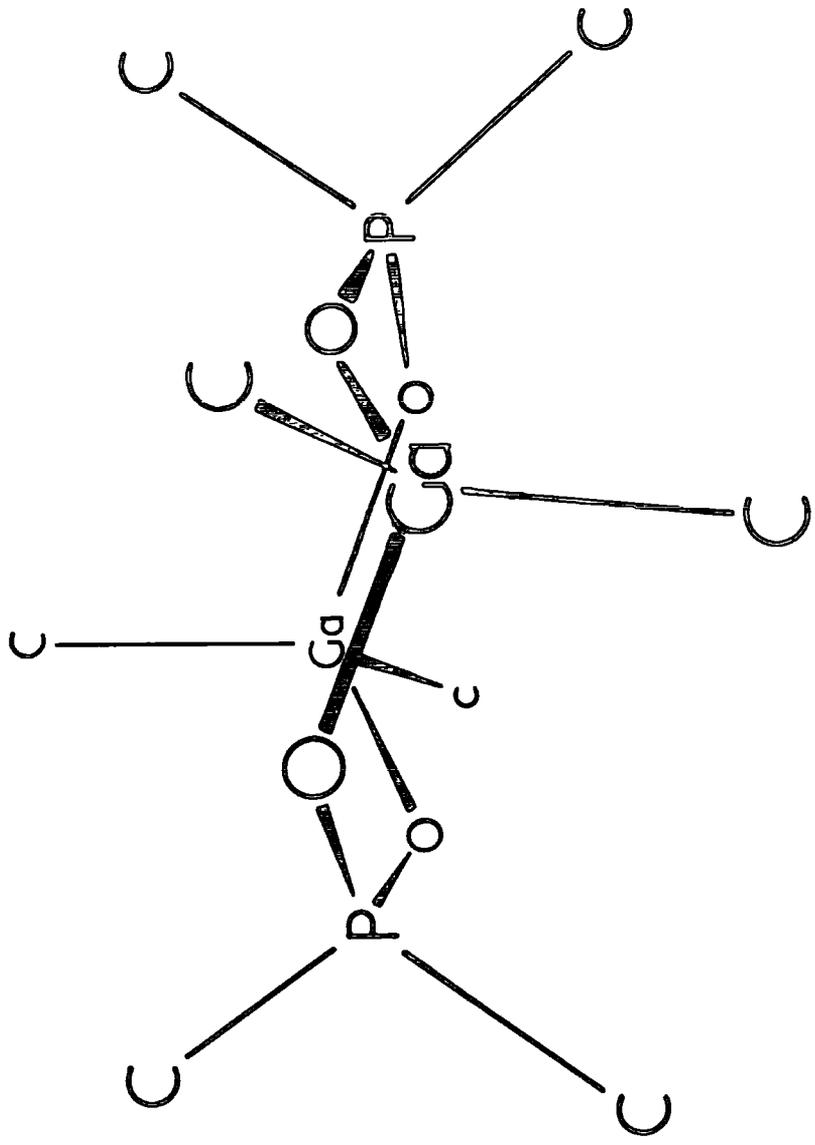
Intramolecular contacts

C3	C4	2.95 <sup>0</sup>
C1'	C2	3.53
Ga	O1'	3.74
Ga	O2	3.79
P	O1	3.93
P	O2	3.99
Ga	Ga'	4.54
P	P'	4.54
O1	O1'	3.85
O2	O2'	3.95
C4	C1	3.79
C1	C3'	3.89



$(\text{Me}_2\text{GaO}_2\text{PMe}_2)_2$  100 projection

FIG. IX.



$(\text{Me}_2\text{GaO}_2\text{PMe}_2)_2$

ring is shown in figure X.

The equation of the mean plane through the ring atoms Ga, P, O<sub>1</sub>, O<sub>2</sub> and the atoms related by the centre of symmetry at  $\frac{1}{4}, \frac{1}{4}, 0$  is

$$-0.3496x' + 0.7556y' - 0.5541z' = -0.0381$$

where the coordinates are referred to orthogonal axes parallel to a, b and c\*. The distances of the atoms from the plane are as follows:

Ga	0.39Å	C <sub>1</sub>	-2.35Å
P	0.00	C <sub>2</sub>	-0.60
O <sub>1</sub>	-0.36	C <sub>3</sub>	1.42
O <sub>2</sub>	0.35	C <sub>4</sub>	-1.44

TABLE XV.       $(\text{Me}_2\text{GaO}_2\text{PMe}_2)_2$ .

Observed and calculated structure factors.

h	k	1	10Fo	10Fc	h	k	1	10Fo	10Fc
c	0	2	2097	2043	1	1	-9	1069	-938
0	0	4	1928	-1988	1	1	-8	<287	-121
0	0	6	306	-452	1	1	-7	1011	-941
0	0	8	685	701	1	1	-6	231	-231
0	0	10	417	488	1	1	-5	1332	1191
0	0	12	222	-170	1	1	-4	1036	-923
0	0	14	316	-321	1	1	-3	2138	1747
0	0	16	281	260	1	1	-1	1613	-1473
0	0	18	396	502	1	1	0	663	719
0	2	0	598	-685	1	1	1	2654	-2697
0	2	1	899	887	1	1	3	<198	140
0	2	2	501	-367	1	1	4	1648	1620
0	2	3	1049	1148	1	1	5	1526	1604
0	2	4	544	699	1	1	6	158	147
0	2	5	<213	-80	1	1	7	314	309
0	2	6	<280	120	1	1	8	651	-570
0	2	7	507	-478	1	1	9	1128	-1136
0	2	8	1702	-1713	1	1	10	458	-440
0	2	9	<252	-143	1	1	11	801	-824
0	2	10	1094	-1235	1	1	12	<124	-182
0	2	11	<273	-46	1	1	13	288	238
0	2	12	320	396	1	1	14	<134	-5
0	2	13	<292	-91	1	1	15	363	305
0	2	14	549	578	1	1	16	<146	27
0	4	0	1059	1216	1	1	17	263	-246
0	4	1	197	-186	1	3	-13	492	-455
0	4	2	382	405	1	3	-12	256	261
0	4	3	<259	-27	1	3	-11	<377	-83
0	4	4	564	-658	1	3	-10	416	371
0	4	5	556	634	1	3	-9	1141	1049
0	4	6	358	-395	1	3	-8	385	-384
0	4	7	631	765	1	3	-7	929	795
0	4	8	298	325	1	3	-6	1361	-1208
0	4	9	<145	28	1	3	-5	792	-790
0	4	10	277	232	1	3	-4	797	-725
0	4	11	503	-566	1	3	-3	1262	-1221
0	4	12	254	-238	1	3	-2	323	372
0	4	13	282	-254	1	3	-1	356	-316
0	6	0	270	-250	1	3	0	179	247
0	6	1	360	370	1	3	1	681	736
0	6	2	351	38	1	3	2	379	-381
0	6	7	309	-313	1	3	3	373	381
1	1	-17	453	-447	1	3	4	192	-206
1	1	-16	<145	178	1	3	5	562	-649
1	1	-15	<255	-70	1	3	6	190	183
1	1	-14	336	309	1	3	7	201	167
1	1	-13	707	715	1	3	8	<357	107
1	1	-12	299	237	1	3	9	1001	1084
1	1	-11	414	412	1	3	10	367	359
1	1	-10	<321	-83	1	3	11	360	300

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
1	3	12	520	-564	2	2	-4	1876	-1797
1	3	13	457	-499	2	2	-3	<250	97
1	3	14	<172	-188	2	2	-2	1734	-1840
1	3	15	326	-321	2	2	-1	186	-102
1	5	-11	338	239	2	2	0	299	345
1	5	-10	341	-302	2	2	1	<231	-195
1	5	-9	<190	48	2	2	2	1475	1521
1	5	-8	<181	125	2	2	3	997	-979
1	5	-7	<172	-121	2	2	4	307	298
1	5	-6	513	476	2	2	5	841	-785
1	5	-5	<395	136	2	2	6	744	-703
1	5	-4	<392	133	2	2	7	486	493
1	5	-3	231	222	2	2	8	<329	140
1	5	-2	450	-427	2	2	9	589	597
1	5	-1	547	-562	2	2	10	640	678
1	5	0	<387	-156	2	2	11	<141	-96
1	5	1	715	-770	2	2	12	<191	-30
1	5	2	657	678	2	2	13	282	-310
1	5	3	221	199	2	2	14	547	-622
1	5	4	645	692	2	4	-12	346	377
1	5	5	704	711	2	4	-11	<160	-127
1	5	6	<165	-93	2	4	-10	176	180
1	5	7	374	351	2	4	-9	188	-154
1	5	8	470	-363	2	4	-8	500	-491
2	0	-16	486	-492	2	4	-7	583	523
2	0	-14	348	334	2	4	-6	496	-520
2	0	-12	1195	1177	2	4	-5	1157	1120
2	0	-10	403	329	2	4	-4	389	388
2	0	-8	1094	-1097	2	4	-3	<103	86
2	0	-6	1011	-992	2	4	-2	452	477
2	0	-4	461	545	2	4	-1	1024	-1098
2	0	0	2398	-2047	2	4	0	626	-635
2	0	4	1641	1611	2	4	1	469	-457
2	0	6	2829	2803	2	4	2	662	-717
2	0	8	734	692	2	4	3	265	342
2	0	10	1361	-1268	2	4	4	418	502
2	0	12	797	-781	2	4	5	259	296
2	0	14	248	264	2	4	6	794	876
2	0	16	220	174	2	4	7	<139	103
2	2	-16	358	407	2	4	8	<141	105
2	2	-15	344	-335	2	4	9	<148	65
2	2	-14	<159	70	2	4	10	346	-387
2	2	-13	263	-311	2	4	11	295	311
2	2	-12	611	-579	2	4	12	218	-172
2	2	-11	254	265	2	4	13	320	357
2	2	-9	341	327	2	6	-1	243	241
2	2	-8	1627	1443	3	1	-17	277	217
2	2	-7	311	-278	3	1	-16	<146	-86
2	2	-6	619	593	3	1	-15	371	357
2	2	-5	<279	-145	3	1	-14	<134	-210

h	k	1	10Fo	10Fc	h	k	1	10Fo	10Fc
3	1	-13	515	-541	3	3	4	641	695
3	1	-12	<126	164	3	3	5	<116	27
3	1	-11	1266	-1158	3	3	6	538	598
3	1	-10	497	511	3	3	7	562	615
3	1	-9	<107	-117	3	3	8	<135	126
3	1	-8	<101	23	3	3	9	183	125
3	1	-7	1155	1158	3	3	10	<149	-42
3	1	-6	<89	47	3	3	11	254	-244
3	1	-5	418	420	3	5	-11	341	-278
3	1	-4	322	136	3	5	-10	328	267
3	1	-3	1777	-1612	3	5	-9	<193	17
3	1	-2	1614	-1308	3	5	-8	300	242
3	1	-1	1411	-1395	3	5	-7	476	470
3	1	0	839	-846	3	5	-6	465	-420
3	1	1	1264	1201	3	5	-5	442	430
3	1	2	<211	-85	3	5	-4	746	-670
3	1	3	1533	1417	3	5	-3	<154	-124
3	1	4	1092	-994	3	5	-2	<139	28
3	1	5	1051	-966	3	5	-1	212	-196
3	1	6	<92	100	3	5	0	389	398
3	1	7	1637	-1517	3	5	1	193	206
3	1	8	1115	1124	3	5	2	<142	-141
3	1	9	190	196	3	5	3	<149	35
3	1	10	375	352	3	5	4	555	-556
3	1	11	962	963	3	5	5	473	-444
3	1	12	252	-222	3	5	6	281	-246
3	1	13	<131	134	3	5	7	375	-373
3	1	14	194	-237	3	5	8	327	290
3	1	15	430	-444	3	5	9	<197	177
3	1	16	258	-219	3	5	10	290	284
3	1	17	253	-206	3	5	11	390	404
3	3	-15	341	-381	4	0	-14	233	241
3	3	-14	313	294	4	0	-12	613	-594
3	3	-13	<165	-6	4	0	-10	967	-974
3	3	-12	289	291	4	0	-8	195	226
3	3	-11	661	666	4	0	-6	1529	1502
3	3	-10	<145	-106	4	0	-4	182	-122
3	3	-9	<139	134	4	0	-2	3723	-2905
3	3	-8	<132	-161	4	0	0	2096	-1963
3	3	-7	927	-879	4	0	2	281	284
3	3	-6	740	674	4	0	4	226	-164
3	3	-5	<113	69	4	0	6	1441	-1519
3	3	-4	939	979	4	0	8	1009	-1053
3	3	-3	1484	1553	4	0	10	572	554
3	3	-2	253	-280	4	0	12	937	900
3	3	-1	755	752	4	0	16	477	-534
3	3	0	836	-925	4	2	-16	400	-416
3	3	1	943	-1032	4	2	-15	<167	-20
3	3	2	<97	-37	4	2	-14	491	-491
3	3	3	1087	-1200	4	2	-13	<155	109

h	k	l	10Fo	10Fc	h	k	l	10Fo	10Fc
4	2	-12	469	502	4	4	9	<154	152
4	2	-10	1234	1197	4	4	10	207	210
4	2	-9	595	-556	4	4	11	236	258
4	2	-8	<124	135	4	4	12	374	415
4	2	-7	304	-267	5	1	-17	281	187
4	2	-6	529	-804	5	1	-16	284	-271
4	2	-5	336	305	5	1	-15	412	-429
4	2	-4	482	427	5	1	-14	251	-270
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4	2	2	1341	-1293	5	1	-8	173	-143
4	2	3	<99	52	5	1	-7	753	-742
4	2	4	1140	-1090	5	1	-6	486	449
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4	2	14	<213	103	5	1	4	621	-535
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4	4	-5	339	-301	5	1	15	241	192
4	4	-4	<121	21	5	1	16	353	134
4	4	-3	291	-287	5	3	-15	363	414
4	4	-2	685	-756	5	3	-14	287	-197
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5	3	0	739	783	6	2	-14	330	363
5	3	1	228	-238	6	2	-13	<159	21
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5	3	4	198	-209	6	2	-10	1058	-928
5	3	5	342	336	6	2	-9	<136	110
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5	3	7	809	-966	6	2	-7	262	292
5	3	8	<143	-32	6	2	-6	844	734
5	3	9	558	-661	6	2	-5	191	-189
5	3	10	380	417	6	2	-4	1677	1627
5	3	11	161	105	6	2	-3	270	-251
5	3	12	306	320	6	2	-2	<108	82
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5	5	7	<191	-3	6	4	-14	357	-317
5	5	8	<199	-88	6	4	-13	312	227
5	5	9	<206	30	6	4	-12	301	-279
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6	0	-14	1215	-833	6	4	-9	271	-260
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6	0	-10	622	703	6	4	-7	781	-832
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6	0	-6	908	-891	6	4	-5	401	-436
6	0	-4	683	-639	6	4	-4	419	-438
6	0	-2	1342	1294	6	4	-3	579	571
6	0	0	1142	1192	6	4	-2	366	317
6	0	4	1421	-1355	6	4	-1	378	419
6	0	6	1199	-1141	6	4	0	636	684
6	0	8	497	530	6	4	1	324	-354
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6	4	6	253	-229
6	4	7	261	248
6	4	8	261	241
6	4	9	<163	-248
6	4	10	<168	117
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6	6	1	365	426
7	1	-17	288	-327
7	1	-16	278	292
7	1	-15	<147	170
7	1	-14	239	234
7	1	-13	917	869
7	1	-12	252	-249
7	1	-11	421	428
7	1	-10	509	-542
7	1	-9	847	-801
7	1	-8	307	-320
7	1	-7	593	-574
7	1	-6	<106	44
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7	1	-4	407	412
7	1	-3	1125	1095
7	1	-2	470	448
7	1	-1	612	-630
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7	1	1	1166	-1156
7	1	2	569	581
7	1	3	342	343
7	1	4	215	202
7	1	5	1394	1336
7	1	6	455	-339
7	1	7	343	267
7	1	8	349	-301
7	1	9	766	-747
7	1	10	<129	-98
7	1	11	242	-253
7	1	13	330	364
7	3	-9	602	582
7	3	-8	516	-517
7	3	-7	142	165
7	3	-6	721	-708
7	3	-5	1032	-939
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7	3	6	<143	62
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7	3	10	<164	-258
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7	3	12	320	-329
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7	5	-12	265	-202
7	5	-11	288	257
7	5	-10	330	-289
7	5	-9	270	-249
7	5	-8	<203	178
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7	5	-6	564	524
7	5	-5	<187	19
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7	5	0	<176	-9
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7	5	2	442	450
7	5	3	237	209
7	5	4	242	285
7	5	5	416	408
7	5	6	<199	-167
7	5	7	<204	127
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8	0	-14	394	466
8	0	-12	1010	1095
8	0	-10	228	282
8	0	-8	1590	-1496
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8	0	-4	1414	1423
8	0	-2	1479	1380
8	0	0	<171	-88
8	0	2	<35	9
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8	0	6	1114	1156
8	0	10	720	-683
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8	2	-16	379	454
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8	2	-11	389	398	9	1	-14	<145	105
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8	2	-9	529	551	9	1	-12	253	276
8	2	-8	334	267	9	1	-11	819	-714
8	2	-7	<136	45	9	1	-10	540	467
8	2	-6	366	-365	9	1	-9	262	235
8	2	-5	533	-542	9	1	-8	339	371
8	2	-4	1404	-1328	9	1	-7	1280	1269
8	2	-3	215	-182	9	1	-6	505	-451
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8	2	1	<124	-129	9	1	-2	241	-193
8	2	2	1124	1172	9	1	-1	719	-691
8	2	3	374	-381	9	1	0	355	331
8	2	4	694	-374	9	1	1	684	651
8	2	5	<134	113	9	1	2	266	229
8	2	6	863	-964	9	1	3	550	482
8	2	7	306	298	9	1	4	522	469
8	2	8	<147	-156	9	1	5	592	-591
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8	2	14	371	-363	9	1	11	381	402
8	4	-12	377	404	9	1	12	<145	-118
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8	4	-9	<166	-42	9	1	15	333	-325
8	4	-8	564	-596	9	3	-11	383	429
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8	4	1	207	-231	9	3	-2	550	-581
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8	4	5	452	519	9	3	2	<143	24
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8	4	7	<163	-64	9	3	4	445	489
8	4	8	<167	-9	9	3	5	429	479
8	4	9	<172	-132	9	3	6	269	199

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9	3	10	284	-235	10	2	0	245	-245
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9	5	-9	217	153	10	2	2	875	-966
9	5	-8	<217	172	10	2	3	244	-241
9	5	-7	572	535	10	2	4	262	-259
9	5	-6	358	-257	10	2	5	<147	-4
9	5	-5	237	194	10	2	6	713	688
9	5	-4	327	-296	10	2	7	<154	-8
9	5	-3	456	-342	10	2	8	553	584
9	5	-2	<196	108	10	4	-13	356	-349
9	5	-1	363	-319	10	4	-12	<190	-96
9	5	0	436	480	10	4	-11	<185	-109
9	5	1	<197	-51	10	4	-10	312	-206
9	5	2	<199	132	10	4	-9	321	357
9	5	3	<202	37	10	4	-8	222	200
9	5	4	264	-235	10	4	-7	322	289
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10	2	-11	<164	-183	11	1	-8	<132	199
10	2	-10	740	787	11	1	-7	646	-575
10	2	-9	334	-317	11	1	-6	254	233
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10	2	-7	<148	-52	11	1	-4	437	439
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11	1	2	763	-727	12	0	4	1252	-1337
11	1	3	1015	-923	12	0	6	323	-463
11	1	4	206	-166	12	0	8	290	305
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11	1	7	389	396	12	2	-13	332	-113
11	1	8	<138	169	12	2	-12	229	70
11	1	9	231	230	12	2	-11	<173	-152
11	3	-11	376	-436	12	2	-10	508	-544
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11	3	-4	<159	-72	12	2	-3	195	-307
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11	3	7	358	-400	12	2	8	309	-300
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11	5	-4	<217	259	12	4	-12	<200	-127
11	5	-3	329	250	12	4	-11	<196	232
11	5	-2	<214	71	12	4	-10	<191	186
11	5	-1	444	451	12	4	-9	<187	-217
11	5	0	370	-324	12	4	-8	<182	186
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11	5	2	354	-286	12	4	-6	229	-166
11	5	3	399	-304	12	4	-5	<176	-18
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12	0	-10	247	264	12	4	-2	222	191
12	0	-8	250	212	12	4	-1	292	295
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12	0	-4	501	-502	12	4	1	<172	27
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13	1	-13	529	438	14	2	-10	<181	-101
13	1	-12	<179	-186	14	2	-9	<177	120
13	1	-11	<175	28	14	2	-8	391	364
13	1	-10	<171	-182	14	2	-7	<167	-135
13	1	-9	619	-565	14	2	-6	<170	33
13	1	-8	<165	-134	14	2	-5	<167	-165
13	1	-7	336	-277	14	2	-4	543	-574
13	1	-6	<160	9	14	2	-3	<166	-5
13	1	-5	580	491	14	2	-2	213	-157
13	1	-4	<155	60	14	2	-1	<165	83
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13	1	-2	<154	90	14	2	1	<166	-20
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13	1	0	311	269	14	2	3	<168	-20
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13	1	4	206	-131	14	4	-3	305	-242
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13	3	2	398	-86	15	1	2	310	174
13	5	-2	329	-256	15	1	3	297	287
14	0	-12	276	372	16	0	-6	286	330
14	0	-10	248	-270	16	0	-4	<127	-178
14	0	-8	526	-648	16	0	-2	434	-471
14	0	-6	195	-195	16	0	0	<97	-21
14	0	-4	353	388	16	0	2	438	502
14	0	-2	311	372	16	0	4	270	313
14	0	2	285	-259	16	2	-5	406	209
14	0	4	278	341	16	2	-4	<168	-118
14	0	6	287	357	16	2	-3	<167	66
14	0	8	283	-261	16	2	-2	293	203
14	0	10	418	-444					

C O M P U T E R   P R O G R A M M E S

The computations were carried out on an Elliott 803 computer using programmes prepared in this laboratory.

The following programmes have been written by myself in Algol.

1. A programme to correct the intensities of reflections, obtained by Weissenberg or precession methods, for Lorentz and polarisation factors. If desired, corrections for spot extension (Phillips, 1956) may also be applied to upper level Weissenberg data.
2. A programme to calculate bond distances and their e.s.d.'s using the formula put forward by Cruickshank, 1953.

$$\sigma^2 = (\sigma(x)_p^2 + \sigma(x)_q^2)l^2 + (\sigma(y)_p^2 + \sigma(y)_q^2)m^2 + (\sigma(z)_p^2 + \sigma(z)_q^2)n^2$$

where l, m and n are the direction cosines referred to orthogonal axes for the bond between p and q.

This programme also calculates the e.s.d.,  $d\theta$  in an angle as follows:

$$\begin{aligned} d\theta^2 &= l_3^2 (\text{Cos}\alpha_3 - \text{Cos}\theta\text{Cos}\alpha_1)^2 \sigma(x)_u^2 \\ &+ (l_1(\text{Cos}\alpha_1 - \text{Cos}\theta\text{Cos}\alpha_3) + l_3(\text{Cos}\alpha_3 - \text{Cos}\theta\text{Cos}\alpha_1))^2 \sigma(x)_v^2 \\ &+ l_1^2 (\text{Cos}\alpha_1 - \text{Cos}\theta\text{Cos}\alpha_3)^2 \sigma(x)_w^2 \end{aligned}$$

plus similar terms for  $\sigma(y)_{u,v,w}$ , and  $\sigma(z)_{u,v,w}$ , where  $\text{Cos}\alpha_1$ ,  $\text{Cos}\beta_1$ ,  $\text{Cos}\gamma_1$  are the direction cosines for the bond  $l_1$  between atoms u and v

and  $\text{Cos}\alpha_3$ ,  $\text{Cos}\beta_3$  and  $\text{Cos}\gamma_3$  are the direction cosines for the bond  $l_3$  between v and w referred to orthogonal axes. (Darlow, 1960).

3. A programme to compute van der Waals contacts between atoms of adjacent molecules. This generates the coordinates for each atom in all the equivalent positions within any combinations of translations of half a cell edge in any direction from one complete unit cell for monoclinic and orthorhombic space groups. The programme then calculates the distance between each atom in the asymmetric unit and each of the stored sets of coordinates for all the atoms, out-putting those less than a pre-set limit.

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