and 50 ml. of anhydrous methanol was added a solution of 3 g. of sodium in 50 ml. of anhydrous methanol. Upon shaking, the pentose dissolved at once and within a few minutes the precipitation of the sodium *aci*-2-deoxy-2-nitroheptitols began. After 5 hours of shaking, the mixture was cooled to −20° and filtered. Following washing with cold methanol, ether and low-boiling petroleum ether, the sodium salts were dissolved in 90 ml. of cold water and the solution was added rapidly, dropwise, to a stirred solution containing 8 ml. of sulfuric acid in 10 ml. of water at 0°. During the addition of the first 60 ml. of the sodium salt solution, an additional 10 ml. of sulfuric acid also was added dropwise to the reaction mixture. Fifteen minutes after all reagents had been added, the solution was deionized,[5] decolorized and concentrated to a sirup. Seeding of this sirup with D-*gluco*-heptulose[6] yielded 4.6 g. of crystals (m.p. 140–145°, $[\alpha]^{20}D$ −32° in water, *c* 2) which contained an appreciable amount of D-arabinose. Accordingly, the total product was redissolved in 300 ml. of water and treated with 4 ml. of bromine in the presence of 20 g. of barium carbonate. After 18 hours at room temperature, excess bromine was removed by aeration and the mixture was filtered and deionized. The effluent was titrated to a stable phenolphthalein end-point with 0.2 *N* sodium hydroxide and again deionized. The titration and deionization were repeated on the effluent and the latter was then concentrated to a sirup. Seeding with D-*gluco*-heptulose yielded 1.6 g. (11.4%) of this heptulose[7] in nearly pure condition, m.p. 168–169°, $[\alpha]^{20}D$ +64.4° in water, *c* 4. Seeding of the residual sirup with D-*manno*-heptulose then yielded 0.66 g. (4.7%) of the latter heptulose,[8] m.p. 151–152°, $[\alpha]^{20}D$ +29.5° in water, *c* 4. Further seeding of the residue gave 0.75 g. (5.3%) of the mixed heptuloses, m.p. 145–148°, $[\alpha]^{20}D$ +44°.

2,7-Anhydro-β-D-*ido*-heptulopyranose.—Five grams of D-xylose was condensed with 2-nitroethanol, and the resulting sodium *aci*-nitroalcohols were hydrolyzed, under the same conditions as those described above for D-arabinose. No attempt was made to remove pentose, but rather the deionized, sirupy product was heated in 50 ml. of 0.2 *N* hydrochloric acid at 100° for 2 hours. Barium hydroxide octahydrate (8 g.) then was added and the heating was continued for 45 minutes to destroy reducing sugars. The sirup obtained following deionization and concentration was seeded with 2,7-anhydro-β-D-*ido*-heptulopyranose to yield 1.21 g. (18.9%) of the anhydroheptulose,[9] m.p. 168–169°, $[\alpha]^{20}D$ −40.3° in water, *c* 2.

2,7-Anhydro-β-D-*altro*-heptulopyranose (Sedoheptulosan).—Five grams of D-ribose was condensed with 2-nitroethanol as described above, except that the reaction mixture was allowed to stand at −20° for 27 hours to increase the precipitation of the sodium salts. The latter were processed further as described in the experiment with D-xylose. Crystallization of the final sirup from absolute methanol yielded 0.31 g. (4.8%) of sedoheptulosan,[10] m.p. 154–156°, $[\alpha]^{20}D$ −140° in water, *c* 3. Benzoylation of the residual sirup provided 0.18 g. (0.9%) of the corresponding tetrabenzoate,[11] m.p. 161–162°.

D-*galacto*-Heptulose and D-*talo*-Heptulose.—Five grams of D-lyxose was condensed with 2-nitroethanol, the resulting sodium *aci*-nitroalcohols were hydrolyzed, and unchanged pentose was removed by bromine oxidation as described above for D-arabinose. The resulting sirup (4.2 g.) did not crystallize when seeded with D-*galacto*-heptulose. Accordingly, it was chromatographed on a column of powdered cellulose (Whatman standard grade, 3.5 × 32 cm.) using the top layer of 1-butanol (50 v.)-ethanol (15 v.)-water (40 v.) as the developing solvent. Twenty fractions of 50 ml. each were collected, and all gave a positive test for ketose with orcinol–trichloroacetic acid reagent. Concentration of the individual fractions to sirups and seeding with D-*galacto*-heptulose produced crystals in fractions 4–6 and 9–15. A total of 0.54 g. (7.7%) of this heptulose[12] (m.p. 105–107°, $[\alpha]^{20}D$ +81° equil. in water, *c* 2) was obtained. The residual sirups were combined and seeded with D-*talo*-heptulose to yield 0.12 g. (1.7%) of the latter heptulose,[13] m.p. 138–139°, $[\alpha]^{20}D$ +15.8° equil. in water, *c* 1.

(5) The ion exchange resins used in this work were Amberlite IR-100, a product of Rohm and Haas Co., Philadelphia, Pa., and Duolite A-4, a product of Chemical Process Co., Redwood City, Calif.

(6) The authors are indebted to Dr. Nelson K. Richtmyer, N. I. A. M. D., National Institutes of Health, for seeding crystals of the heptuloses and anhydroheptuloses described in this paper.

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[CONTRIBUTION FROM THE SCHOOL OF PHARMACY OF THE UNIVERSITY OF CALIFORNIA, SAN FRANCISCO, VARIAN ASSOCIATES, AND THE UNIVERSITY OF PENNSYLVANIA]

Steric Effects on the Nuclear Magnetic Resonance Spectra of Some Cyclohexanone, Indanone and Camphor Compounds

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Cyclohexanone has two peaks whose areas are in the ratio of 4:6 suggesting that the hydrogens adjacent to the carbony are different from the others. There is no evidence of a difference between equatorial and axial hydrogens which would result in a 5:5 ratio. 2-Chlorocyclohexanone has multiplets in the ratio 1:2:6 as would be expected. 1-Chloro-2-indanone has three sharp peaks in the ratio 1:2:4, while the spectrum of 1-bromo-2-indanone is very similar except the peak arising from the two hydrogens on the number 3 atom is lower and broader possibly due to an indirect steric effect of the larger bromine or to the magnetic anistropy of the bromine. α-Chlorocamphor has a doublet with 5 c.p.s. spacing while α′-chlorocamphor has a singlet shifted about 20 c.p.s. Thus both the magnitude of the chemical shift and whether the spin–spin coupling takes place in this case appears to depend on the configuration. Bromine in these ring compounds causes a greater chemical shift to lower field strengths than does chlorine, contrary to the behavior in aliphatic compounds. In α,α′-dibromocamphor, peaks due to three different methyl hydrogens are present while only two are present in the α-bromocamphor indicating that the close approach of the α′-bromine is affecting one of the *gem*-dimethyl groups making it different from the other *gem*-dimethyl group.

High resolution NMR spectra of cyclohexanone, 2-chlorocyclohexanone, 1-chloro-2-indanone, 1-bromo-2-indanone, D-α-chlorocamphor, D-α′-chlorocamphor, D-α-bromocamphor and D-α,α′-dibromocamphor were obtained at 40 mc. in a magnetic field of approximately 9400 gauss with the aim of correlating shifts in the spectra with expected steric effects. The compounds were all studied in dilute solution in carbon tetrachloride, the zero of reference being taken as pure benzene in an external annular

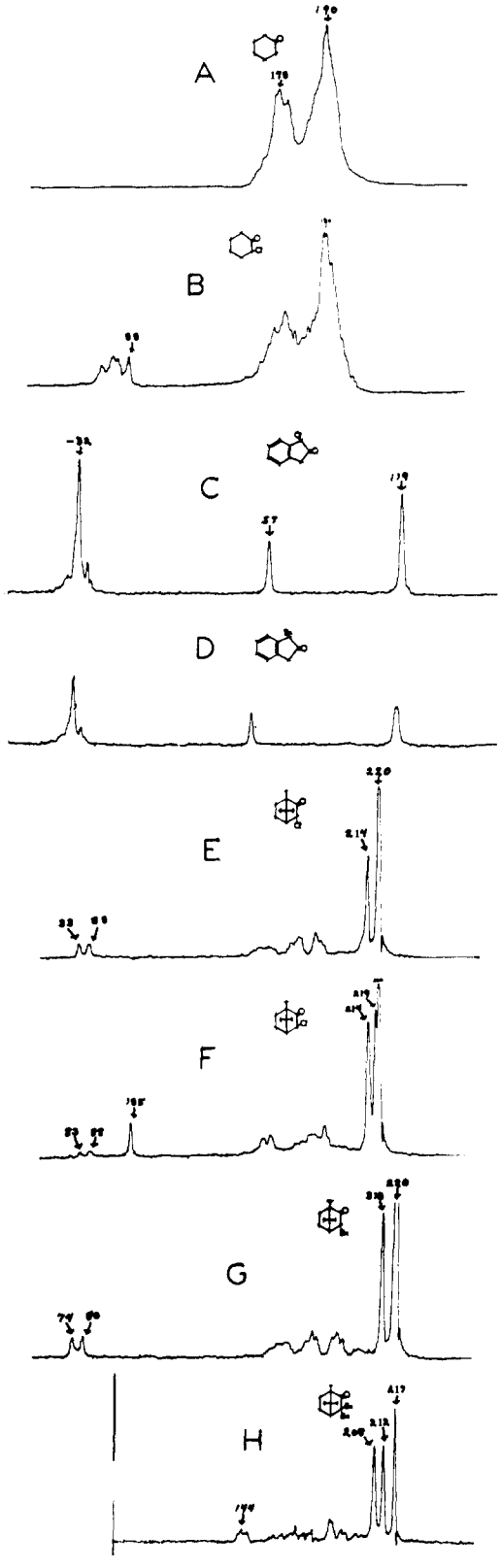

Fig. 1.

cell, and the shifts of certain of the peaks determined by the audio-frequency side band method[1] in cycles per second (c.p.s.). The sign of the shift is chosen to be positive when the resonance falls at a higher applied field than the reference. The shift of any peak in the generally accepted dimensionless units (in parts per million of the applied field) can be determined by dividing the frequency obtained by linear interpolation between measured peaks by 40. This corresponds to the definition $\delta = 10^6 \times (H - H_{ref})/H_{ref}$.

The spectrometer employed for these measurements was a Varian Associates V-4300-B high resolution NMR spectrometer with associated 12″ electromagnet system equipped with a VK-3506 flux stabilizer. Samples were placed in 5-mm. glass tubes and rotated at several hundred r.p.m. by a small air turbine during the recording of the spectra. A special precision annular cell (Wilmad Glass Co., Landisville, N.J.) was employed for the shift measurements. Audio-frequency side bands were generated with a Hewlett-Packard 200-CD audio oscillator and measured with a Hewlett-Packard 521C electronic counter.

The high resolution NMR spectrum of cyclohexane contains one peak and therefore does not give evidence of any difference between the equatorial and axial hydrogens. This is almost certainly due, however, to rapid interconversion between equatorial and axial hydrogens. Cyclohexanone (Fig. 1A) has two resonance peaks with areas representing approximately 40 and 60% of the total, suggesting that the four hydrogens adjacent to the carbonyl give rise to the smaller peak and the other six hydrogens to the larger peak. If the shift were due to the difference in axial and equatorial protons, the areas would be equal. Both peaks give evidence of a small amount of fine structure, presumably arising from spin–spin coupling.

The spectrum of 2-chlorocyclohexanone (Fig. 1B) is characterized by three multiplets with areas in the approximate ratio of 1:2:6. The one farthest to the left has $^1/_9$ the total area and arises from the hydrogen on the carbon to which the chlorine is attached. Spin–spin coupling resulting from this hydrogen interacting with the two hydrogens on an adjacent carbon atom gives rise to a multiplet which is strongly suggestive of a doublet of doublets as would be expected if the two hydrogens were non-equivalent. The next multiplet to the right, which has an area approximately $^2/_9$ of the total, is attributed to the two hydrogens on the number 6 carbon adjacent to the carbonyl. The main peak corresponding to $^6/_9$ of the area also has some fine structure due to spin–spin coupling. The shoulder (at 170–178 cycles) to the left of this peak is doubtless associated with the two hydrogens on the number 3 carbon. These being next to the chlorine would be subject to a slightly greater chemical shift toward lower applied magnetic field than would the remaining four hydrogens.

The spectrum of 1-chloro-2-indanone (Fig. 1C) has three narrow peaks whose areas are in the ratio of 1:2:4 and arise from the one hydrogen on the number 1 carbon, the two hydrogens on the number 3 carbon and the four on the benzene ring. There is no hydrogen on the carbons adjacent to the one to which the chlorine is attached to give rise to

(1) J. T. Arnold and M. E. Packard, *J. Chem. Phys.*, **19**, 1608 (1951).

spin–spin coupling with the hydrogen on the number 1 carbon. The same situation obtains for the hydrogens on the number 3 carbon so it also has just one sharp resonance peak. The other peak arising from the four hydrogens on the benzene ring has a small amount of fine structure near its base which probably arises from spin–spin coupling between these hydrogens themselves. Although these four hydrogens are not identical, they are not sufficiently different to give rise to more than a small amount of fine structure arising from spin–spin coupling.

The spectrum of 1-bromo-2-indanone (Fig. 1D) is similar to that of the chloro compound. The distances between the peaks for the hydrogens on carbon 3 and the benzene hydrogens are identical for both compounds. The peak for the hydrogen on the carbon to which the bromine is attached is shifted about 6 cycles farther toward lower applied magnetic field, that is to the left, which is contrary to the direction of the shift observed in going from aliphatic chlorides to bromides.[2] The peak for the hydrogens on the number 3 carbon is much broader and lower in the bromine compound suggesting it may now be an unresolved doublet. This suggests that the larger bromine in some way causes the two hydrogens on the number 3 carbon to no longer be identical, and this may be due to a steric effect. If so, the distances are too great for the bromine to come directly into contact with one of the hydrogens on the number 3 carbon so the effect is probably indirect. Repulsion between the C–Br and C=O dipoles and interaction between the bromine and the π-orbitals of the benzene ring may be involved.

Another possible explanation for this behavior is local magnetic anisotropy in bonds[3] such as –C–Br which may result in shifts in resonances for remote protons and thus contribute to the observed effect.

Of great interest is the fact that D-α-chlorocamphor (Fig. 1E) has a well resolved doublet to the left of the graph at 83 and 88 cycles while D-α'-chlorocamphor (Fig. 1F) has a singlet at 105 cycles. These peaks arise from the hydrogen on the carbon to which the chlorine is attached and in the case of the α-compound where the chlorine is presumably *endo* the peak is converted into a doublet by spin–spin coupling with the hydrogen on the number 4 carbon while in case of the α'-compound the peak is a singlet with no evidence of any coupling. Furthermore, the amount of the chemical shift differs by 17 cycles depending on whether the chlorine is α or α'. This shift was checked in cyclohexane and found to be unchanged; it therefore is probably not a solvent effect. Thus both the magnitude of the chemical shift and whether spin–spin coupling takes place with the hydrogen on the number 4 carbon would appear to depend upon the configuration.

The peak at 214 cycles in both α- and α'-compounds is assigned to the methyl group on the number 1 carbon atom. The 6 cycle shift to lower field relative to the peak at 220 c.p.s. is consistent with the proximity of the carbonyl group.

(2) B. P. Dailey and J. N. Shoolery, THIS JOURNAL, **77**, 3977 (1955).
(3) H. M. McConnell, *J. Chem. Phys.*, **27**, 226 (1957).

The strong peak at 220 cycles in both the α- and α'-compounds is attributed to the two methyl groups attached to the same carbon atom which are sufficiently alike to give rise to only one line. A small peak is resolved on the leading slope of this line in the α'-compound; however, the α'-compound is somewhat unstable and the fact that a weak doublet is present in its spectrum at 83 and 88 cycles suggests that this compound has isomerized to the extent of about 20% in the few months between its preparation and measurement even though it was refrigerated most of the time. The dimethyl peak of the α-compound could easily be shifted 1 cycle in going from the α-solution to the α'-solution to account for the extra peak in the latter.

The spectrum of D-α-bromocamphor (Fig. 1G) is very similar to that of the α-chloro-compound. It also has a doublet to the left of the chart and it is of interest that this is 8 cycles farther to the left than is the doublet for the α-chloro-compound, thus again giving evidence that bromine in cyclohexane derivatives causes a larger shift to low field than does chlorine. This larger shift of bromine compared with chlorine in this case as in the case of the 2-indanones may result from a steric crowding effect of the larger bromine which overcomes the effect expected from the greater electronegativity of the chlorine or this may be another example of the C–Br bond magnetic anisotropy overriding the electronegativity effect.

The spectrum of D-α,α'-dibromocamphor (Fig. 1H) does not have any peaks in the region 80–110 cycles as is to be expected since the hydrogen giving rise to these peaks in other compounds would be missing in this compound. The methyl groups now yield three distinct peaks of about equal separation and equal area. This is interpreted as indicating that the α'-bromine is now coming very close to one of the methyl groups attached to the number 8 carbon, making this methyl group sufficiently different from the other two to give a distinct peak. A model of the compound suggests steric interference. However, the greater sharpness and consequent higher amplitude of the peak at 217 c.p.s. indicates that the methyl group represented by this peak is less hindered in its rotation than the other two. This line is, therefore, assigned to the *gem*-methyl group which does not contact the α'-bromine; furthermore, it is shifted only slightly from the dimethyl peak in the monohalogenated compounds. The model indicates that this methyl group does, indeed, have greater freedom of rotation than the other two. The peak at 212 c.p.s. is assigned to the methyl group on carbon atom number 1 as in the monohalogen compounds. The line at 208 c.p.s. must then be assigned to the other *gem*-methyl group, giving a shift of 12 c.p.s. from the position in the monohalogen compounds to be associated with either steric crowding due to the *exo*-bromine or to the close approach of the magnetically anisotropic cloud of electrons associated with the –C–Br bond.

The multiplet at 144–148 c.p.s. in the α,α'-dibromine compound lies farther to the left than the corresponding multiplet in the monohalogen com-

pounds by about 18 cycles. It is not clear whether this shift is due to steric effects due to the additional crowding imposed by the two bromine atoms, inductive withdrawal of electrons by the additional halogen atom shielding due to magnetic anisotropy of the -C–Br bonds or all effects operating simultaneously.

We have also measured the NMR spectrum of camphor for comparison purposes and find that the peaks due to the methyl groups are at 221 and 225 c.p.s. while they have been appearing at 214 and 220 in the monochloro compounds, at 213 and 220 in the monobromo compound, and at 208, 212 and 217 in the dibromo compound. This difference may be due to a chemical shift resulting from the magnetic anisotropy of the halogens. If this is so, the magnetic anisotropy of the carbonyl group may result in a similar effect and one would predict the methyl peaks in camphane would fall at a higher field strength.

Compounds.—Cyclohexanone was fractionated through a one-meter column packed with glass helices. α-Chlorocyclohexanone was a portion of the sample described by Huitric and Kumler.[4] The other compounds were from samples on which the infrared spectra were reported in the paper by Brutcher, Roberts, Barr and Pearson.[5]

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[CONTRIBUTION FROM THE ORGANIC CHEMISTRY LABORATORY, NATIONAL SUGAR INSTITUTE]

The Structure of *Acacia sundra* Gum. Part I. Nature of the Sugars Present and Structure of the Aldobiouronic Acid

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Acacia sundra gum on hydrolysis yields D-galactose, L-arabinose, L-rhamnose and D-glucuronic acid. The aldobiouronic acid component of the gum obtained by graded hydrolysis is shown to be 6-*O*-[β-D-glucopyranosyluronic acid]-D-galactose. Information on the structure of the gum also has been obtained by periodate oxidation studies.

Amongst the gums of the species of Acacia genus the studies on the structure of gum arabic have been most extensive.[1-6] Apart from gum arabic the other gums that have been studied are: *Acacia mollissima*[7] (black wattle gum), *A. pycantha*,[8] *A. cyanophylla*[9] and *A. karroo*.[10] Of the gums obtained from Indian species only *A. catechu*[11] appears to have been investigated. Though all of these contain the same monosaccharide units and the same aldobiouronic acid is produced on acid hydrolysis (with the exception of *A. karroo* which gives two aldobiouronic acids), these differ in the proportions of the different component sugars and equivalent weights. The present investigation deals with the structure of *Acacia sundra* gum and it was of interest to find out what relation it bears to other gums of the Acacia genus.

This communication deals with the composition of *A. sundra* gum and determination of the structure of an aldobiouronic acid produced on hydrolyzing the gum with acid.

Complete hydrolysis (bath temp. 95–98°) of the gum followed by partition chromatography, measurement of specific rotation and preparation of crystalline derivatives has shown that the gum contains D-galactose, L-arabinose, L-rhamnose and D-glucuronic acid. A faint spot corresponding to R_f value of xylose also was detected on paper chromatogram. The molecular ratio of D-galactose, L-arabinose and L-rhamnose was found to be 3:2:1. This ratio agrees fairly well with the one found in the case of *A. verek*.[12]

Aqueous solutions of the gum are sufficiently acidic to undergo slow autohydrolysis when the solution is heated on a water-bath. On autohydrolysis all the rhamnose and part of the arabinose and some galactose is removed. More drastic hydrolysis of the gum affords D-galactose, L-arabinose and an aldobiouronic acid composed of a unit of D-glucuronic acid and D-galactose. Paper partition chromatography of the aldobiouronic acid showed two spots, one faint and the other strong, which is indicative of the probability of a small proportion of another aldobiouronic acid also being present.

Structure of the aldobiouronic acid was established with the help of methylation studies. The fully methylated derivative of the aldobiouronic acid on hydrolysis afforded equal amounts of 2,3,4-tri-*O*-methyl-D-galactose and 2,3,4-tri-*O*-methyl-D-glucuronic acid, the former being identified as the crystalline anilide and the latter as the 1,5-lactone 6-methyl ester. The methylated aldobiouronic acid is levorotatory. These facts suggest that the structure I assigned to the aldobiouronic acid is correct.

When the gum was oxidized with periodate 1.6 moles of formic acid was produced per equivalent

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(4) F. Smith, *ibid.*, 1724 (1939).

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(12) W. W. Pigman and R. M. Goepp, Jr., "Chemistry of the Carbohydrates," Academic Press, Inc., New York, N. Y., 1948, p. 633.