789. *Aspects of Stereochemistry. Part XV.*[1] *Influence of Intramolecular Hydrogen Bonding on the Rates of Esterification of Some Derivatives of* 5-*Hydroxy*-1,3-*dioxan and of* 1,4:3,6-*Dianhydro*-D-*glucitol.*

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By means of competitive reactions with *p*-phenylazobenzoyl chloride in pyridine it has been found that, for the 4-phenylcyclohexanols, the ratio of the rate constants at 37° is *trans* : *cis* 6·6 : 1. The greater reactivity of the *trans*-compound would be expected on conformational grounds. The ratio of the rate constants for the 5-hydroxy-2-phenyl-1,3-dioxans is *cis* : *trans* 5·6 : 1. The greater reactivity of the *cis*-isomer is interpreted in terms of intramolecular hydrogen bonding.

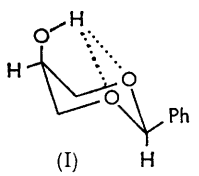
In parallel with these latter results is the observation that when 1,4:3,6-dianhydro-D-glucitol was allowed to react with a deficiency of *p*-phenylazobenzoyl chloride in pyridine, the 5-hydroxyl group was much more rapidly esterified than was the 2-hydroxyl group. Only the 5-hydroxyl group can form an intramolecular hydrogen bond.

Several reactions have now been described where intramolecular hydrogen bonding involving hydroxyl groups has been invoked to account for stereoselectivity and/or

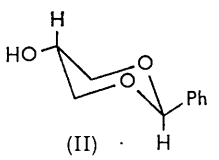
[1] Part XIV, Bukhari, Foster, Lehmann, Randall, and Webber, preceding paper.

enhanced rate of reaction. There are two categories of these reactions: (1) where the relevant hydroxyl group is the proton source in a hydrogen bond and, although affecting reactivity, the hydroxyl group does not undergo a chemical reaction as, for example, in the epoxidation of cyclohex-2-enol [2] and glycals,[3] the hydrolysis of the mono-*O*-acetates of certain diols,[4] and in the reaction of certain polyhydric alcohols with aldehydes; [5] (2) where the chemical properties of the hydroxyl group itself are modified because of intramolecular hydrogen bonding as, for example, in the selective sulphonylation of 1,4:3,6-dianhydro-D-glucitol.[6] We now report further examples of the second category which involve the esterification of certain alcohols with *p*-phenylazobenzoyl chloride in pyridine.

Esterification of *cis*- and *trans*-5-hydroxy-2-phenyl-1,3-dioxan (1,3-*O*-benzylideneglycerol) and of the cyclohexane analogues *cis*- and *trans*-4-phenylcyclohexanol was examined first. Each of these compounds is conformationally flexible. The infrared spectra in the hydroxyl stretching region for dilute solutions in carbon tetrachloride of *cis*- and *trans*-5-hydroxy-2-phenyl-1,3-dioxan show that the *cis*-isomer has absorption for bonded hydroxyl groups only (3590 cm.$^{-1}$) and therefore exists in conformation (I) with the hydroxyl group involved in hydrogen bonding with the ring-oxygen atoms. On the



(I)



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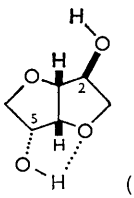

(III)

other hand, the *trans*-isomer has absorptions at 3633 (ε 79) and 3601 cm.$^{-1}$ (ε 26) for free and bonded hydroxyl groups and must exist to a large extent in conformations with unbonded hydroxyl groups.[7] It has been concluded,[8] on the basis of nuclear magnetic resonance spectroscopy, that in concentrated solution in chloroform *trans*-5-hydroxy-2-phenyl-1,3-dioxan exists in conformation (II) with the hydroxyl and phenyl groups equatorial, whereas the *cis*-isomer is conformationally unstable. If intramolecular hydrogen bonding occurs to any extent in the *cis*-isomer under these conditions, then the basicity of the oxygen atom of the hydroxyl group should be enhanced and esterification should be facilitated. Such facilitation should not occur in the *trans*-isomer. However, if only intermolecular hydrogen bonding occurs, then, if there is any resultant enhancement of reactivity, it should occur in both isomers and, because of the greater steric accessibility of the hydroxyl group, it should be more significant in the *trans*-isomer. Essentially, it is this situation which exists in the 4-phenylcyclohexanols and for which a greater rate of acetylation has been observed [9] for the *trans*-isomer. Thus, the behaviour of *cis*- and *trans*-5-hydroxy-2-phenyl-1,3-dioxan on esterification should reveal whether there is any correlation between the pattern of intramolecular hydrogen bonding observed in dilute solutions in inert solvents and the chemical reactivity of the hydroxyl groups.

Esterification with *p*-phenylazobenzoyl chloride in pyridine was selected because of the convenient properties of the esters in chromatography.[10] The results of a series of competitive reactions are shown in Table 1. Equimolar proportions of the two alcohols

[2] Henbest and Wilson, *J.*, 1957, 1958.
[3] Barker, Brimacombe, Foster, Whiffen, and Zweifel, *Tetrahedron*, 1959, **7**, 10.
[4] Henbest and Lovell, *J.*, 1956, 1965; Bruice and Fife, *J. Amer. Chem. Soc.*, 1962, **84**, 1973.
[5] Buck, Foster, Richtmyer, and Zissis, *J.*, 1961, 3633.
[6] Lemieux and McInnes, *Canad. J. Chem.*, 1960, **38**, 136.
[7] Dobinson and Foster, *J.*, 1961, 2338.
[8] Baggett, Dobinson, Foster, Homer, and Thomas, *Chem. and Ind.*, 1961, 106.
[9] Eliel and Lukach, *J. Amer. Chem. Soc.*, 1957, **79**, 5986.
[10] Baggett, Foster. Haines, and Stacey, *J.*, 1960, 3528.

TABLE 1.

Relative rate constants for competitive *p*-phenylazobenzoylations at 37°.

Alcohol (rate constant)	Relative rate	Source *
cis-4-Phenylcyclohexanol (k_1)	1·0(k_1/k_4)	$k_2/k_4 \cdot k_1/k_2$
trans-4-Phenylcyclohexanol (k_2)	6·6(k_2/k_4)	Direct
cis-5-Hydroxy-2-phenyl-1,3-dioxan (k_3)	6·1(k_3/k_4)	Direct
	5·6	$k_3/k_1 \cdot k_1/k_2 \cdot k_2/k_4$
trans-5-Hydroxy-2-phenyl-1,3-dioxan (k_4)	1·0	Reference
Cyclohexanol (k_5)	2·6(k_5/k_6)	Direct
5-Hydroxy-1,3-dioxan (k_6)	1·0	Reference

At 80° k_3/k_1 was 2·6 and 2·5 at *ca.* 120°; at *ca.* 120° k_5/k_6 was 3·2.

* The values k_1/k_3, k_2/k_4, k_3/k_4, and k_1/k_2 were determined experimentally (see Table 2).

were allowed to react with one molar proportion of *p*-phenylazobenzoyl chloride in pyridine at 37°; the reaction mixtures were homogeneous in each case. The composition of each product mixture was determined either by separation of the components by elution or extrusion chromatography on alumina, or by infrared spectroscopy of solutions of the mixtures in chloroform or carbon disulphide. The accuracy of each method (see Experimental) was determined by analysis of a series of standard mixtures and, although variously within the range ±2—10%, the differences of reactivity noted in Table 1 are well outside the range of experimental error and therefore meaningful.

The first group of competitive esterifications involved the following pairs of compounds: *cis*- and *trans*-5-hydroxy-2-phenyl-1,3-dioxan (k_3, k_4); *cis*- and *trans*-4-phenylcyclohexanol (k_1, k_2); *cis*-5-hydroxy-2-phenyl-1,3-dioxan and *cis*-4-phenylcyclohexanol; *trans*-5-hydroxy-2-phenyl-1,3-dioxan and *trans*-4-phenylcyclohexanol. The results in Table 1 for the phenyl-substituted derivatives, are expressed in terms of the rate constants relative to that of *trans*-5-hydroxy-2-phenyl-1,3-dioxan and, for a given competitive reaction, were calculated from the equation [11] (1):

$$\frac{k_x}{k_y} = \frac{\log ([A]_t/[A]_0)}{\log ([B]_t/[B]_0)}, \quad (1)$$

where k_x and k_y are the rate constants for the competitive reactions (2) and (3) in which

$$A + nC \longrightarrow \text{Products} \quad (2)$$
$$B + nC \longrightarrow \text{Products} \quad (3)$$

A and B do not react with each other and where $[A]_t$ and $[A]_0$, $[B]_t$ and $[B]_0$, are the concentrations of A and B at time t and initially. The results in Table 1 show clearly that *trans*-4-phenylcyclohexanol was more readily esterified than was the *cis*-isomer (k_2/k_1 6·6), an observation which accords with the findings of other workers [9] and would be expected on conformational grounds [12] since, for cyclohexane derivatives in chair conformations, a more rapid reaction of equatorial hydroxyl groups (*trans*-4-phenylcyclohexanol) should occur than of axial hydroxyl groups (*cis*-isomer). However, the reverse order of reactivity was observed for *cis*- and *trans*-5-hydroxy-2-phenyl-1,3-dioxan (k_3/k_4 5·6), where the *cis*-isomer was esterified much more readily. Thus, the reactivity of the hydroxyl group in *cis*-5-hydroxy-2-phenyl-1,3-dioxan is enhanced to a significant degree and it appears, for the reasons considered above, that intramolecular hydrogen bonding is important in the esterification of this compound. A further consequence of intramolecular hydrogen bonding in compound (I) will be the restriction of rotation about the C–OH bond which could also contribute to the enhanced nucleophilicity of the oxygen atom.

[11] Lee in "Techniques of Organic Chemistry," Edited by Weissberger, Interscience, New York, Vol. VIII, p. 100.

[12] Barton and Cookson, *Quart. Rev.*, 1956, **10**, 44.

It is noteworthy that cyclohexanol (k_5) was acylated more readily than was 5-hydroxy-1,3-dioxan (k_6, k_5/k_6 2·6). Whilst it is possible that intramolecular hydrogen bonding occurs to some extent in 5-hydroxy-1,3-dioxan in the esterification mixture [the dilute-solution spectrum shows [3] absorption at 3636 (ε 21) and 3593 cm.$^{-1}$ (ε 100) for free and bonded hydroxyl groups, respectively], any resultant activation of the hydroxyl group is swamped by some other, deactivating effect. The latter effect is probably electronic in origin and arises from the electronegativity of the ring-oxygen atoms which increase the positive character of the carbon atom which carries the hydroxyl group, with consequent diminution of the basicity of the oxygen atom. Such an effect would be operative in both *cis*- and *trans*-5-hydroxy-2-phenyl-1,3-dioxan and hence differences in reactivity due to intramolecular hydrogen bonding become apparent. That the deactivating effect is operative in the 5-hydroxy-2-phenyl-1,3-dioxans is indicated by the similar rates of esterification of *cis*-4-phenylcyclohexanol (axial hydroxyl group) and *trans*-5-hydroxy-2-phenyl-1,3-dioxan (equatorial hydroxyl group).

The relative reactivity of cyclohexanol and 5-hydroxy-1,3-dioxan was not significantly changed by elevation of the temperature to 120°, but the difference in relative reactivity of *cis*-4-phenylcyclohexanol (k_1) and *cis*-5-hydroxy-2-phenyl-1,3-dioxan (k_3) diminished with increase of temperature from 37° (k_3/k_1 5·6) to 80° (k_3/k_1 2·6) but did not change significantly (k_3/k_1 2·5) on further elevation of temperature to 120°.

The second molecular system examined was 1,4:3,6-dianhydro-D-glucitol (III) which is conformationally rigid since it contains two *cis*-fused tetrahydrofuran rings. The 5-hydroxyl group is *endo* in this ring system and can form an intramolecular hydrogen bond with the 4-oxygen atom whereas the 2-hydroxyl group is *exo* and cannot form a hydrogen bond to the 3-oxygen atom; a saturated solution (<0·005M) of the dianhydride in carbon tetrachloride showed absorption at 3627 and 3555 cm.$^{-1}$ for free and bonded hydroxyl groups, respectively. The difference in absorption frequency of each type of hydroxyl group permits the determination of the position of unblocked hydroxyl groups in monosubstituted derivatives.

It has been known for some time that the hydroxyl groups in 1,4:3,6-dianhydro-D-glucitol have different reactivities because of the ease of formation of monosubstituted derivatives and it was thought that, because of apparent greater steric accessibility, the *exo*-2-hydroxyl group was more reactive. Lemieux and McInnes [6] demonstrated conclusively that sulphonylation occurs preferentially at the *endo*-5-hydroxyl group. The greater reactivity of this hydroxyl group was subsequently interpreted in terms of intramolecular hydrogen bonding.[13] Essentially similar selective reactions have been reported by other workers.[14]

When 1,4:3,6-dianhydro-D-glucitol was allowed to react with one molar proportion of *p*-phenylazobenzoyl chloride in pyridine at 37° for 22 hr., reaction was incomplete and the product mixture contained esters in the following proportions: 2,5-di *ca.* 9%, 2-mono *ca.* 12%, and 5-mono *ca.* 36%. Clearly, the 5-hydroxyl group, which can be involved in an intramolecular hydrogen bond, is markedly more reactive than is the 2-hydroxyl group. For comparison it may be noted that Lemieux and McInnes [6] found that, with one molar proportion of toluene-*p*-sulphonyl chloride in pyridine at 5° for 46 hr., 1,4:3,6-dianhydro-D-glucitol gave toluene-*p*-sulphonates in the following proportions: 2,5-di 17·1%, 2-mono 11·7%, and 5-mono 45·4%.

The structure of the mono-*O*-*p*-phenylazobenzoates of 1,4:3,6-dianhydro-D-glucitol was assigned on the basis of the dilute-solution spectra in carbon tetrachloride; the 5-ester had absorption for free hydroxyl groups at 3624 cm.$^{-1}$ whilst the 2-ester had absorption for bonded hydroxyl groups at 3557 cm.$^{-1}$. Other properties of the mono-esters were consistent with these assignments; thus, the 2-ester was more readily eluted

[13] Foster, *Ann. Rev. Biochem.*, 1961, **30**, 45.
[14] Gatos, Zech, and LeMaistre, Abs. Papers Amer. Chem. Soc. Meeting, Washington, D.C., March 1962, p. 2D.

from alumina than was the 5-ester. It is known that the affinity of free hydroxyl groups for alumina is greater than that of intramolecularly bonded hydroxyl groups.[7,12] The 2-ester was also much more soluble in carbon tetrachloride than was the 5-ester, reflecting the reduced polar character of the former compound because of intramolecular hydrogen bonding.

It is possible that the steric effects previously suspected to be operative in the esterification of 1,4:3,6-dianhydro-D-glucitol do in fact occur and counteract to some extent the effect of intramolecular hydrogen bonding on the 5-hydroxyl group. The problem is being studied further.

Experimental

Preparation of Alcohols.—5-Hydroxy-1,3-dioxan (1,3-*O*-methyleneglycerol) was prepared by saponification of the benzoate with aqueous alkali [3] and had b. p. 85—87°/15 mm. Cyclohexanol was fractionally distilled through a 30 cm. column packed with glass helices.

cis- and *trans*-4-Phenylcyclohexanol were prepared by Ungade's method [15] from 4-phenylcyclohexanone and had m. p. 75—76° and 119—120°, respectively.

cis-5-Hydroxy-2-phenyl-1,3-dioxan (1,3-*O*-benzylideneglycerol) prepared according to the method of Verkade and van Roon [16] had m. p. 82—83°. *trans*-5-Hydroxy-2-phenyl-1,3-dioxan was prepared by the method of Dobinson and Foster [7] by reduction of 5,5-dihydroxy-2-phenyl-1,3-dioxan (2 g.) with sodium borohydride. Fractionation of the product on a column (40 × 2·5 cm.) of alumina (Peter Spence, type H) by elution with chloroform (200 ml. fractions) gave:

Fraction 1 (97·5 mg., 5·3% after two recrystallisations), m. p. 63—64°, the infrared spectrum (Nujol mull) had $\nu_{max.}$ at 808 and 832 cm.$^{-1}$; it was *cis,trans*-5-hydroxy-2-phenyl-1,3-dioxan.[7]

Fractions 2—4 (0·875 g., 47·6% after two recrystallisations), m. p. 63—64°; they were pure *trans*-5-hydroxy-2-phenyl-1,3-dioxan since the infrared spectrum (Nujol mull) had no absorption at 808 and 832 cm.$^{-1}$ characteristic of the *cis*-isomer.[7]

The *p*-phenylazobenzoates of all the above alcohols have been described in previous papers.[7,10]

Competitive p-*Phenylazobenzoylations.*—The general method is illustrated by the following example.

To a solution of *cis*-5-hydroxy-2-phenyl-1,3-dioxan (100 mg., 1 mol.) and *cis*-4-phenylcyclohexanol (97·7 mg., 1 mol.) in pyridine (1 ml.) was added a solution of *p*-phenylazobenzoyl chloride (138·5 mg., 1 mol.) in pyridine (10 ml.). Both solutions were at 37° and the mixture was maintained thereat for 22 hr. Water (1 drop) was then added and after 30 min. the mixture was poured into 30% aqueous sodium chloride (700 ml.) and extracted with chloroform until the aqueous layer was colourless (*ca.* 3 × 100 ml.). The combined extracts were washed with water and 10% aqueous sodium hydrogen carbonate, dried ($MgSO_4$), and then passed down a short column of alumina by elution with chloroform; *p*-phenylazobenzoic acid was thereby removed. The solution was concentrated and unchanged alcohols were removed by distillation at 100°/0·1 mm. A solution of the residue in benzene was fractionated on a column (40 × 2·5 cm.) of neutral alumina [17] (Brockmann III) by elution with benzene. From a series of separations on artificial mixtures the method appeared to be accurate to ±2% for each fraction. In addition to the above mixture the following mixtures were subjected to competitive esterifications and the product mixture fractionated in a similar manner: cyclohexanol and 5-hydroxy-1,3-dioxan; *trans*-4-phenyl-cyclohexanol and *trans*-5-hydroxy-2-phenyl-1,3-dioxan. In each case the cyclohexane derivative was eluted first from the alumina column and the separations were clean cut.

The mixture obtained after competitive *p*-phenylazobenzoylation of *cis*- and *trans*-5-hydroxy-2-phenyl-1,3-dioxan could not be fractionated by the above method. Two, alternative methods were devised:

(*a*) A solution of the mixture of esters obtained by the above general method in the minimum amount of benzene was adsorbed on a column (20 × 4·5 cm.) of alumina (neutral, Brockmann

[15] Ungade, *J. Org. Chem.*, 1948, **13**, 365.
[16] Verkade and van Roon, *Rec. Trav. chim.*, 1942, **61**, 831.
[17] Baggett, Brimacombe, Foster, Stacey, and Whiffen, *J.*, 1960, 2574.

III) supported in a precision-tapered glass tube.[18] The column was developed with benzene–light petroleum (9 : 1 v/v), then extruded, and the two bands were segregated and extracted with chloroform. The preceding operations were carried out in the dark as far as possible. Each of the products obtained on concentration of the chloroform solutions was refractionated in the same way, and the appropriate purified fractions were combined. From the infrared spectra (Nujol mulls) of the pure esters and of artificial mixtures it proved possible to detect 1—2% of the *cis*-ester as impurity in the *trans*-compound, but $<10\%$ of the *trans*-ester could be detected as contaminant in the *cis*-compound.

From trial separations with known mixtures it was found that the method was accurate to $\pm$*ca.* 5% of each fraction.

(*b*) The analysis of mixtures to an accuracy of $\pm 10\%$ was possible by infrared spectroscopy on 0·5 mm. layers of solutions (10 mg./ml.) of the mixed esters in methylene chloride by using the Perkin-Elmer model 21 spectrometer. Comparisons were made with mixtures of known composition, with the following characteristic absorptions: *cis*-5-hydroxy-2-phenyl-1,3-dioxan 1082 (strong) and 1116 cm.$^{-1}$ (medium); *trans*-isomer 1105 cm.$^{-1}$ (strong,broad). The spectra of mixtures showed absorption at 1118, 1105, and 1086 cm.$^{-1}$.

TABLE 2.

Results of competitive *p*-phenylazobenzoylations.

Competing pair of alcohols	Total yield of ester (%)	Yield (%) of each ester (1)	Yield (%) of each ester (2)	Ratio of yield, 1 : 2	Ratio $k_1 : k_2$
cis-5-Hydroxy-2-phenyl-1,3-dioxan (1)	53·0	43·1	9·89	4·42	5·41
cis-4-Phenylcyclohexanol (2)	53·2	43·05	10·14	4·25	5·27
	70·2 *	48·05	22·20	2·17	2·61
	70·8 †	48·00	22·80	2·10	2·53
trans-4-Phenylcyclohexanol (1)	70·2	57·6	12·6	4·58	6·38
trans-5-Hydroxy-2-phenyl-1,3-dioxan (2) ...	69·3	57·5	11·8	4·86	6·80
cis-5-Hydroxy-2-phenyl-1,3-dioxan (1)	38·9 ‡	32·8	6·13	5·36	6·28
trans-5-hydroxy-2-phenyl-1,3-dioxan (2) ...	38·9 ‡	32·4	6·54	4·95	5·92
	68·6	—	—	*ca.* 5 §	
	65·8	—	—	*ca.* 5 §	
trans-4-Phenylcyclohexanol (1)	51·5	43·1	8·4	5·1	6·43
cis-4-Phenylcyclohexanol (2)	56·8	47·1	9·6	4·9	6·33
Cyclohexanol (1)	63·1 ¶	43·7	19·4	2·26	2·67
5-Hydroxy-1,3-dioxan (2)	58·2 ¶	39·8	18·4	2·16	2·49
	65·3 †	47·2	18·1	2·61	3·20

The alcohol (0·568 mmole, *ca.* 100 mg.) was treated with acid chloride (138·5 mg.) in pyridine (11 ml.) at 37° for 22 hr. Experimental variations: * 80° for 3 hr. † 120° for 1 hr. ‡ Amount of acid chloride reduced by an inefficient transfer process. § Infrared spectroscopic determination. ¶ Acid chloride (244·5 mg.) and pyridine (19·8 ml.).

Mixtures of the *p*-phenylazobenzoates of *cis*- and *trans*-4-phenylcyclohexanol could not be fractionated on alumina. Analysis could be effected with an accuracy of $\pm 2\%$ for each component by infrared spectroscopy on 1 mm. layers of solutions (20 mg./ml.) in carbon disulphide by making use of the following characteristic absorption bands: *cis*-isomer 921 cm.$^{-1}$ (strong), *trans*-isomer 945 cm.$^{-1}$ (medium). The *trans*-isomer had weak absorption at 921 cm.$^{-1}$ but this did not interfere. The spectra were compared with those of standard mixtures.

The results obtained by the various fractionation procedures described above are given in Table 2.

p-*Phenylazobenzoylation of* 1,4:3,6-*Dianhydro*-D-*glucitol*.—A solution of 1,4:3,6-dianhydro-D-glucitol [19] (0·3 g.; m. p. 101—103°) and *p*-phenylazobenzoyl chloride (1·51 g.) in dry pyridine (30 ml.) was kept at 100—110° for 3 hr. and then worked up in the usual manner.[10] Recrystallisation of the product from benzene–light petroleum (b. p. 60—80°) gave the 2,5-*di*-O-p-*phenylazobenzoate* (84%), m. p. 183—184°, which showed no absorption in the hydroxyl stretching region (Found: C, 68·4; H, 5·1; N, 9·7. $C_{32}H_{26}N_4O_6$ requires C, 68·4; H, 4·7; N, 10·0%).

A solution of the dianhydride (1 g.) in pyridine (10 ml.) at 37° was treated dropwise with a

[18] Scientific Co., New Jersey, U.S.A.
[19] Montgomery and Wiggins, *J.*, 1946, 390.

solution of acid chloride (1·66 g.) also in pyridine (33 ml.), and the mixture was stored at 37° for 24 hr. The crude mixture of esters was isolated in the usual manner [10] and a solution in the minimum volume of chloroform was added to a column (*ca.* 50 × 2 cm.) of neutral alumina [17] of activity Brockmann III. Elution with chloroform gave the following fractions: (1) 2,5-di-*O*-*p*-phenylazobenzoate, m. p. 183·5—184·5° after recrystallisation from benzene–light petroleum (b. p. 60—80°); (2) 1,4:3,6-*dianhydro*-2-O-p-*phenylazobenzoyl*-D-*glucitol*, m. p. 139·5—140·5° (from aqueous ethanol), $\nu_{max.}$ 3557 cm.$^{-1}$ (for a *ca.* 0·005M-solution in CCl_4) (Found: C, 64·25; H, 5·2; N, 7·6. $C_{19}H_{18}N_2O_5$ requires C, 64·4; H, 5·1; N, 7·9%); (3) 1,4:3,6-*dianhydro*-5-O-p-*phenylazobenzoyl*-D-*glucitol*, m. p. 186—187° (from aqueous ethanol), $\nu_{max.}$ 3624 cm.$^{-1}$ (Found: C, 64·6; H, 5·2; N, 8·0%).

Competitive esterifications similar to that described above with solutions of dianhydride (250 mg.) in pyridine (2·5 ml.) and acid chloride (420 mg.) in pyridine (31 ml.) to ensure homogeneity of the reaction mixture, and reaction at 37° for 22 hr. were repeated in triplicate in order to determine the percentage yields of the esters. The results were as follows:

2,5-diester, 9·3, 9·7, 8·4; average 9·13%.
2-monoester, 13·0, 13·0, 11·1; average 12·37%.
5-monoester, 35·9, 36·1, 35·5; average 35·8%.

Infrared Spectra.—The dilute solution spectra were measured on 3 cm. layers of solutions of the alcohols in CCl_4 in a Unicam S.P. 100 spectrometer equipped with a grating (3000 lines per in.). Frequencies were checked against polystyrene absorptions.

1,4:3,6-Dianhydro-D-glucitol had $\nu_{max.}$ at 3627 and 3555 cm.$^{-1}$.

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