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CONFORMATIONS AND ROTATION OF ISO-PROPYL GROUPS ATTACHED TO THE SAME SATURATED CARBON CENTRE. A DYNAMIC N.M.R. AND MOLECULAR MECHANICS STUDY OF 1,1,1-TRIS-ISO-PROPYLETHANE, DI-ISO-PROPYL-TERT-BUTYLMETHANE, AND 1,1-DI-ISO-PROPYL-TERT-BUTYLETHANE

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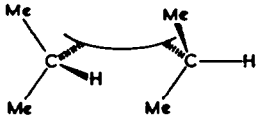
Abstract

The title compounds have temperature-dependent n.m.r. spectra from which rotational barriers for iso-propyl and tert-butyl groups can be determined. Molecular mechanics calculations are used to indicate the conformations involved in these rotations and other stable conformations, and the possible pathways for their interconversions.

Iso-propyl groups when attached to the same atom or adjacent atoms in a molecular framework have interesting conformational properties which have aroused much recent interest[1,2,3,4,5]. Dynamic n.m.r. spectroscopy is an important technique for such investigations because there are two equivalent conformational arrangements of the general form 1 and 2 for the iso-propyl groups in such molecules, and approximately 180° rotation of these fairly large substituents 1 ⇌ 2 is likely to produce barriers which fall within the range (4-24 kcal/mol), of this technique.



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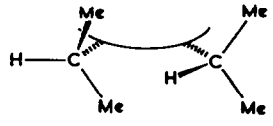

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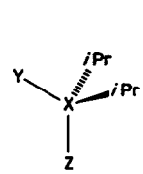
The work on iso-propyl groups attached to planar molecular residues has been reviewed recently[1]. Much less work has been done on molecules where the two iso-propyl groups are attached to the same sp³-hybridised atom as in 3. In such a fragment, the straightforward question of the conformation along each of the two carbon to iso-propyl bonds is overlaid by the question of the through-space interaction between the iso-propyl groups. As the diagram 4 for one conformation of the simple molecule 2,4-dimethylpentane (di-iso-propylmethane) illustrates, perfect staggering along the 2-3 and 3-4 bonds with large groups antiperiplanar, none-the-less produces two methyl--hydrogen parallel-1,3-interactions[6], which correspond to steric strain of about 1.8 kcal/mol[7].



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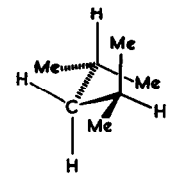

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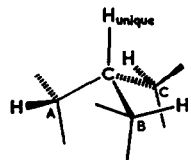

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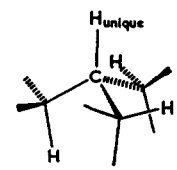

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In tris-iso-isopropylmethane 5, H_{unique}-$C(CHMe_2)_3$, the questions are even more complicated as recent investigation has indicated[4]. There, interest lay in determining and explaining the dihedral angles H_{unique}-C-C-H for each iso-propyl group in the molecule. Dynamic N.M.R. measurements and molecular mechanics calculations show[4] that 5 exists as a mixture of conformations of the gauche, gauche, gauche type, 6, (-g -g -g) and the anti, gauche, gauche, type 7 (a -g -g), the latter having enthalpy lower by 0.21 kcal/mol. These two conformations interconvert very rapidly with a barrier calculated to be about 3.3 kcal/mol. (+)Gauche and (-)gauche mean that viewing from the iso-propyl group towards the central unique hydrogen, the H-C-C-H_{unique} relationship is clockwise and anticlockwise respectively. We arbitrarily decide to represent trialkylmethanes (and mutatis mutandis trialkylethanes) as in 6, and to cite the conformation of centres A,B and C in that order. There exists an equally likely enantiomeric set of conformations (+g +g +g) 8, and (a +g +g) 9, not shown. Rotation of isopropyl groups interconverts the two enantiomeric sets by way of intermediate meta-stable conformations like (a -g +g), with a barrier to this interconversion measured to be 6.6 kcal/mol and calculated to be 5.3 kcal/mol.

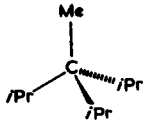
An important feature of the conformational analysis of 5 is that on the basis of calculations the populated ground-state conformations (and other less stable conformations which need not concern us here), although described in terms of gauche and anti, show considerable rotations away from perfectly staggered arrangements, considerable increases in C-C-C bond angles and decreases in H-C-C bond angles as Table 1 shows, and other less-striking changes.

A computer can be used to generate an accurate perspective picture of such conformations, but often, atoms unimportant in the context being discussed obscure significant bonds, or vice versa. Free drawn diagrams like 6 or 7, which do not show all the atoms of the methyl groups or diagrams with perfect 60° staggering like 4 are often useful if not completely accurate representations of conformational minima. Appropriate reservations due to these inaccuracies should never be forgotten.

In this paper we want to discuss three molecules of general type 3, each of which is a more highly substituted analogue of 5, viz. tris-iso-propylethane 10 (2,3,4-trimethyl-3-[1-methylethyl]-pentane), where the unique hydrogen of 5 has been replaced by a methyl group, di-iso-propyl-tert-butylmethane 11 (2,2,4-trimethyl-3-[1-methylethyl]-pentane), where one iso-propyl group of 5 is replaced by a tert-butyl group, and 1,1-di-iso-propyl-1-tert-butyl ethane (2,2,3,4-tetramethyl-3-[1-methylethyl]-pentane 12, which combines both these changes.

The questions to be answered are equivalent to the ones considered in the work on 5. To what extent are the various combinations of gauche and anti conformations for iso-propyl groups populated? How distorted are these

conformations from perfectly staggered, and how distorted from other ideals, to reach the lowest energy conformations? What is the barrier to interconversion of enantiomeric conformations or sets of conformations?



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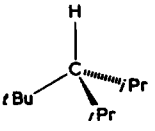

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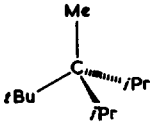

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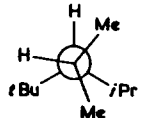
When the rotations of interest are about bonds joining two trisubstituted carbons, and iso-propyl group rotation in 11 is one example, then there are two likely stable conformations. These occur when hydrogens at either end of the single bond are nearly orthogonal to each other,[10,11] and interconversion of these conformations involves almost 180° of rotation, 13⇋14, usually by way of the conformation with the hydrogens anti to each other.



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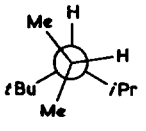

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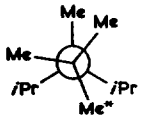

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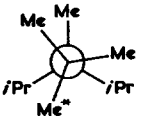

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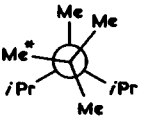

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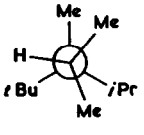

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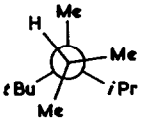

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Most of the bonds we are considering in 10 to 12 are pentasubstituted however, and a different phenomenon has to be considered. Between adjacent high-energy eclipsed conformations, there are likely to be two minima, skewed on either side of the perfectly staggered conformation and interconverting by libration through the latter conformation[12,13]. For the tert-butyl group in 12 for example, such conformations are as in 15 and 16 and the higher energy for the perfectly staggered conformation is due to the parallel, 1,3-interactions we discussed earlier for structure 4. Because of symmetry of the molecule 12, these conformations 15 and 16 are of the same energy and there are other identical conformations e.g. 17 which are reached by rotation through eclipsed transition states.

For a less symmetrically substituted bond, e.g. the iso-propyl to carbon bond in 12, the two conformational minima connected by libration, 18 and 19 need not have the same energy.

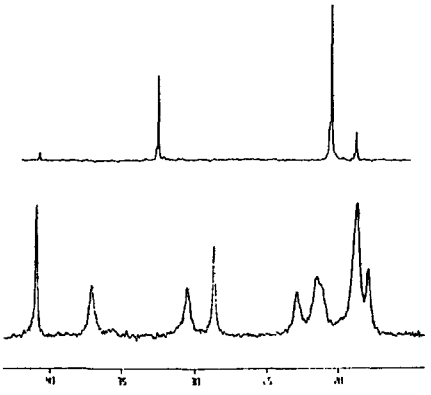


Figure 1. Carbon-13 nmr spectrum of 10 at room temperature and at -145°C (bottom).

In extreme cases the population of one minimum may be very small, or the minimum may become only a point of inflexion in the potential energy diagram.

The compounds 10 to 12 thus have a complex conformational analysis, but such highly branched molecules deserve consideration since they allow us to study extreme conformations, well-removed from perfect staggering. However, much simpler saturated hydrocarbons already show small variations from ideal conformations of precisely the kind that 10 to 12 demonstrate so clearly. 2,3-Dimethylbutane[14], and 2,2,3,3-tetramethylbutane[15] are examples.

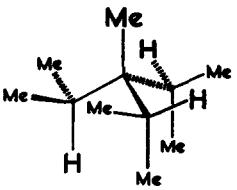
Results and Discussion

The nmr spectra of each compound 10-12 will be considered in turn. Full details are given in Tables 7 and 8 in the experimental section. Tables 1-4 report results for molecular mechanics calculations.

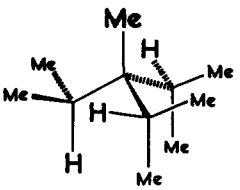
tris-Isopropylethane, 10. As the temperature is lowered, two sets of changes are seen in the signals of the iso-propyl groups of this compound, but the signals of the unique methyl and of the central carbon are invariant. This suggests that there is only one kind of conformation for the molecule, but within that conformation there are various possibilities for any iso-propyl group.

The proton-decoupled carbon-13 nmr spectrum of this compound shows four signals at room temperature see Figure 1 and Table 7. The methine carbon signal splits below about - 124° to appear as a broad 2:1 doublet at about -127°, which becomes a 1:1:1 triplet with further cooling from ~ -130° to -145°. The signal of the iso-propyl methyl carbons also shows two sets of changes on cooling, first splitting to a 1:1:1 triplet, which then splits further to give several overlapping signals which are suggested to be six singlets of equal intensity. The proton spectrum show similar changes, there being in particular three methine proton multiplets at -150°, and at least three iso-propyl methyl signals, see Table 8.

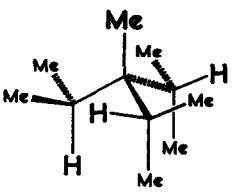
Molecular mechanics calculations suggest (see Table 3) that there are two kinds of conformation which are particularly stable, namely 20, (a -g -g) and 21 (a +g -g). Paradoxically, the two (-)gauche groups in 20 are non-equivalent, with their methine hydrogen pointing away from and towards the anti-group respectively, while the (+)gauche and (-)gauche groups in 21 despite their different names are equivalent. There is an enantiomeric conformation (a +g +g), 22 equivalent in energy to 20 and the symmetric conformation 21 is a likely midpoint in the rotational pathway interconverting these enantiomers. Calculations suggest that at -145 °C there should be only 1.7% population of conformation 21 and less



20 (a -g -g)



21 (a +g -g)



22 (a +g +g)

than 1% of all others. Nmr spectra at that temperature show no sign of a second set of signals which could be ascribed to 21 or any other second conformation. Discussion in terms of one conformational isomer 20 and its enantiomer 22 thus seems reasonable, even though there may be a significant population of conformation 21 at room temperature.

Each of the three iso-propyl groups may in turn be the one to take up the anti-position, so we can postulate three sets containing a pair of conformations which could be labelled 20 and 22, 20' and 22',and 20" and 22". Interconversion between sets takes place by way of the less stable conformations shown in Table 1, while interconversion of pairs within a set takes place by way of 21, 21', or 21" respectively.

At room temperature conformational interconversions both between sets and within sets are rapid on the nmr timescale, and averaged signals are seen, but at -145 °C both processes are slow on the nmr time-scale. Each molecule thus gives rise to a set of signals for each of the three different iso-propyl groups see 20, (or 22) viz. six iso-propyl methyl signals and three methine CH-signals. Above about -130°, interconversion within each set ie. 20 ⇋ 22 etc becomes rapid on the nmr timescale so the second and third iso-propyl groups become equivalent. The barrier to this process which we suggested above goes via conformation 21 is 6.4 kcal/mol at -130°. Above about -125°, interconversion of the anti and gauche-conformations in any one molecule e.g. 20 ⇋ 20' ⇋ 20" ⇋ 20 becomes fast on the nmr timescale and a single signal is seen for each part of the iso-propyl group. The barrier to this second process is 6.8kcal/mol at -125 °C. There are two obvious ways by which this second process might happen, either by conformations where all the iso-propyl groups are gauche in the same sense, or by conformations where two iso-propyl groups are in an anti-conformation.

Table 1 Relative Stability of Various Conformations of 5 and 10 ($R(i\text{-}Pr)_3$) as Suggested by Molecular Mechanics Calculations

Conformation of Isopropyl Groups A, B, and C	Isoenergetic Conformation	5, R = Hydrogen				10, R = Methyl			
		Relative Enthalpy (kcal/mol)	Dihedral Angles[j] A	B	C	Relative Enthalpy (kcal/mol)	Dihedral Angles[j] A	B	C
(-g -g a)	(+g +g a)	0.00[k]	-95.5	-63.1	179.0	0.00[m]	-91.9	-61.9	-173 6
(-g -g -g)	(+g +g +g)	0.21	-81.8	-82.2	-80.0	2.29	-49.2	-49.4	-49 4
(-g +g a)		2.00	-47.5	70 9	180.0	3.05	-94.3	72.0	-172 2
(-g -g +g)	(+g +g -g)	2.34	-82.2	-84.1	50.0	3.65	-81.8	-78.7	46 0
(+g -g a)		3.04	95.1	-72.2	171.4	0.86	42.1	-67.3	-174 3
(-g a a)	(+g a a)	3.70	-78.9	-137 9	-180.0	2 90	-75.2	-149.9	-178 6
(a a a)		8.15	-151.7	-151.5	-153 4	5 70	157.5	157.4	157 5

[j] Of the isopropyl methine hydrogens with the unique hydrogen in 5 or the unique methyl in 10. Diagram 6 defines A, B, and C.

[k] The MM2 Final Steric Energy of this conformation is 17.37 kcal/mol, H_f° = -59.53 kcal/mol.

[m] The MM2 Final Steric Energy of this conformation is 25.96 kcal/mol, H_f° = -59.65 kcal/mol.

It is interesting to compare the results of calculations for tris-iso-propylmethane, 5 and tris-iso-propyl ethane 10 which are shown in Table 1. The (a -g -g) conformation is the most stable in both cases with remarkably similar dihedral angles, but just one additional methyl group in 12 raises the final steric energy by almost exactly 50%. This is a further demonstration that a symmetrical ethane 5 with four large substituents, with H-C-C-H dihedral angles of about 81°, is disproportionately better able to accomodate steric strain than a penta-substituted ethane[10,11]. Again, for 5, the (-g -g -g) conformation is almost as stable as the (a -g -g) one . By distorting the H-C-C-H dihedral angle towards 90°. This places one methyl of each isopropyl group within 40° dihedral angle with the unique hydrogen, so it is not surprising that the equivalent conformation of 10 now with a unique methyl group, is not particularly stable. There is now a very different H-C-C-H dihedral angles, 81° being replaced by 49°, and the unique methyl and isopropyl methyls are now quite far apart although still gauche.

In compound 5 as a result of the easy accessibility of the (-g -g -g) conformation, the three isopropyl groups of the ground-state (a -g -g) conformation, although instantaneously different, are equivalent on the nmr timescale even at -150 °C, i.e. the equivalent for 5, of the equilibrum 20 ⇋ 20' ⇋ 20" has a low barrier and only interconversion of the enantiomeric (-)-gauche and (+)-gauche series ie 20 ⇋ 22 etc. is slow on the nmr timescale. In contrast for 10 at -145°C, the three different isopropyl groups of a single (a -g -g) conformation can be observed since both processes are slow, for access to the (-g -g -g) conformations now requires an isopropyl methyl group to eclipse the unique methyl group.

Tert-butyl-bis-isopropylmethane, 11 There are various ways in which the spectra of 11 are temperature-dependent. In the carbon-13 nmr, lowering the temperature below about -75°, the tert-butyl signal broadens and splits below about -109° to a 2:1 doublet, indicating that tert-butyl group rotation is slow on the nmr timescale at that low temperature with a barrier to rotation of 7.3 kcal/mol at -109°. On further cooling, iso-propyl group conformational isomerisation becomes slow on the nmr timescale, as shown by the tert-butyl group signal changing from 2:1 doublet to a 1:1:1 triplet, the signal of the central carbons of the iso-propyl groups changing from a singlet to a 1:1-doublet, and the iso-propyl methyl doublet appearing as a complex set of signals which should be 1:1:1:1 quartet see Figure 2. Similar changes are seen less clearly in the proton nmr. The barrier to this second process is 6.4 kcal/mol at -134°C.

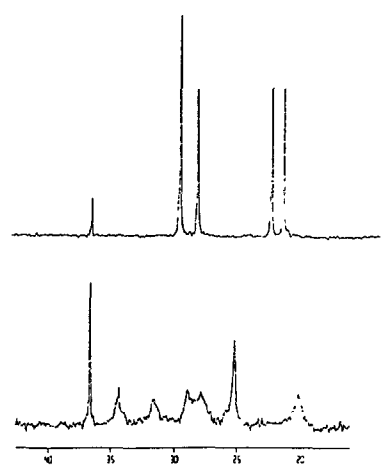


Figure 2 Carbon 13 nmr spectrum of 11 at room temperature and -150°C (bottom).

Table 2 Relative Stability of the Various Conformations of 11 and 12 (R-C(i-Pr)$_2$$t$-Bu) as Suggested by Molecular Mechanics Calculations.

Conformation of Isopropyl Groups B and C	Isoenergetic Conformation	11, R = Hydrogen				Structure[p]	12, R = Methyl			
		Relative Enthalpy (kcal/mol)	Dihedral Angles[k] A	B	C		Relative Enthalpy (kcal/mol)	Dihedral Angles[k] A	B	C
(-g -g)	(+g +g)	0.00[m]	167.1	-83.1	-84.4	29',29	0.19	163.6	-79.0	-81.5
(-g a)	(a +g)	3.42	153.5	-62.5	-174.7	27,27'	0.00[n]	156.2	-61.9	-177.1
(-g +g)		4.97	166.2	-80.1	88.9	26	3.12	159.0	-77.0	45.8
(+g -g)		0.32	-161.7	88.5	-55.2	31	0.68	170.2	51.4	-83.4
(a -g)	(+g a)	3.53	175.9	167.5	-101.1	28',28	0.60	-152.2	175.7	-75.0
(a a)		8.95	148.7	173.2	-149.5	30	3.36	168.4	143.8	165.8

[k] Of the isopropyl methyl hydrogens or the anti methyl of the tert-Butyl group with the unique hydrogen in 11 or the unique methyl in 12. Diagram 6 defines A, B, and C.

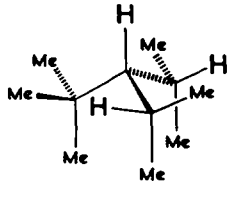
[m] The MM2 Final Steric energy of this conformation is 23.17 kcal/mol, H_f° = -58.77 kcal/mol by calculation.

[n] The MMS Final Steric energy of this conformation is 35.54 kcal/mol, H_f° = -63.79 kcal/mol.

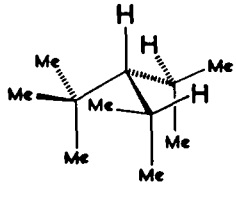
[p] See Figure 4.

In the proton nmr spectrum there is a coupling between the unique proton and the isopropyl methine protons which changes from 1.08Hz to 1.98Hz over the temperature range -60 °C to 175 °C indicating the presence of two different overall conformations. This interpretation is supported by the unusually large temperature-dependence of the relative chemical shift of the diastereotopic methyl groups in both the proton and carbon-13 nmr spectra. In the latter case this changes from 45Hz to unresolved 0Hz (50Mhz operating frequency) without dynamic broadening, between 25 °C and -100 °C.

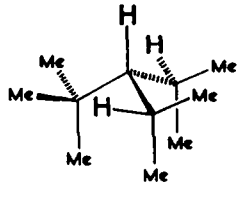
The molecular mechanics calculations reported in Tables 2 to 4 give clear suggestions as to the conformational situation which explains these results. Three conformations for 11 are more stable than the six others, namely the (+g, +g) 23, its enantiomer (-g, -g) 24 and the more symmetrical (+g, -g) 25. On the basis of the molecular mechanics calculations and assuming no entropy difference for 23-25 there should be about 12% population of conformation 25 at -145 °C, and about 26% at +175 °C. In the more stable (-g, -g) conformation, H-C-C-H dihedral angles are reckoned to be -83.1° and -84.4° whereas in the (+g, -g) conformation these angles are 88.5° and -55.2°. The 55.2° dihedral angle should lead to higher coupling constants than 80°-90° angles[11], so the observed increase in the coupling constant confirms the predicted increased proportion of the conformation 25 at higher temperatures.



23 (+g +g)



24 (-g -g)



25 (+g -g)

The quality of the spectrum at -145°, the lowest temperature that we were able to reach, is not good enough to permit observation of a small population of conformation 25, but the observed changes are otherwise in agreement with an equilibrium between the enantiomeric (+g, g+), 23 and (-g, -g), 24 conformations, with a barrier to interconversion of 6.4 kcal/mol at -134°C. Any of the more or less symmetrical conformations (+g, -g), 25, (-g, +g), or (a a) may be an intermediate in this process but since 25 is calculated to be by far the most stable of these, and appears to be populated, to that extent it indicates the most likely pathway.

The barrier to tert-butyl group rotation in 11, 7.3 kcal/mol is little more than that of 6.9 kcal/mol found for tert-butyldimethylmethane[16,17] and probably reflects the increased steric strain present in the ground-state conformation of 11 but less markedly important in the rotational transition state. The same kind of argument may well explain why the barrier to isopropyl group rotation for 11 at 6.4kcal/mol is in fact a little less than in the less substituted compound 5.

1-Tert-butyl-1,1-bis-isopropylethane 12. There are two sets of changes in the carbon-13 nmr with lowering temperature for this compound, showing two processes becoming slow on the nmr timescale. Below about -35°, the tert.butyl methyl signal broadens, and splits below about -76° to a 2:1 doublet indicating that rotation of the tert-butyl group has become slow on the nmr timescale with a barrier of 8.7 kcal/mol at -76°. Below about -60° all signals except the central quaternary carbon one begin to broaden, and each splits at slightly different temperatures round about -110° to what appears to be doublets of almost equal intensity, all reflecting barriers of about 7.1 kcal/mol. The same process thus appears to be the origin of all these latter changes. The most significant change is that of the unique methyl carbon signal. That it should split to two signals means that two different conformations or sets of conformations of the molecule, are populated. That the populations appear to be equal is a coincidence.

Molecular Mechanics calculations help to provide an explanation and Table 2 shows the relative energies of the various combinations of gauche and anti arrangements for the two isopropyl groups. There are four kinds of conformation (and their enantiomers) that are calculated to be separated by less than 1 kcal/mol in total enthalpy. These fall into two sets as Figure 3 shows, and there are two high energy processes which interconvert these sets. One of these is shown viz passage through the (a, a) conformation, and the other is direct interconversion of a (+)-gauche and (-)-gauche conformation of one isopropyl group. Various pairs of structures, one each from the top and bottom group in Figure 3 are connected by this second rotation, so it is not shown. It may indeed be of improbably high energy since it requires the isopropyl group methyls to eclipse a tert-butyl and an isopropyl group respectively.

The first set comprises structures 26 and 27 (and 27') which are expected to interconvert easily with a low barrier - all that is needed is a rotation of the anti group in 27 through only 97°, and an adjustment of the gauche group conformation by 22°. The second set comprises 31 and 29 (or 31' and 29') which again interconvert easily by 95° rotation of the anti-group and a 17° adjustment to the gauche group. Structures 30 and 28 are of higher energy and unlikely to be much populated, but because of their symmetry perform intermediate roles between the sets as shown in the diagram. It requires rather greater degrees of rotation and other adjustments of structure to reach these conformations.

The nmr results require that passage through structure 30 have a considerably higher barrier than passage through 28, and that the former be slow on the nmr timescale at -135° while the latter is still fast.

Compounds 11 and 12 are different from 5 and 10 and other highly branched alkanes[11] in that two different kinds of conformation are populated and interconverting slowly on the nmr timescale at the low temperatures available. The above analysis indicates that the nmr spectral changes agree well, as far as they go, with the quite precise details of conformation indicated by molecular mechanics calculations.

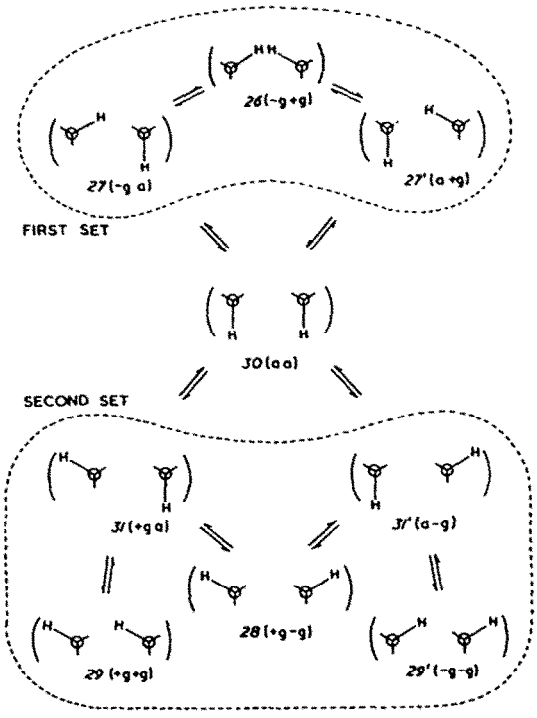


Figure 3 Conformational Isomerisation Pathways for the isopropyl group in 12. Methyl groups are not shown explicitly.

Table 3 Molecular Mechanics Calculated Geometric Parameters[a] for the Most Stable Conformation of Compounds 5, 10, 11, and 12 (R-C_1[C_tH(CH_3)$_2$]$_2$[C_qR'(CH_3)$_2$])

Compound and Description of the Conformation	5 R = R' = H (a -g -g)	10 R = CH_3, R' = H (a -g -g)	11 R = H, R' = CH_3 (-g -g)	12 R = R' = CH_3 (-g a)
Bond Lengths (Å)				
C_1--R	1.115	1.552	1.110	1.555
C_1--C_t	1.558	1.576	1.559	1.588
C_1--C_q	---	---	1.561	1.596
C_t--CH_3	1.541	1.545	1.538	1.547
C_q--CH_3	---	---	1.545	1.553
Bond Angles (°)				
R--C_1--C	104.8	108.0	102.4	107.1
C_t--C_1--C	113.7	110.9	115.5	111.7
C_1--C--CH_3	114.2	116.2	112.4	113.7
CH_3--C--CH_3	109.2	107.3	106.3	104.9
Dihedral Angles[b] (°)				
(R-C_1-C_q-C)	---	---	11.5	24.4
(R-C_1-C_t-C)	13.2	15.6	26.1	5.5

[a] Values underlined are averages for several equivalent groups.

[b] is a measurement of the extent (°) that dihedral angles are different from 60° or 180°.

Table 4 Contributions (kcal/mol) to the Final Steric Energy of the Most Stable Conformations of 9, 10, 11, and 12.

Compound and Description of Conformation	9 $(i\text{-Pr})_3CH$ (a -g -g)	10 $(i\text{-Pr})_2CHMe$ (a -g -g)	11 $t\text{-BuCH}(i\text{-Pr})_2$ (-g -g)	12 $t\text{-BuC(Me)}(i\text{-Pr})_2$ (-g a)
Compression[a]	1.71	3.51	3.51	5.80
Bending	4.37	6.28	7.13	9.59
Stretch-Bend	0.56	0.84	0.73	1.16
van der Waals 1,4	6.55	7.36	7.45	8.18
other van der Waals	-0.52	2.17	-0.30	4.62
Torsion	4.69	5.81	5.64	6.17
TOTAL	17.36	25.96	23.17	35.84

Compound 11 completes the record of the synthesis of the series of hydrocarbons HCR'R"R'" where R = methyl ethyl, iso-propyl, and tert-butyl. Tables 5 and 6 report chemical shifts of the methine proton in that series and similar ones.

While our results show that occasionally different kinds of conformations may contribute to the average structure and thus to that chemical shift, conformational averaging is much less than for the CH_3-group or CH_2-group in any set of compounds R-CH_2R' or R"-CH_3 respectively. As a result, the methine proton chemical shift is more likely to reflect the substitution pattern than the conformational behaviour.

β-Substitution by methyl groups is well known to produce downfield shifts of 0.39-0.63ppm as the series methane, δ = 0.23, ethane δ = 0.86, propane δ = 1.33, isobutane δ = 1.72 indicates. γ-Substitution as a conformationally aware analysis or Table 8 suggests, produces upfield shifts if the methyl group substitutes a proton gauche to the methine hydrogen, and downfield shifts if the proton substituted is anti to the methine proton in view. That all subsequent methine protons in Table 8 are upfield from the first entry indicates only that there are more gauche positions, and that they are conformationally preferred. δ-Substitution as Table 6 indicates, produces downfield shifts.

Table 5 Chemical Shift Values (δ) of the Methine Proton in Compounds HCR'R"R'"[a]

R'	R"	R'"	δ	R'	R"	R'"	δ	R'	R"	R'"	δ
Me	Me	Me	1.72	Me	i-Pr	i-Pr	0.98	Et	i-Pr	i-Bu	0.87[b]
Me	Me	Et	1.47	Me	i-Pr	t-Bu	1.15	Et	t-Bu	t-Bu	0.78[b]
Me	Me	i-Pr	1.40	Me	t-Bu	t-Bu	1.18[b]	i-Pr	i-Pr	i-Pr	0.83[c]
Me	Me	t-Bu	1.39	Et	Et	Et	1.16	i-Pr	i-Pr	t-Bu	1.11[d]
Me	Et	Et	1.27	Et	Et	i-Pr	0.90	i-Pr	t-Bu	t-Bu	1.10[b]
Me	Et	i-Pr	1.48	Et	Et	t-Bu	0.73	t-Bu	t-Bu	t-Bu	1.38[e]
Me	Et	t-Bu	1.53	Et	i-Pr	i-Pr	0.78				

[a] Determined from spectra published as America Petroleum Research Institute Project 44, unless otherwise stated. [b] reference 20. [c] reference 4. [d] this work. [e] reference 12.

Table 6. Chemical Shift of Methine Proton δH_{obs} in Compounds $(CH_3)_2CH_{obs}$--CH_2R, $(CH_3)_2CH_{obs}$--CHMeR, and $(CH_3)_2CH_{obs}$--$C(Me)_2R$ for R = methyl, ethyl, iso-propyl and tert-butyl[a].

Substituent R	δH_{obs} in $(CH_3)_2CH_{obs}$--CH_2R	δH_{obs} in $(CH_3)_2CH_{obs}$--CHMeR	δH_{obs} in $(CH_3)_2CH_{obs}$--$C(Me)_2R$
Methyl	1.47	1.40	1.39
Ethyl	1.55	1.57	1.49
iso-propyl	1.63	1.66	1.67
tert-butyl	1.67	1.99	1.81

[a] See footnote a, Table 7.

The epitome of a downfield shift for a relatively unstrained hydrocarbon methine proton is in bicyclo[3,3,3]undecane, δ = 2.31. The epitome of an upfield shift is that of 0.36 in [cis, cis, cis]dodecahydrophenalene with six gauche substituents.

Our present results help to indicate that ideal staggered structures are so un-likely that any more precise analysis of substituent effects on chemical shifts must take conformational distortions into careful consideration.

Conclusion

In each compound of type 3 studied here and elsewhere, there are calculated to be different kinds of conformation significantly populated, and enantiomeric versions of each conformation. In the various examples of 3 considered, it is always possible to slow interconversion of enantiomeric sets on the nmr timescale, but interconversion of different kinds of conformation within each set, which may only involve the equivalent of a single 120° rotation, is usually fast on the nmr timescale even at -150°C.

Experimental

Compounds 10 and 11 were obtained from di-isopropyl-tert-butylcarbinol[19,20]. Dehydration with sulphuric acid[19] led to a mixture of olefins from which 2,4,4-trimethyl-3-isopropylpent-2-ene[21] and 2,3,4-trimethyl-3-isopropylpent-1-ene could be separated by preparative gas-liquid chromatography. Platinum catalysed hydrogenation of these olefins gives 10 and 11 respectively.

10, tris-isopropylethane, 2,3,4-trimethyl-3-isopropylpentane, b.pt. 63-65° at 14 mmHg (Found: C, 84.35; H, 15.38. $C_{11}H_{24}$ requires C, 84.52; H, 15.48%).

11, tert-butyl-di-isopropylmethane, 2,3,4-trimethyl-3-isopropylpentane, b.pt. 74° at 15 mmHg (Found: C, 84.40; H, 15.25. $C_{11}H_{24}$ requires C, 84.52; H, 15.48%.

12 was prepared by the method of Hellmann[19].

Nmr spectra reported in Tables 7 and 8 were recorded on a Varian XL200 or a Varian VXR400 spectrometer, and are for approximately 0.2M solutions in an approximately 4:4:1 mixture of CHF_2Cl:$CHFCl_2$:CD_2Cl_2. Molecular mechanics calculations used Allinger's MM282 program.[9]

Table 7 Carbon-13 nmr chemical shifts (δ) for 10-12. $(CH_aH_3)_2C_bH\text{-}C_f(R_e\text{-}i\text{-}Pr)\text{-}C_g(C_cH_3)_2R_d$ at ambient and at low temperature.

Compound and Substituents	Temperature (°K)	a	b	c	d	e	f	g
10	298	19.9	33.1	19.9	---	18.0	42.2	33.1
R_d = hydrogen		22.5	36.8	22.5				36.8
R_e = methyl	123	20.9	30.1	20.9	---	18.2	40.6	30.1
		17.5	28.2	18.2				28.2
		18.2						
		23.0						
11	298	23.9	29.2	30.5	30.5	---	58.2	36.8
R_d = methyl		20.2	29.1	25.2	25.2			
R_e = hydrogen	123	25.8	27.9	31.4	31.4	---	56.3	36.7
				34.5	34.5			
12	298	21.9	35.3	30.5	30.5	18.1	45.1	39.9
		21.8						
R_d = R_e =		22.3	37.0	32.0	32.0	19.2		
methyl	143	22.0					44.0	39.2
		21.0	32.5	31.6	31.6	16.8		
		20.9		27.4	27.4			

Table 8 Proton NMR spectra of 10-12, $(CH_{e3})_2CH_a$-$C(R_d)(r\text{-}1v)$-$C(CH_{e3})_2R_e$ at ambient and at low temperatures.

Compound and Substituents	Temperature (°K)	a	b	c	d	e	
10							
R_d = hydrogen	298	0.93	1.92	0.93	1.92	0.78	J_{ab} = 7.1 Hz
R_e = methyl			1.70		1.70		
	123	0.89[a]	1.85	0.89[a]	1.85	0.74	
			2.08		2.08		
11							
R_d = methyl	298	1.01	2.02	0.98	2.02	1.10	J_{ab} = 7.15 Hz
R_e = hydrogen		1.04					J_{be} = 1.48 Hz
12							
R_d = R_e = methyl	298	0.73	1.91	0.99	0.99	0.78	J_{ab} = 7.0, 7.1 Hz

[a] Poorly resolved

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