ANALYSIS AND INTERPRETATION OF THE FLUORINE N. M. R. SPECTRUM OF 1, 3-DIMETHOXY-1, 1, 2, 3, 3-PENTAFLUOROPROPANE

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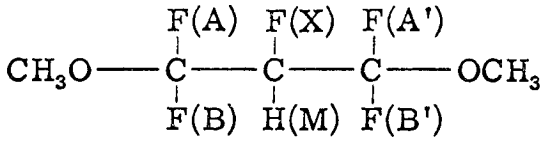
INTRODUCTION

A variety of physical techniques including infrared, microwave and Raman spectrocopies and dipole measurements have been used to study conformational preferences and restricted rotation in aliphatic compounds. N. m. r. spectra are now of recognized utility in studies of this sort (1, 2, 3, 4).

This thesis is concerned with a study of the n. m. r. spectrum of 1, 3-dimethoxy-1, 1, 2, 3, 3-pentafluoropropane (I) and presents information about the propensities for conformational preferences in alkyl fluoroalkyl ethers.



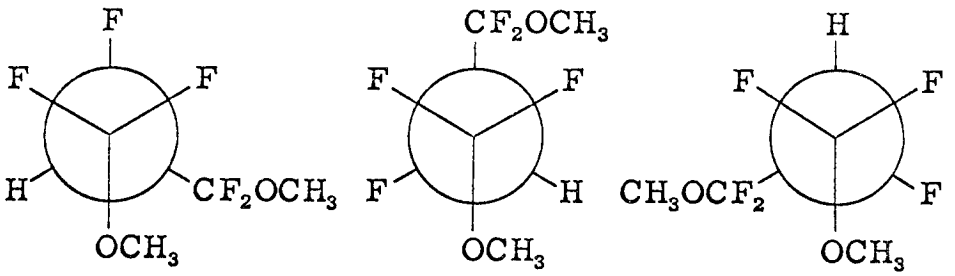
I

It has been shown (5) that the protons of a methylene group separated from center of asymmetry by an oxygen atom are, in certain cases, magnetically nonequivalent* and give AB-type n. m. r. spectra. Similarly, Drysdale and Phillips (1) have shown that the fluorine magnetic resonance spectrum of 1, 2-dibromo-1, 1-difluoro-2-phenylethane displays the eight distinct resonances typical of the

*There are two ways to differentiate magnetically between two nuclei. One way is the chemical shift and the other is the spin-coupling constant between these and a third nucleus. Here we will be concerned with both types of nonequivalence.

AB part of an ABX-type system (6), instead of the simple doublet expected in the event of "free" rotation about the C–C linkage. In the case of I, the spectrum of the geminal fluorines also displays a pattern of the AB-type (A'≡A, B'≡B due to symmetry).

Before proceeding further it will be helpful to consider the possible factors which may contribute to the magnetic nonequivalence of the two nuclei. For simplicity, we will consider an isolated molecule of I in the gas phase and will assume as usual, that the staggered conformations are energetically preferred. The three possible staggered conformations of I with respect to either of the C–C bonds are represented in Fig. 1.



Possible configurations of I

Figure 1

The magnetic nonequivalence of the geminal fluorines may result from any combination of these structures, because even if rotation is rapid the chemical-shift differences between the geminal groups will

not necessarily be averaged unless the residence times of the molecule in each of the various rotational configurations . . . are equal (7). *

Another factor which might possibly contribute to the magnetic nonequivalence of the geminal fluorines is what Pople (8) calls the "neighboring-group anisotropy" effect. This effect, which is important in compounds without aromatic rings, originates in the movement of electrons in the σ bonds of the molecule. Under the influence of an external magnetic field, the bonding electrons will produce a secondary magnetic field, the magnitude of which is dependent on the nature of the bond. These secondary magnetic fields may increase or decrease the shielding of neighboring groups. Since the geminal fluorines of I neighbor on an asymmetric center, it is possible that each of the different C–Y (Y=H, F, CF_2) bonds may produce a different magnetic field and, as a consequence, produce different degrees of shielding for the geminal fluorines which would then become magnetically nonequivalent.

Another possible cause of nonequivalence noted by Grocki (9) concerns the unshared electron pairs on the oxygen. If one thinks

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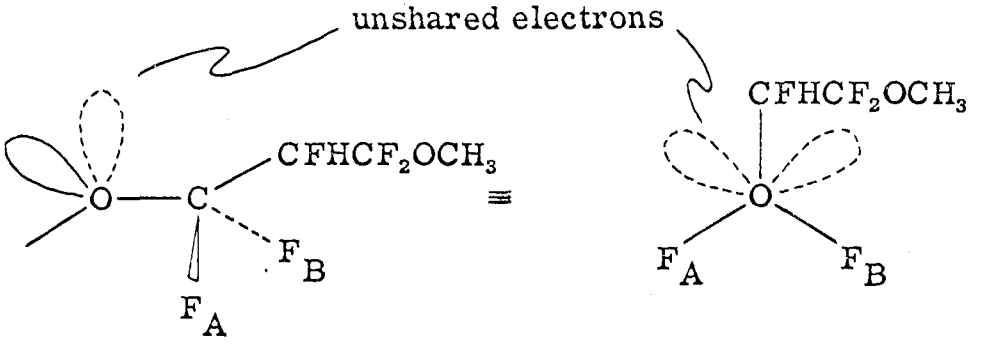
*Rapid rotation here refers to 360° rotations of sufficient frequency to theoretically average the chemical shifts (1), i.e.,

$$\nu \geq \delta\,(2\pi)$$

where δ is the chemical shift between A and B and ν is the frequency of rotation.

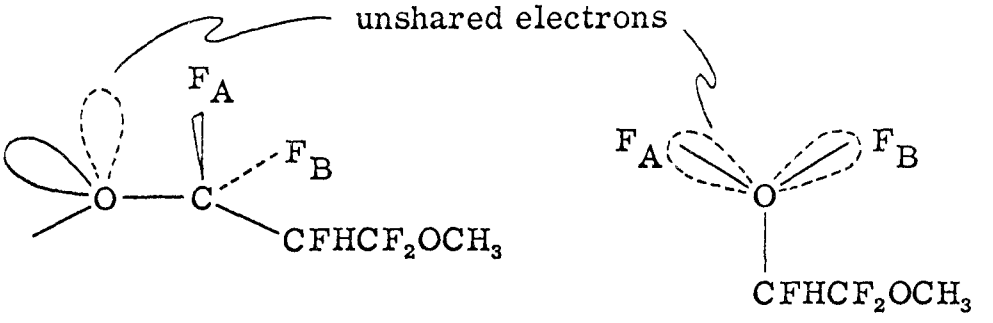
of each pair as a dipole, the only ways in which the geminal fluorines can experience equal shielding from these dipoles would be for the fluorines to be eclipsed by or opposed to the unshared pairs (Fig. 2). Examination of the molecular model of I shows that the eclipsed form is very unfavorable sterically while the opposed form is probably the most stable of all conformations. No conclusions on the importance of this effect can be drawn, therefore, without further work.

As we shall see, the results indicate that in the case of 1, 3-dimethoxy-1, 1, 2, 3, 3-pentafluoropropane the most important factor by far is the distribution of the molecules among the various rotational isomers.



Side view End view

a. Opposed to F_A and F_B



Side view End view

b. Eclipsed by F_A and F_B

Unshared electron pairs on oxygen of I

Figure 2

RESULTS AND DISCUSSION

a. Room-Temperature Spectra

The spin system of I can be thought of as belonging to the AA' BB' MX type*--where the hydrogen on C-2 is taken as M. The fluorine magnetic resonance spectrum at room temperature shows two principal groups of lines--one, centered on 4855 c.p.s. upfield from fluorotrichloromethane, due to the 1, 1, 3, 3-fluorines (Fig. 3a) and the other, centered on 11, 854 c.p.s. upfield from fluorotrichloromethane, due to the 2-fluorine (Fig. 3b).

The spectrum of the 2-fluorine (X) is a quite symmetrical nonet.† There is a 44-c.p.s. coupling to the 2-proton (M) and apparently equal couplings to the geminal fluorines of approximately 11 c.p.s., i.e., $J_{AX} = J_{BX} \sim 11$ c.p.s.

The spectrum of the 1, 1, 3, 3-fluorines exhibits <u>two closely spaced</u> (26 c.p.s.) quintets and the "wings" characteristic of the AB-type spectra (10), each located 149 c.p.s. (J_{AB}) from a quintet.

The proton spectrum (Fig. 4) shows two symmetrical quintets centered on 258 c.p.s. downfield from tetramethylsilane and separated by 44 c.p.s. (J_{MX}). There is also a large peak at 203 c.p.s. downfield from tetramethylsilane due to the CH_3O-protons.

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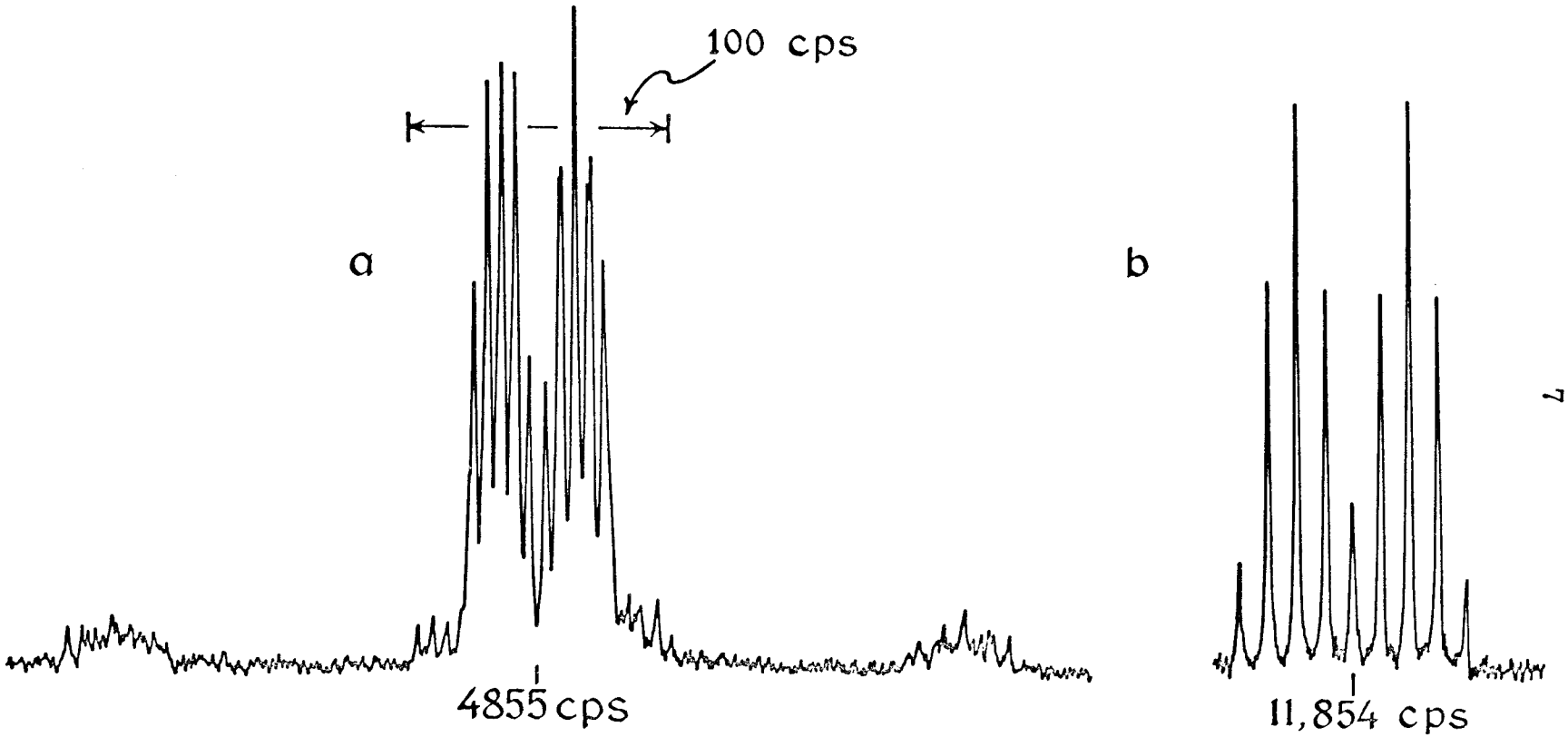
*There seem to be no significant splittings due to the CH_3O-protons.

†Actually, two overlapping quintets.



a. Spectrum of the 1, 1, 3, 3-fluorines

b. Spectrum of the 2-fluorine

Experimental spectrum of I at room temperature

Figure 3

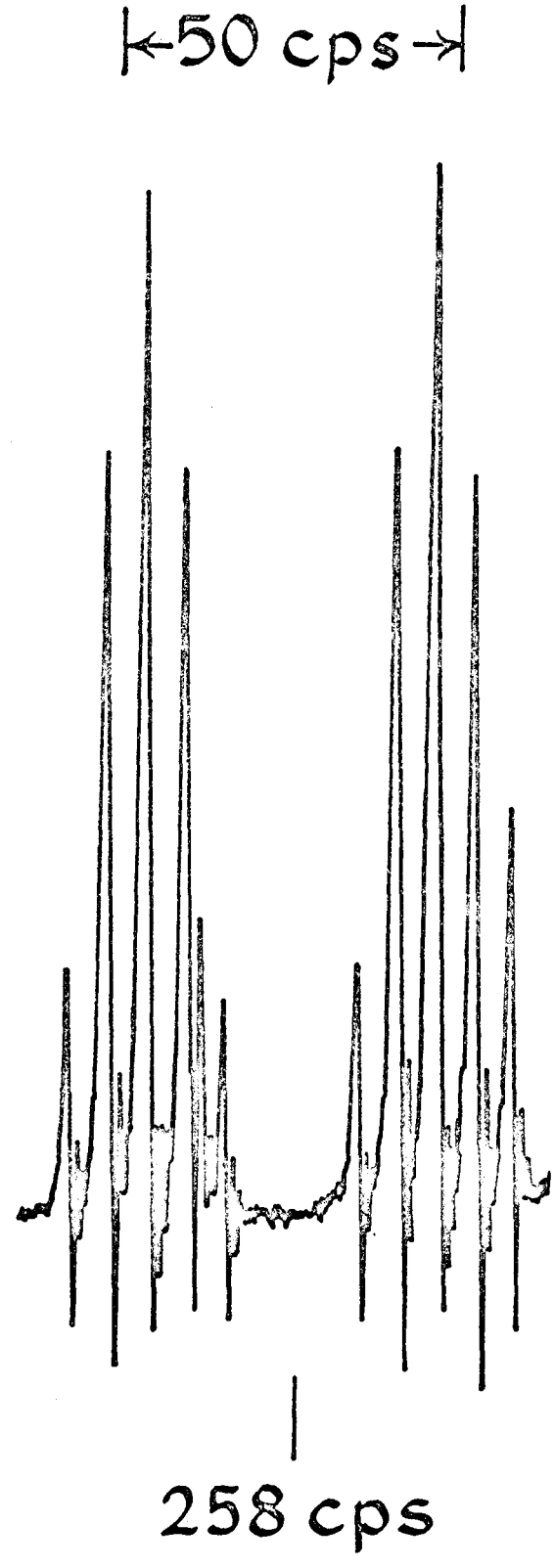


Figure 4. Proton spectrum of I at room temperature

A more detailed analysis of the spectrum was undertaken using what empirical parameters were available from the spectra and the treatment of Hahn and Maxwell (11) to determine an approximate value of the chemical shift between the A and B fluorines, $\nu_A - \nu_B$.* Optimum values for parameters which were not available were determined by a trial-and-error approach. Using the following values for the various parameters (all in c. p. s.), the best fit for the observed spectrum (Figs. 5a and 5b) was obtained:

$$\nu_M = 258.0$$
$$\nu_X = 10000.0^a$$
$$\nu_A = \nu_{A'} = 19993.0^a$$
$$\nu_B = \nu_{B'} = 20099.0^a$$
$$J_{AA} = J_{BB'} = -9.0^b$$
$$J_{AB} = J_{A'B'} = -149.0$$
$$J_{A'B} = J_{AB'} = -10.0$$
$$J_{AX} = J_{A'X} = J_{BX} = J_{B'X} = 11.0$$
$$J_{MA} = J_{MA'} = 6.5$$
$$J_{MB} = J_{MB'} = 6.1 \qquad J_{MX} = -44.0$$

[a]Arbitrarily fixed: the only important quantity is $\nu_A - \nu_B$.

[b]The signs of the couplings are uncertain since changing them makes no discernible difference in the calculated spectrum.

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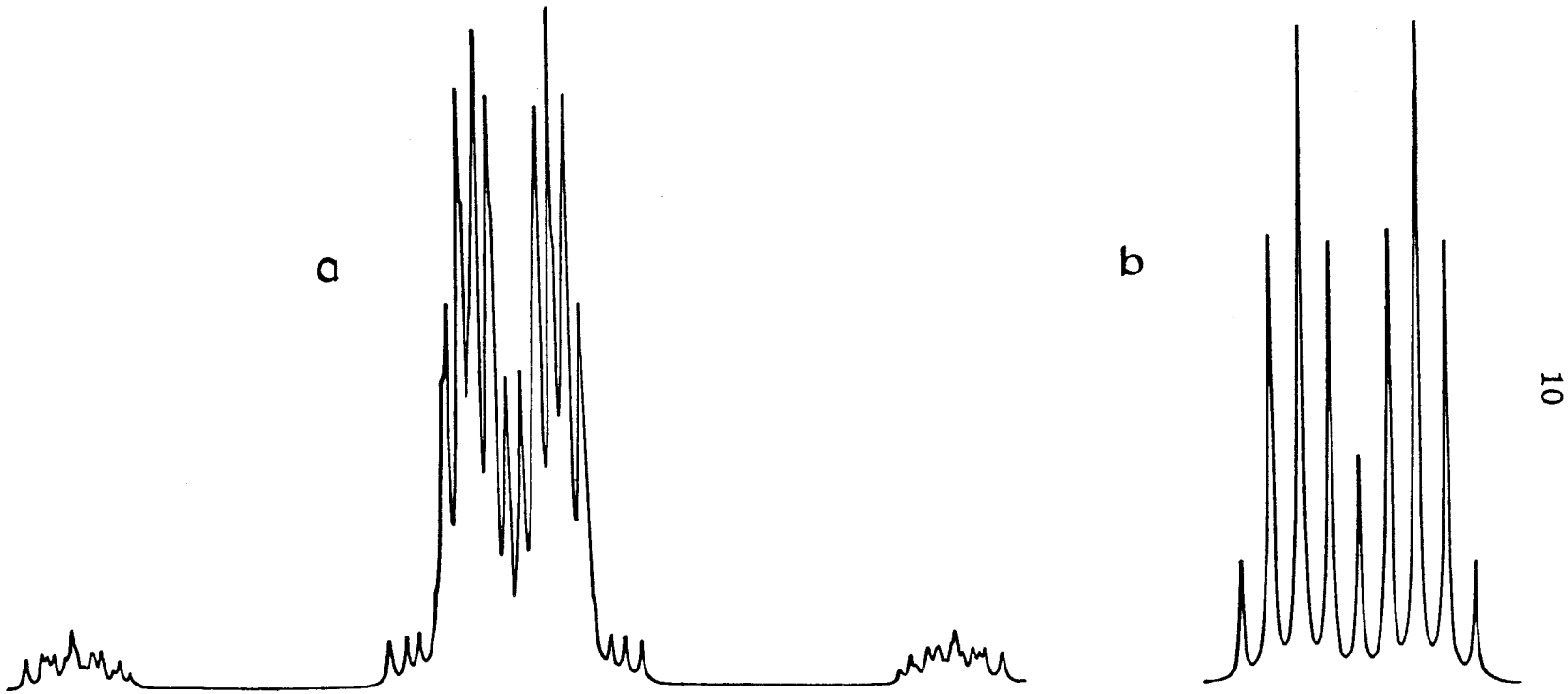
*Hahn and Maxwell have found that when the spin-spin coupling constant is of the same order of magnitude as the chemical shift, the separation between the doublet centers is not δ but $(J^2 + \delta^2)^{1/2}$.



a. Spectrum of the 1, 1, 3, 3-fluorines

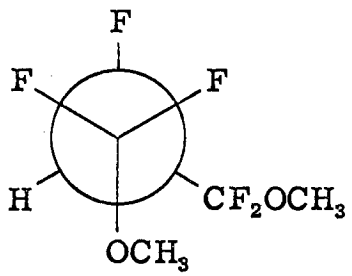
b. Spectrum of the 2-fluorine

Calculated spectrum of I at room temperature

Figure 5

It will be noted that the couplings of the 2-fluorine (X) to the geminal fluorines (A and B) are equal. Also the couplings between the 2-proton (M) and the two geminal fluorines differ by a less than 0.5 c. p. s. With regard to the first point, that $J_{AX} = J_{BX}$, and assuming that the conformations represented in Fig. 1 are the only ones available, there are three possible ways to account for the results.*

The simplest way to have the 2-fluorine equivalently located <u>on the average</u> with respect to the geminal fluorines is to assume that conformation 1a, with the 2-fluorine located between the geminal fluorines and <u>trans</u> to the methoxyl, is the only one present.



1a

However, if we assume that vicinal H–F couplings, like proton-proton couplings (12), are sensitive to the dihedral angle between the bond directions, this is not an attractive choice, since it does not explain the nearly equal values of J_{MA} and J_{MB}.

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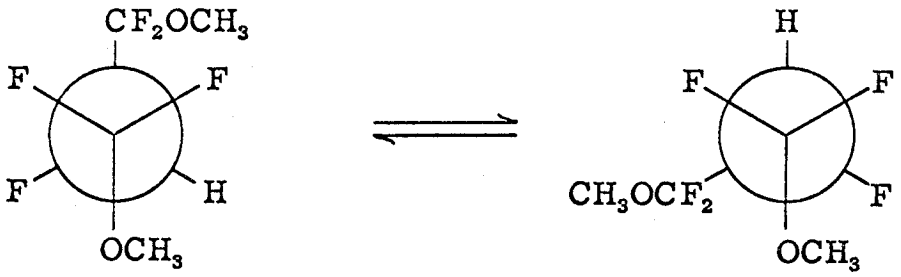
*The reason for assuming that conformational preferences underlie this phenomenon will be discussed later.

A second way (to have $J_{AX} = J_{BX}$) would be to have the conformations 1b and 1c present in approximately equal proportions (and in rapid equilibrium) so that the 2-fluorine is equivalently located on the average with respect to the geminal fluorines.



1b 1c

This would require that these two forms be quite similar energetically and for reasons which will become apparent in the next section, this is not an attractive possibility either.

A third possibility is to have a mixture of all three conformations, with 1b and 1c in roughly equal proportions. Obviously, then, there could be a continuum of compositions with different proportions of 1a which would have $J_{AX} = J_{BX}$. However, we can see that the amount of 1a cannot quite equal the amount of 1b (or 1c) since this would require that $J_{MA} = J_{MB}$.

b. Temperature Dependence of ^{19}F Spectra

Spectra were taken at several different temperatures ranging from -27° to 100°. Unfortunately, the region containing the 2-fluorine lines was not accessible on the spectrometer available. Several spectra taken by England and the proton spectra, however, indicate

that the only portion of the spectrum which is of consequence with respect to temperature changes is the AB-portion. The spectra taken at 100° and -27° are shown in Figs. 6 and 7.

As the temperature increases from room temperature, the chemical shift, $\nu_A - \nu_B$, decreases and the "wings" become less intense, i. e., the geminal fluorines become more nearly equivalent. At the highest temperature employed (Fig. 6), the group of lines at 4855 c. p. s. from fluorotrichloromethane is an almost symmetrical octet and the "wings" are nearly indiscernible.* As the temperature decreases from room temperature, $\nu_A - \nu_B$ increases and the "wings" become more intense, i. e., the geminal fluorines become more non-equivalent. A plot of the chemical shift, $\nu_A - \nu_B$, versus temperature (Fig. 8) is very nearly linear. This is not the kind of variation one would expect if the distribution of conformations among the various possible forms follows the Boltzmann law. However, it may be that the temperature range covered is not sufficiently large to show the expected exponential behavior. This is particularly likely because the chemical shift difference between the A, B fluorines might be as much as 1000 c. p. s. or more for any one of the conformations.

A good fit (Fig. 9) for the spectrum taken at 100° was obtained using the following parameters (all in c. p. s.):

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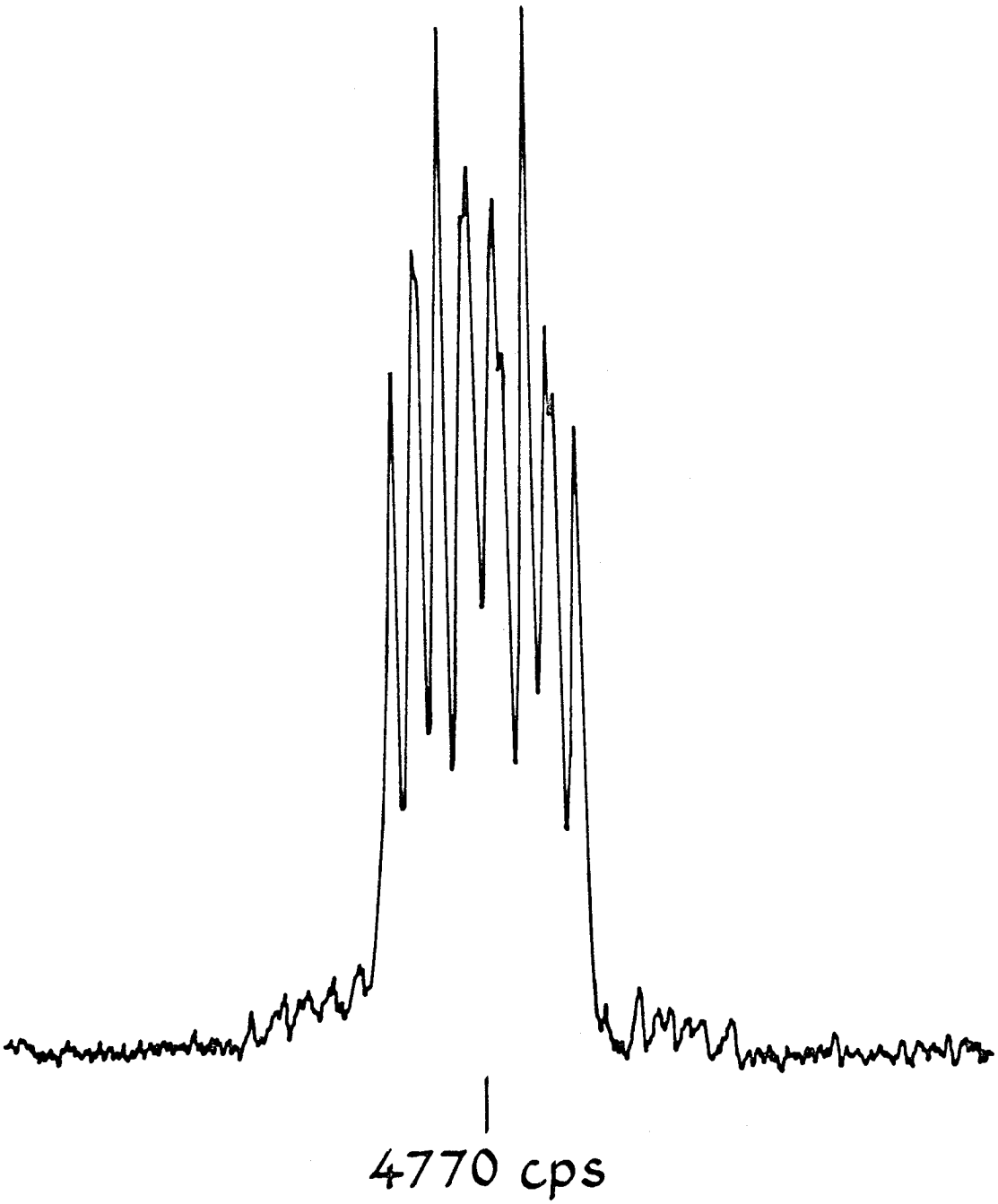
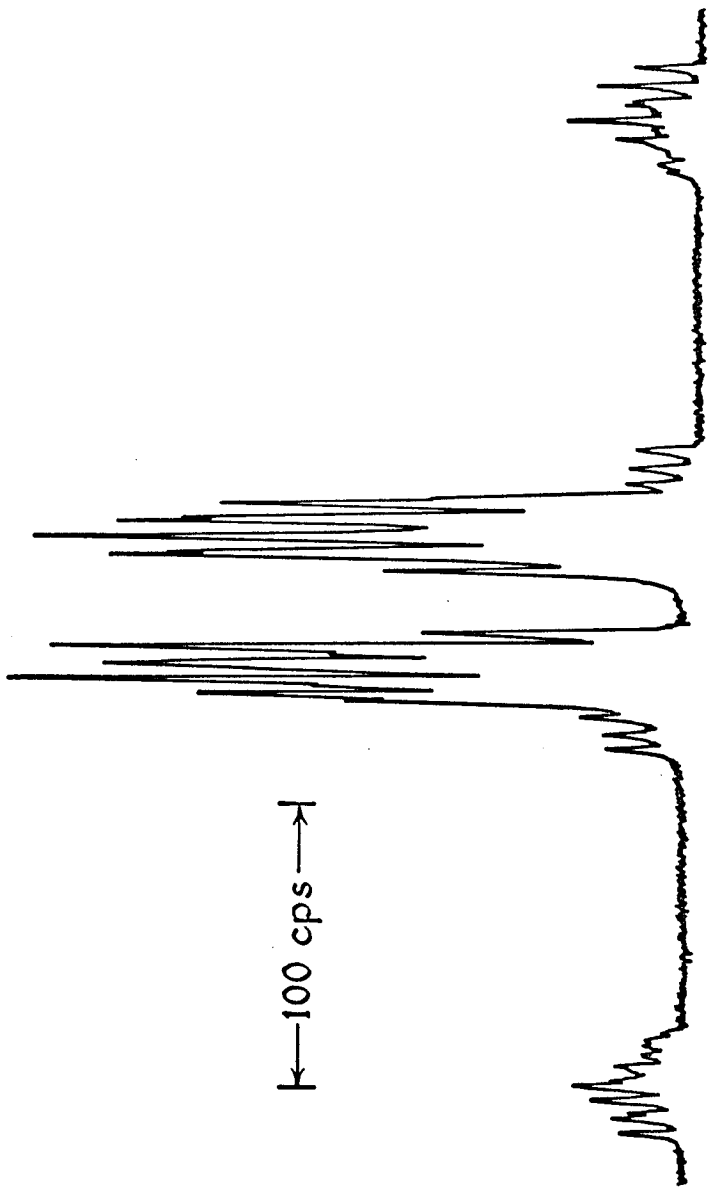
*The "wings" in fact are not shown in Fig. 6.



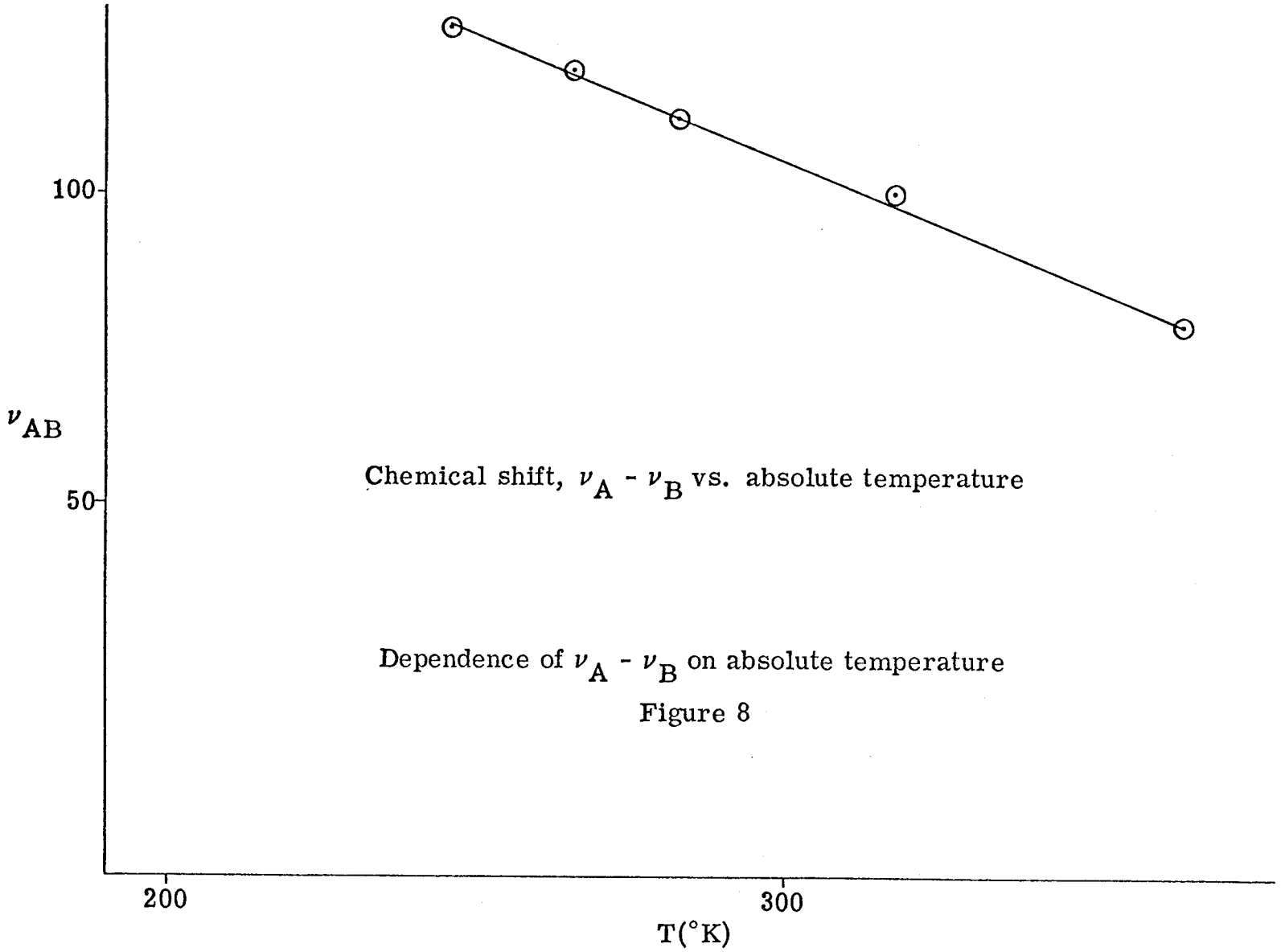
Spectrum of the 1, 1, 3, 3-fluorines at 100°

Figure 6



Spectrum of the 1, 1, 3, 3-fluorines at -27°

Figure 7



Chemical shift, $\nu_A - \nu_B$ vs. absolute temperature

Dependence of $\nu_A - \nu_B$ on absolute temperature

Figure 8

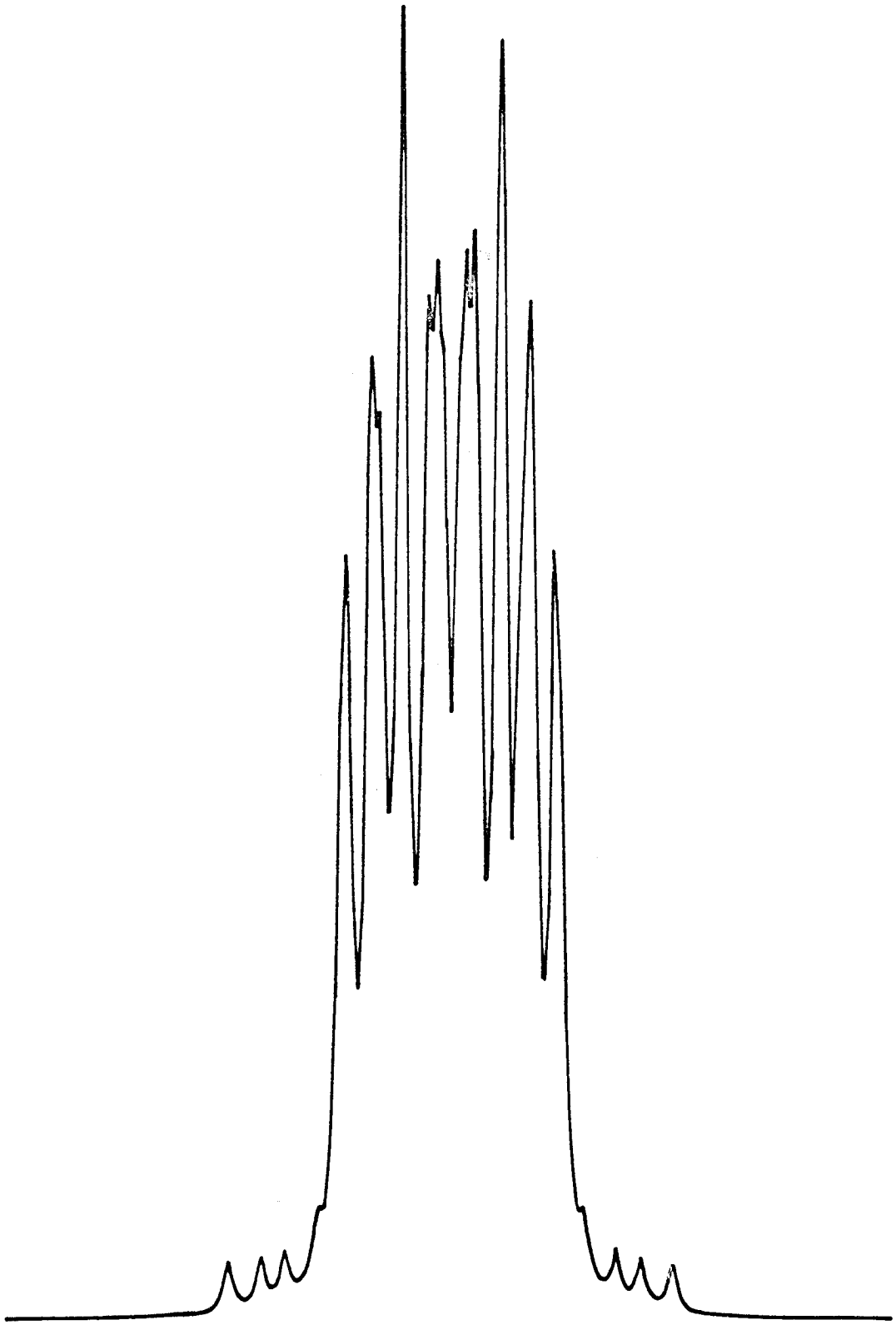


Figure 9. Calculated spectrum of the 1, 1, 3, 3-fluorines of I at 100°

$$\nu_M = 258.0$$
$$\nu_X = 10000.0$$
$$\nu_A = \nu_{A'}$$
$$\nu_B = \nu_{B'}$$
$$J_{AA'} = J_{BB'}$$
$$J_{AB} = J_{A'B'} = -9.0$$
$$J_{A'B} = J_{AB'} = -149.0$$
$$J_{AX} = J_{A'X} = J_{BX} = J_{B'X} = 11.0$$
$$J_{MA} = J_{MA'} = 6.5$$
$$J_{MB} = J_{MB'} = 6.1 \quad J_{MX} = -44.0$$

It will be noted that the coupling constants are relatively insensitive to temperature changes between 30° and 100°. This insensitivity of the coupling constants to temperature changes is a possible reason for rejection of the possibility of a rapid equilibrium existing between 1b and 1c with no 1a present. If this were the case, in order to alter the observed chemical shift, it would be necessary to change the relative amounts of 1b and 1c. Such an alteration, however, is inconsistent with the observation that the coupling constants are essentially temperature invariant, at least over the range 30° to 100°. Unfortunately, a fit for the low-temperature spectrum was not obtained.

Then the only remaining possibility--and the solution to our problem--is to have 1b and 1c present in approximately equal proportions and a smaller amount of 1a whose exact proportion depends on the temperature.

c. Solvent Dependence

Attempts to study the n. m. r. spectrum of I were made difficult by its limited solubility in most organic solvents. The AB-portion of the spectrum was studied in CCl_4, $CHCl_3$, CH_2Cl_2, and MeOH solutions. These solvents have dielectric constants of 2.2, 4.8, 9.1, and 32.6 respectively. The effect of the solvents seemed to be that, with increasing dielectric constant, the magnetic environments of the A and B fluorines become less equivalent; that is to say $\nu_A - \nu_B$ increases. Since it has been postulated (13) that the solvent does indeed affect conformational preferences,* this observation lends strong support to the hypothesis that conformational preferences underlie the peculiarities of the spectrum of the compound studied.

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*The effect observed for proton spectra (13) was that of an inverse relation between $\nu_A - \nu_B$ and dielectric constant. However, there is no reason to expect a parallelism with such different types of studies.

EXPERIMENTAL

The sample of 1, 3-dimethoxy-1, 1, 2, 3, 3-pentafluoropropane was obtained from Dr. D. C. England of the E. I. du Pont de Nemours and Company.

All spectra were obtained by means of a Varian A-56-60 High Resolution n. m. r. spectrometer equipped with a variable temperature probe.

Fluorine magnetic resonance spectra were obtained at 56. 4 Mc. p. s. and were calibrated in terms of displacements in cycles per second from the fluorine resonance of an external sample of fluorotrichloromethane.

Proton spectra were obtained at 60. 0 Mc. p. s. and were calibrated in terms of displacements from the proton resonance of an external sample of tetramethylsilane.

Solutions were approximately 10% by volume.

Theoretical spectra were computed with the aid of the "magnetic equivalence factoring" program developed by Swalen and Reilly (14) and modified by Stanley, Marquardt, and Ferguson (15, 16) and 7090/94 computer whose output was fed to a plotter.

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