Table I. Acidity of Phenylacetylene

Run	Indicator[a] RH	Indicator pK[b]	Concn at equil, 10^3 M R⁻	RH	PhA⁻	PhA	Total change in R⁻, 10^6 mol[c]	pK PhA
23A	4,5-MP	22.60	0.345	16.8	0.698	175	21	23.31
29A			0.256	0.787	1.36	131	50	23.10
27	9-MF	22.70[d]	2.34	39.3	3.89	172	63	23.23
28A			1.92	25.4	5.28	222	88	23.20
28B			2.53	20.4	4.65	112	76	23.18
29C	1,2-BF	19.97	0.864	0.505	0.281	313	11	23.25
30H			0.928	0.626	0.265	329	10	23.24
30B	2,3-BF	23.16	2.58	20.8	6.26	44.2	116	23.10
31			1.35	15.1	3.80	40.1	81	23.19
							Av	23.20 ± 0.05

[a] 4,5-MP = 4,5-methylenephenanthrene; 9-MF = 9-methylfluorene; 1,2-BF = 1,2-benzfluorene; 2,3-BF = 2,3-benzfluorene. [b] Reference 3. These values are approximately based on the aqueous solution as standard state. As such, ΔpK's are far more accurate than the absolute pK values. [c] Decrease in the total quantity of indicator anion on addition of the PhA. [d] Reference 5.

ether[1] and for acetylene in ammonia.[2] We report here the equilibrium acidities of phenylacetylene (PhA) and *tert*-butylacetylene (BuA) toward lithium cyclohexylamide (LiCHA) in cyclohexylamine (CHA). In previous work we reported[3] relative acidities of hydrocarbons toward LiCHA by spectrometric measurements of the equilibria

$$R^-Li^+ + R'H \rightleftharpoons RH + R'^-Li^+ \qquad (1)$$

The lithium salts of acetylenes have no visible spectrum but equilibrium constants for the equilibria 1 could be obtained from the reduction in absorbance of a suitable hydrocarbon indicator when a known amount of the acetylene was added. Control experiments established the amount of indicator lost from the simultaneous admission of adventitious moisture. The results in Table I for PhA with four different hydrocarbon indicators demonstrate the self-consistency and reproducibility of this technique. Because of its lower acidity, BuA was measured against only a single indicator but reproducible results were obtained for a range of concentrations (Table II).

Table II. Acidity of *tert*-Butylacetylene

Run	Concn at equil, 10^3 M R⁻[a]	RH[a]	BuA⁻	BuA	K
40A	2.88	14.4	3.94	91.8	4.66
51	10.1	12.6	8.62	50.9	4.75
58	5.33	36.0	5.43	180	5.21
105	8.72	11.3	12.3	85.7	5.40
				Av	5.01 ± 0.30
				pK	25.48 ± 0.03

[a] Indicator is 9-*tert*-butylfluorene, pK = 24.79 (ref 5). See also Table I, footnote *b*.

For convenience, the equilibrium constants for the equilibria (1) have been converted to "pK" values, PhA, 23.20 ± 0.05, BuA, 25.48 ± 0.03, relative to the value, 18.49, for 9-phenylfluorene. The latter value is approximately that for the aqueous standard state[4] based on the usual H_- assumptions. The lithium salts of localized acetylenic carbanions are not expected to have the same activity coefficient behavior as those of delocalized fluorenyl anions so that the acetylenic pK's may differ substantially from a water basis; nevertheless, toward LiCHA in CHA, the assigned values may be compared with other structures having comparable acidity: fluorene, 22.6,[4] and 9-*tert*-butylfluorene, 24.8.[5]

McEwen[1] estimated the acidity of PhA to be about that of 9-phenylfluorene with respect to the sodium salts in ether, whereas we find a difference of almost 10^5 in acidity with respect to the lithium salts in CHA. In both cases ion-pair equilibria are involved and it appears that the difference can best be accounted for in terms of increased cation solvation in CHA compared to ether. By simple electrostatic attraction, the more concentrated charge of the essentially localized acetylenic carbanion provides more effective solvation of the metal cation in an ion pair than does a delocalized fluorenyl anion; hence, the acetylenic ion pair is less sensitive to the cation-solvating power of the solvent. Consequently, the 9-phenylfluorenyllithium ion pair is stabilized more by the better cation-solvating solvent than is the phenylacetylenyllithium ion pair. This difference emphasizes the impossibility of setting up a universal acidity scale for hydrocarbons of different types.

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(5) D. M. E. Reuben, results to be published.

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Molecular Conformation of Orotidine, a Naturally Occurring Nucleoside, in the Syn Conformation in Aqueous Solution

Sir:

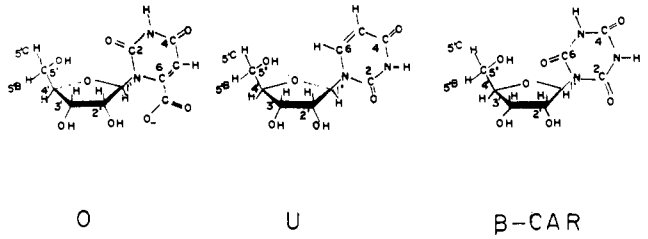
We report here a complete analysis of the 100-MHz spectrum of orotidine (6-carboxyuridine, O) and a comparison of the data with those of uridine (U) and β-cyanuric acid riboside (β-CAR), Figure 1. O

Table I. Proton Chemical Shifts and Coupling Constants of Orotidine, Uridine, and β-Cyanuric Acid Riboside

	Chemical shifts, ppm[a]				Coupling constants, Hz		
	O	U	β-CAR		O	U	β-CAR
H_6		7.862		J_{56}		8.0	
H_5	5.751	5.887		$J_{1'2'}$	3.6	4.4	3.9
$H_{1'}$	5.558	5.901	6.102	$J_{2'3'}$	6.3	5.3	6.4
$H_{2'}$	4.735	4.341	4.580	$J_{3'4'}$	7.0	5.5	6.6
$H_{3'}$	4.325	4.222	4.365	$J_{4'5'B}$	3.0	3.0	3.2
$H_{4'}$	3.935	4.128	3.965	$J_{4'5'C}$	6.1	4.4	6.2
$H_{5'B}$[b]	3.853	3.907	3.848	$J_{5'B5'C}$	−12.2	−12.7	−12.8
$H_{5'C}$[b]	3.742	3.803	3.714				

[a] The chemical shifts relative to internal DSS and coupling constants are estimated to be accurate to within 0.003 ppm and 0.1 Hz, respectively. Temperature of solution: O, 50°; U, 28°; β-CAR, 50°. [b] In the spectral analysis the 4′ and 5′ hydrogens are treated as an ABC system, hence the subscripts B and C. An absolute assignment of the methylene protons cannot be made from the data; the arguments presented here are, however, not dependent on an absolute assignment of the 5′ hydrogens.

is an essential unit for the biosynthesis of pyrimidine nucleosides; its 5′-phosphate is converted directly to uridylic acid by the enzyme orotidine 5′-phosphate



O U β-CAR

Figure 1. Structural formulas of orotidine (O), uridine, and β-cyanuric acid riboside (β-CAR). The bases are drawn in their lactam forms and the carboxyl is shown as its predominant anionic form at neutral pH (see ref 13).

decarboxylase. There is now little doubt that U and its 5′-monophosphates exist predominantly in their anti[1] conformations; the evidence presented here indicates that the syn conformation is the energetically favored form of O. To date few structural studies of this molecule have appeared in the literature.

The proton chemical shifts and spin–spin coupling constants are presented in Table I. The data for U were obtained at 220 MHz and have been discussed in greater detail elsewhere.[2]

The data for O[3] and for β-CAR (obtained by Dugas, *et al.*[4]) were measured at 100 MHz. The spectral assignments were made through double irradiation of the various multiplets and checked by computer simulation of the observed spectra. The nucleoside concentration in each case was about 0.12 *M* in D_2O. The solutions were lyophilized to reduce the HDO concentration and the pD was adjusted to about 7.0.

There is now overwhelming evidence from numerous spectroscopic studies that common pyrimidine nucleosides and their monophosphates exist predominantly in their anti rather than syn conformations about the *N*-glycosyl bond.[2,4–8] In the former conformation, according to the nomenclature of Donohue and Trueblood,[1] the C_6 position of the pyrimidine base lies above the ribose ring; in the latter the C_2 position is found above the sugar moiety. That the syn rotamer is not present to any detectable extent in aqueous solution is generally agreed to be a consequence of special steric interactions not present when the molecules are anti. In the syn form multiple unfavorable close contacts are made between the 2-keto group and the ribose $C_{2'}$ and $C_{3'}$ carbons and their endo[9] hydrogens $H_{2'}$ and $H_{3'}$ and the $O_{1'}$ oxygen. β-CAR, however, poses a special problem—a keto group is found at both positions on the base ortho to the glycosyl bond and, as a consequence, one such group must be situated above the furanose ring in close proximity with its endo substituents. The expected close-contact interactions and their effect on the ribose ring conformation are manifest in the observed chemical shift and coupling constant differences of U and β-CAR; a more complete consideration of these differences has been given by Dugas, *et al.*[4] For instance, $H_{2'}$ and $H_{3'}$ are shifted downfield in β-CAR by 0.339 and 0.139 ppm, whereas $H_{4'}$, $H_{5'B}$, and $H_{5'C}$ are shifted upfield by 0.163, 0.059, and 0.089 ppm, respectively. Changes as large as 2 Hz are noted in the coupling constant data. These differences may be related *via* the Karplus[10] equation to distortions of the dihedral angles in the relevant H–C–C′–H′ fragments and indicate significant alterations in the puckering of the ribose ring.[4]

Comparison of the data for O and β-CAR reveals some interesting trends consistent with the existence of the former as a syn rotamer in which the 2-keto is located above the sugar. First, for this pair of molecules all corresponding *J*'s are identical to within 0.6 Hz, with an average deviation of only 0.3 Hz. We may safely argue then that the three-dimensional geometries of their ribose moieties are similar, a surprising result if the more bulky carboxyl group were to lie above the ring. Secondly, we note a striking similarity in their $H_{3'}$, $H_{4'}$, and $H_{5'}$ chemical shifts. This observation as well argues against the anti conformation in which these hydrogens (in particular $H_{3'}$) are expected to sense the electric fields associated with the carboxylate. In the syn conformation only $H_{1'}$ and $H_{2'}$ are in the vicinity of the negatively charged 6 substituent and the data

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(9) Endo means that the atom is located on the same side of the plane defined by $C_{1'}$, $O_{1'}$ and $C_{4'}$, as the $C_{4'}$–$C_{5'}$ bond.
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reveal these to be strongly affected by its presence. Relative to the corresponding shifts in β-CAR a *shielding* of 0.547 ppm is observed for $H_{1'}$, whereas a *deshielding* of 0.154 ppm is observed for $H_{2'}$.

The relative magnitudes of the carboxylate contribution to the overall $H_{1'}$ and $H_{2'}$ magnetic shielding constants are reasonable in view of the larger distance of the latter hydrogen from the 6 position in the syn conformation. The fact that the contributions are of opposite sign may be surprising at first sight but is readily rationalized if the predominant shielding mechanism is assumed to result from the electric field associated with the 6 substituent.[11] Examination of space-filling molecular models indicates that the rotation of the carboxyl moiety is severely restricted owing to steric interactions with the $H_{1'}$ hydrogen. The most favored orientation, which minimizes these effects, appears to be that in which the plane of the carboxyl is essentially perpendicular to the uracil moiety. Assuming this relative orientation of base and carboxyl and an overall syn conformation for the molecule, simple Buckingham electric field calculations[12] predict a diamagnetic contribution for $H_{1'}$ and a somewhat attenuated paramagnetic contribution to $H_{2'}$. Moreover, the opposite result is predicted if an anti model is chosen.

The orotidine moiety is implicated in the sequence of enzymic reactions which convert orotic acid (6-carboxyuracil) to orotidylic acid[13] and finally in a decarboxylative step to uridylic acid. Little information is available concerning the active site conformation, mode of binding of substrate, and mechanism of the conversion. Binding of the negatively charged carboxyl group to the active site has been proposed.[13] The present results giving details of relevant molecular conformations may be of importance toward a better understanding of the problem. It is interesting to note that the substrate of the decarboxylative step (orotidylic acid) may safely be predicted to exist in its syn conformation, whereas the product (uridylic acid) is anti.[14] More data are now being collected.[14a]

(11) That the shielding arises largely from a "through-space" mechanism rather than from inductive effects through the σ-bond network is a very reasonable assumption in view of the considerably smaller carboxylate effect on the H_5 resonances. (Compare data for U and O.) More detailed calculations of course would include inductive and magnetic anisotropic effects but would lead to qualitatively identical predictions.

(12) A. D. Buckingham, *Can. J. Chem.*, **38**, 300 (1960).

(13) J. Imsande and P. Handler in "The Enzymes," Vol. 5, P. D. Boyer, H. Lardy, and K. Myrback, Ed., Academic Press, New York, N. Y., 1961, p 302.

(14) We do not expect 5′-phosphorylation to result in rotation of O into its anti range of sugar-base torsion angles, in view of our knowledge of other pairs of pyrimidine nucleosides and nucleotides.

(14a) NOTE ADDED IN PROOF. After submission of this manuscript, Schweizer, *et al.* (M. P. Schweizer, J. T. Witkowski, and R. K. Robins, *J. Amer. Chem. Soc.*, **93**, 277 (1971)), reported their observations of the 2-keto anisotropic effects upon the ribose chemical shifts of a number of pyrimidine nucleosides. The authors demonstrated that a qualitative determination of their syn *vs.* anti conformation could be based on these specific shielding and deshielding phenomena alone.

(15) I am grateful to Drs. H. Dugas, B. J. Blackburn, R. K. Robins, and I. C. P. Smith for communicating their views and data on β-CAR prior to publication and to a National Research Council of Canada grant which made this work possible. Kindly address correspondence to the University of Manitoba.

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A Novel Rearrangement in a Class of Stereochemically Nonrigid Five-Coordinate Complexes

Sir:

Stereochemical nonrigidity has been presumed for many five-coordinate transition metal complexes;[1-3] however, the phenomenon was not rigorously established for a member of this group until the studies of Udovich and Clark.[4,5] In these and all other investigations of five-coordinate complexes, only a Berry[6] type of rearrangement has been seriously considered.[1-3,7-13] We report here the first observation of limiting, slow exchange nmr spectra for a class of transition metal hydrides of the type HML_4. We propose for these nonrigid hydrides a rearrangement mechanism which comprises a hydrogen atom traverse of faces in the ML_4 tetrahedral substructure.

The ^{19}F (84.66 MHz) and ^1H (90 MHz) nmr spectra of $HOs(PF_3)_4^-$ [14,15] and $HRh(PF_3)_4$[15] at three temperatures are shown in Figures 1 and 2. Similar spectra were obtained for $HRu(PF_3)_4^-$, $HCo(PF_3)_4$, and $HIr(PF_3)_4$[15] in the same temperature range. Chlorodifluoromethane was the solvent for the low-temperature studies.

The proton and fluorine nmr spectra establish the spectroscopic equivalence of the phosphorus and fluorine nuclei at 25°. The proton spectra consist of a group of 13 sets of quintets (of proper binomial distribution), with an additional doublet splitting due to Rh–H coupling for the rhodium complex. Values for J_{PH}, J_{FH}, and J_{RhH} can be obtained from the spectra and are given in Table I. The ^{19}F spectra are complex, and, in the absence of a complete analysis, the only additional information contained in the high-temperature limit spectrum is an approximate value for the J_{PF} coupling constant (about 1250 Hz in all cases). The proton spectrum of $HCo(PF_3)_4$ is broad at room temperature due to quadrupole relaxation of the ^{59}Co nucleus. On cooling to −60° (chlorodifluoromethane solution) the spectrum begins to sharpen and the structure can be observed down to −110°. On further

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(12) W. Mahler and E. L. Muetterties (*Inorg. Chem.*, **4**, 1520 (1965)) have proposed a primarily fluorine atom motion for the rearrangements in Cl_2PF_3 and Br_2PF_3. However, there is no experimental justification for this alternative proposal.

(13) The turnstile mechanism recently proposed by L. Ugi, *et al.* [*Angew. Chem., Int. Ed. Engl.*, **9**, 703 (1970)] is permutationally indistinguishable from the Berry rearrangement, and there is as yet no rationale that would justify serious consideration of this essentially equivalent mechanism.

(14) T. Kruck (*Z. Anorg. Allgem. Chem.*, **371**, 1 (1969)) reported the spectrum of $HOs(PF_3)_4^-$ to consist of two quartets. This reported spectrum is due to a complex other than $HOs(PF_3)_4^-$, produced in the neutralization reaction described by Kruck.

(15) T. Kruck (*Angew. Chem., Int. Ed. Engl.*, **6**, 53 (1967)) has described the preparation and general properties of trifluorophosphine complexes of transition metals.