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RELATIVE REACTIVITY OF TWO HYDROXYL GROUPS IN ACYLATION AND ALKYLATION REACTIONS OF SACCHARIDES; A KINETIC APPROACH LEADING TO THE EVALUATION OF ALL RATIOS OF RATE-CONSTANTS

JAN STANĚK, JR.,*
Department of Organic Chemistry, Charles University, 128 40 Prague 2 (Č.S.S.R.)
PAVEL CHUCHVALEC,
Department of Physical Chemistry, Prague Institute of Chemical Technology, 166 28 Prague 6 (Č.S.S.R.)
KAREL ČAPEK, KAREL KEFURT, AND JIŘÍ JARÝ
Laboratory of Monosaccharides, Prague Institute of Chemical Technology, 166 28 Prague 6 (Č.S.S.R.)

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ABSTRACT

A method is described for calculating all ratios of rate-constants characterizing the reaction of a diol with an acylating or alkylating reagent. The application of these ratios, for estimating the amount of reagent needed for maximal yield of each monosubstituted derivative under definite reaction conditions, is presented. These rate-constant ratios are also useful for calculating the proportions of products at optional degrees of substitution and for investigation of reaction mechanisms.

INTRODUCTION

Numerous studies of differences between hydroxyl groups in carbohydrate derivatives toward acylation or alkylation reactions have been made[1] since Ohle and Dickhäuser in 1925 described[2] the partial acylation of 1,2-*O*-isopropylidene-α-D-glucofuranose; these differences in reactivity have been mainly used for the synthesis of otherwise unavailable compounds. Current interest is directed more toward elucidating the factors influencing the reactivity of particular hydroxyl group and to the relations between these factors. In addition to the roles of the acylating or alkylating reagent, the catalyst, and the solvent (which can be held constant) there are many structural features of the sugar molecule itself (such as steric and polar effects of adjacent groups connected with configuration and conformation) that may influence the reactivity of individual hydroxyl groups. Quantitative evaluation of the

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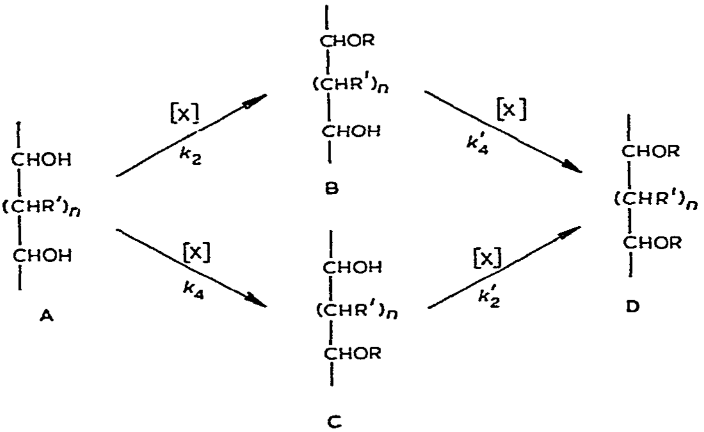
*Present address: Laboratory of Monosaccharides, Prague Institute of Chemical Technology, 166 28 Prague 6 (Č.S.S.R.)

contribution of all of these effects to the reaction rate should make it possible to predict the net reaction pattern for any polyol under a given set of reaction conditions. Unfortunately, the common sugar derivatives having three or four free hydroxyl groups give too complex results for this purpose, even in simplest reactions. Derivatives of trideoxy sugars (or their analogues) having only one free hydroxyl group could serve as the simplest model compounds (see ref. [3]), but they cannot be used to determine the effect of one free hydroxyl group on the reactivity of another hydroxyl group in the molecule. Furthermore, they are usually inaccessible in the gram amounts needed until recently for detailed kinetic measurements[3]. Compounds having two hydroxyl groups are thus more convenient, and the literature records a number of studies on partial reactivity (leading references only are given), for example, on alkyl 4,6-*O*-benzylidene-aldohexopyranosides[4,5], on other appropriately substituted derivatives of glycosides[6] and cyclitols[7], on dideoxy hexosides[8] and their acetamido analogues[9,10], on dianhydroalditols[11], on substituted 1,6-anhydro sugars[12], and on nucleosides[13]. However, their reaction with one equivalent of the acylating or alkylating reagent does not stop at the stage of monosubstituted derivatives, and a part of the reagent is consumed in a subsequent reaction leading to a disubstituted derivative (Scheme I). As four different rate-constants* (k_2, k_4, k'_2, and k'_4) may be involved, the interpretation is complicated to such an extent that it is generally not possible to estimate the differences in the reactivity of hydroxyl groups (namely



$n \geq 0$
X= acylating or alkylating reagent
R= acyl or alkyl residue
R= differs from OH, NH_2, SH

Scheme 1

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*This designation of rate constants for the model compounds employed here (Scheme II) is used for the general method presented.

k_2/k_4) in the starting diol **A** from the final distribution of products* usually the only information available from the experiment). Nevertheless, knowledge of k_2/k_4 and other rate-constant ratios can help to clarify the effects of some of the structural features already listed for the sugar molecule. For instance, the ratio k'_2/k_2 quantitatively describes (Scheme I) the increase or decrease of reactivity of a particular hydroxyl group occasioned by a change of the neighboring hydroxyl group into an acyloxy or alkoxy group, and the ratios k'_2/k'_4 and k_2/k_4 indicate which one of the hydroxyl groups reacts the more rapidly. The last-mentioned rate-constant ratio also reflects the effect of a neighboring hydroxyl group upon the reactivity of a particular hydroxyl group.

Methods of kinetic evaluation hitherto described (see, for instance, ref. [5]) for the system given in Scheme I used many approximations (for example, $k_2 = k_4$ and $k'_2 = k'_4$, or $k'_2 = k_2$). This paper presents a method for evaluating all desired ratios of rate constants, based on relatively little experimental data; the irreversibility of the reaction is the necessary condition.

RESULTS AND DISCUSSION

Among the various pairs of rate constants noted in Scheme I, the ratio k'_2/k'_4 is the only one that can be determined directly by experiment. In this case of competitive reactions of two monohydroxy derivatives **B** and **C**, the following equation is valid:

$$\mathrm{k} = \frac{k'_2}{k'_4} = \frac{\log c_{\mathrm{C_0}} - \log c_{\mathrm{C}}}{\log c_{\mathrm{B_0}} - \log c_{\mathrm{B}}} \qquad (1)$$

where $c_{\mathrm{C_0}}$ and $c_{\mathrm{B_0}}$ are the initial concentrations of compounds **B** and **C**, and c_{C} and c_{B} their concentrations at time *t*. This ratio can be obtained from the reaction of a synthetic mixture of **B** and **C** with less than 1.0 equivalent (preferably about 0.5 equivalent) of the reagent, under the same conditions as those used for the reaction of **A** alone. When compared with the direct kinetic evaluation of k'_2 and k'_4, about 15 times less of compounds **B** and **C** are required, in an experimentally simpler procedure, to achieve comparable accuracy. As the resulting ratio of rate constants is a dimensionless number, the concentrations can be expressed in moles, mole-percent, percent, and so on. The same is also true for the other calculations described in this paper.

Thus, to observe the reaction of methyl 3-acetamido-3,6-dideoxy-β-D-glucopyranoside ("**A**") with acetyl chloride in pyridine (Scheme II), a mixture of methyl 3-acetamido-2-*O*-acetyl-3,6-dideoxy-β-D-glucopyranoside ("**B**") and the corresponding 4-*O*-acetyl derivative ("**C**") in the ratio 1.11:1.0 was prepared from the individual

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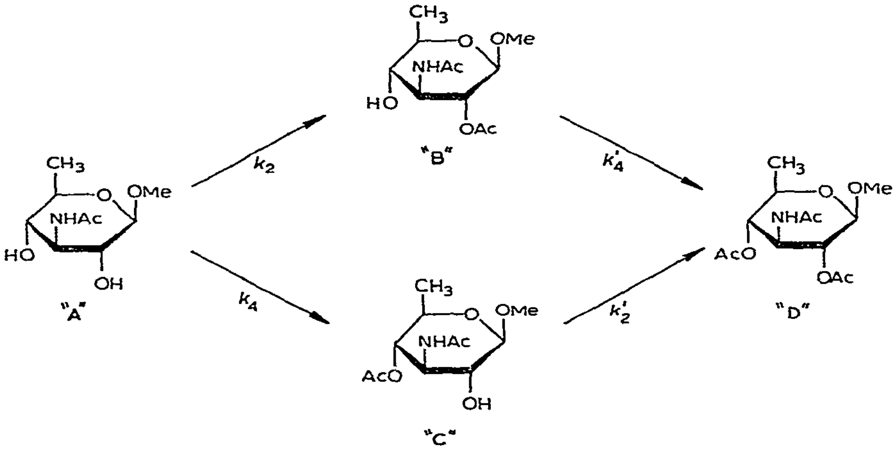
*An excess of the monosubstituted derivative **B** over **C** (Scheme I) may arise either by a higher rate of formation of **B** from **A** ($k_2/k_4 > 1$), by a slower disappearance of this derivative ($k'_2/k'_4 > 1$), or by a combination of both of these effects.

monoacetates, and this mixture was acetylated with 0.74 equivalent of acetyl chloride* under the same conditions as these used in the standard acetylation of "**A**". From the reaction mixture, 68.5% of unreacted "**B**" and 32.7% of unreacted "**C**" were isolated by careful column chromatography on silica gel (by weighing the dried, combined, chromatographically pure fractions), and this result leads to the value $k'_2/k'_4 = 3.0$. In order to achieve the accuracy $k'_2/k'_4 = 3.0 \pm 0.2$, concentrations c_B and c_C must be estimated with a precision ±1% (starting with 50 mg of each monosubstituted derivative, this requires an accuracy of ±0.5 mg in weighing).



Reaction of methyl-3-acetamido-3,6-dideoxy-β-D-glucopyranoside ("A") with acetyl chloride in pyridine

Scheme II

The same competitive reaction can also be accomplished with two monosubstituted derivatives of different compounds, thus permitting correlation of results for various diols.

The ratio k_2/k_4 can be obtained (with some uncertainty) from the amounts of compounds **B** and **C** present in the final mixture from acylation or alkylation of diol **A**, under conditions where the amount of a disubstituted derivative **D** is negligible, by using the equation:

$$\frac{k_2}{k_4} = \frac{c_B}{c_C} \qquad (2).$$

Unfortunately, rate-constants for carbohydrate derivatives are usually not sufficiently different and, at a low concentration of **D** ($c_D \rightarrow 0$) the degree of substitution (d.s.) (and also c_B and c_C) is too low to permit accurate estimation of the ratio. In addition, experiments at low d.s. are less practical from the preparative point of

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*Examples used in this paper utilize experimental data from ref. 10.

view. Somewhat more-accurate results can be obtained if the amount of the disubstituted derivative **D**, instead of being neglected, is distributed between its precursors, that is, between **B** and **C**, according to the previously expressed ratio k_2'/k_4' (eq. *1*). For both procedures the precision of the ratio obtained becomes lower as the concentration c_D increases.

For instance, the reaction of methyl 3-acetamido-3,6-dideoxy-β-D-glucopyranoside ("A") with 1.3 equivalents of acetyl chloride in pyridine (Scheme II), gave, after chromatographic separation on silica gel, the following amounts of products: $c_{\text{"A"}}$ 18.8, $c_{\text{"B"}}$ 23.7, $c_{\text{"C"}}$ 7.1, and $c_{\text{"D"}}$ 50.3%. For such a large fraction of disubstituted derivative "**D**", an erroneous value (3.3) will be obtained for k_2/k_4 by neglecting $c_{\text{"D"}}$, instead of the correct value of 1.2 (see method I.**a**). By using the distribution of "**D**" between "**B**" and "**C**" ($k_2'/k_4' = 3.0$), the value of 0.8 was obtained from the calculated values of $c_{\text{"B"}}$ 35.6, and $c_{\text{"C"}}$ 45.8% at $c_{\text{"D"}}$ extrapolated to zero.

However, the correct results can be obtained only by kinetic evaluation of this problem. The solution presented here for a system of second-order, irreversible equations (Scheme I), which may also be used for reactions following first-order kinetics (the concentration of the reagent c_X is not a factor in this calculation), makes the following calculations possible:

I. Evaluation of the ratios k_2/k_4, k_4'/k_2, k_2'/k_4, k_2'/k_2, and k_4'/k_4 for certain reaction, given data on either (*a*) the distribution of compounds **A**, **B**, **C**, and **D** (that is, the concentrations c_A, c_B, and c_D) and the ratio k_2'/k_4' (equation *1*), or (*b*) two (and more) distributions corresponding to different d.s., that is, c_A, c_B, c_C, c_A', c_B', and c_C'.

II. Calculation (employing estimated ratios of rate constants) of (*a*) the maximum yield of the monosubstituted derivative **B**, together with the corresponding degree of substitution at this stage (that is to say, the amount of acylating or alkylating reagent needed in order to achieve this maximum yield of compound **B**); (*b*) the maximum yield of **C**, together with the amount of reagent required; and (*c*) the composition of the reaction mixture at any given concentration of unreacted starting compound.

I.*a Evaluation of ratios of rate constants* k_2/k_4, k_4'/k_2, k_2'/k_4, k_2'/k_2, *and* k_4'/k_4 *at known values of* c_A, c_B, c_C, *and* k_2'/k_4'. — For this reaction system, involving one competitive and two consecutive, second-order reactions (Scheme I), the following differential equations are valid:

$$-\frac{dc_A}{dt} = (k_2 + k_4)c_A c_X \tag{3}$$

$$\frac{dc_B}{dt} = k_2 c_A c_X - k_4' c_B c_X \tag{4}$$

$$\frac{dc_C}{dt} = k_4 c_A c_X - k_2' c_C c_X \tag{5}$$

$$\frac{dc_D}{dt} = k'_4 c_B c_X + k'_2 c_C c_X \qquad (6)$$

$$-\frac{dc_X}{dt} = k_2 c_A c_X + k_4 c_A c_X + k'_4 c_B c_X + k'_2 c_C c_X \qquad (7)^*,$$

where $-dc_A/dt$ is the rate of disappearance of the starting diol **A**, $-dc_X/dt$ is the rate of disappearance of the reagent, and dc_B/dt, dc_C/dt, and dc_D/dt denote the rate of increase of the substances **B**, **C**, and **D**; c_A, c_B, c_C, c_D, and c_X are defined as the instantaneous molar concentrations of the substances **A**, **B**, **C**, **D**, and **X** at time t, and k_2, k_4, k'_2, k'_4 are the corresponding rate-constants.

Dividing equation (*4*) by equation (*3*) yields the differential equation (*8*), which describes the dependence of concentration of compound **B** on the concentration of the diol **A**. Analogously, equation (*9*), describing the dependence of concentration of the monosubstituted derivative **C** on the concentration of **A**, was obtained from equations (*5*) and (*3*).

$$-\frac{dc_B}{dc_A} = \frac{k_2}{k_2+k_4} - \frac{k'_4 c_B}{(k_2+k_4)c_A} \qquad (8)$$

$$-\frac{dc_C}{dc_A} = \frac{k_4}{k_2+k_4} - \frac{k'_2 c_C}{(k_2+k_4)c_A} \qquad (9)$$

After substituting $\frac{k_2}{k_2+k_4} = \mathbf{p}$ (*10*) and $\frac{k'_4}{k_2+k_4} = \mathbf{q}$ (*11*), the solution of the linear, differential equation (*8*) is given by (*12*). The analogous solution of (*9*) may be rewritten in the form (*13*), after substitution of $\frac{k_4}{k_2+k_4} = 1 - \mathbf{p}$ (*14*) and $\frac{k'_2}{k_2+k_4} = \mathbf{kq}$ (*15*):

$$c_B = \frac{\mathbf{p}}{(\mathbf{q}-1)}\left(c_A - c_{A_0}^{(1-\mathbf{q})} c_A^{\mathbf{q}}\right) \qquad (12)$$

$$c_C = \frac{1-\mathbf{p}}{(\mathbf{kq}-1)}\left(c_A - c_{A_0}^{(1-\mathbf{kq})} c_A^{\mathbf{kq}}\right) \qquad (13).$$

Now it is possible, on the basis of experimental values for c_A, c_B, c_C, and $k = k'_2/k'_4$ (c_{A_0}, the initial concentration of the starting diol **A**, equals 100%), to determine the unknown values **p** and **q** from equations (*12*) and (*13*); the desired ratios of rate constants are then obtained by simple algebraic operations, employing equations (*1*), (*10*), and (*11*). Thus $k'_4/k_2 = \mathbf{q}/\mathbf{p}$, and so on. For computational purposes it is suitable

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*This equation is valid only when no side reactions of **X** (reaction with water, decomposition, and so on) are involved. However, these side-reactions do not affect the result obtained from equations (*8*) and (*9*).

to express **p** in terms of equation (*12*); substitution into the relationship (*13*) then leads to the form (*16*), where **q** is the only unknown.

$$\left[\frac{1-\dfrac{c_B(\mathbf{q}-1)}{(c_A-c_{A_0}^{(1-\mathbf{q})}c_A^{\mathbf{q}})}}{(\mathbf{kq}-1)}(c_A-c_{A_0}^{(1-\mathbf{kq})}c_A^{\mathbf{kq}})\right]-c_C=0 \tag{16}$$

To find the root of this nonlinear equation, the "half interval" method was used. All calculations were performed on a Hewlett–Packard 2116B computer.

Thus, substituting the data previously noted from the reaction of methyl 3-acetamido-3,6-dideoxy-β-D-glucopyranoside ("A") with 1.3 equivalent of acetyl chloride in pyridine (Scheme II), namely, $c_{\text{“A”}}$ 18.8, $c_{\text{“B”}}$ 23.7, $c_{\text{“C”}}$ 7.1, and $c_{\text{“D”}}$ 50.3%, together with the value of 100% for c_{A_0}, and the value 3.0 for the ratio k'_2/k'_4 (see eq. *1*), the following values of the ratios of rate constants were calculated: k_2/k_4, 1.2; k'_4/k_2, 1.2; k'_2/k_4, 4.3; k'_2/k_2, 3.5; k'_4/k_4, 1.4. The differences between the values are significant as they are well outside experimental error [when approximately gram amounts of "A" were used in the reaction and the composition of the product was estimated by weighing (±0.3 mg) the dried, combined, chromatographic fractions (the total yield was usually higher than 99.5%), the deviation of given ratio from the mean never exceeded 10% in different experiments]. From the values obtained, it is obvious that there is a significant difference between the reactivity of a particular hydroxyl group in the diol and in its monoacetate. This enhancement of reactivity due the substitution in the β-position is higher for the 2-OH group (k'_2/k_2) than the for 4-OH group (k'_4/k_4)*.

All of these equations may be used in connection with acylation or alkylation reactions obeying second- or first-order kinetics. Moreover, in the latter case, it is possible to integrate equation (*3*), and to substitute the solution, $c_A = c_{A_0}\,e^{-(k_2+k_4)t}$, in equations (*12*) and (*13*). Then, if the distribution at time *t* (not the final distribution) is known, absolute values of the rate constants can be obtained. These equations can be transformed into the form employed by Garegg[14] for this special case.

When there is no interaction possible between the two hydroxyl groups, or between the substituted and the free hydroxyl group (usually for $n > 1$, if no long-range effects are anticipated[15]), $k_2 = k'_2$, $k_4 = k'_4$ and, therefore, $\mathbf{p} = 1-\mathbf{q}$. Substitution in equation (*12*) gives (*17*), from which the value $k_2/k_4 = k'_2/k'_4 = (1-\mathbf{q})/\mathbf{q}$ can be calculated. This modification:

$$\mathbf{q} = \frac{\log(c_B+c_A)-\log c_{A_0}}{\log c_A-\log c_{A_0}} \tag{17},$$

is valid also for deoxy sugars (R′ = H, $n = 1$), such as 1,6-anhydro-3-deoxy-β-D-*xylo*-hexopyranose and methyl abequoside, that do not possess the 1,3-diaxial arrangement of hydroxyl groups.

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*For further discussion, see ref. 10.

I.*b Evaluation of the ratios* k_2/k_4, k'_4/k_2, k'_2/k_4, k'_2/k_2, k'_4/k_4, *and* k'_2/k'_4 *at two known different distributions* c_A, c_B, c_C, and c'_A, c'_B, c'_C. — Evaluation of the ratio k'_2/k'_4 by equation (*1*) may be difficult when the differences between the individual rate-constants are too great, that is, if one of the monosubstituted derivatives is formed in very low yield and, therefore, is unavailable in sufficient amount. In addition to this complication, the partially substituted compounds that are generally the synthetic objective are consumed again in this second stage of the reaction. In such cases it is advantageous to perform the acylation or alkylation of the diol **A** to two different degrees of substitution. The pair of equations (*16*) and (*16'*) obtained are solved in such a way that an optional value of **k** is substituted (values starting with $\mathbf{k} = 0.1$ and successively increasing by 0.2 can be used) in equations (*16*) and (*16'*) in order to calculate **q** and **q'**. The correct value of **k** is then situated at the minimum of the dependence $|\mathbf{q} - \mathbf{q}'|$ versus **k.** It is evident that, for exact values of all concentrations, the difference $|\mathbf{q} - \mathbf{q}'|$ is zero for the correct value of **k**. The validity of **k** estimated in this way can be verified by comparing the ratios of rate constants calculated for both degrees of substitution according to I.*a*. The accuracy of the ratios thus calculated depends on the experimental error in determining the concentrations of single components of the reaction mixture. This error becomes more significant when two similar distributions are used for the calculation. For more-accurate results, it is advisable to use one of the distributions having c_A near zero ($c_A < 5\%$) in order to obtain sufficient sensibility in $\mathbf{k} = k'_2/k'_4$. The use of a third (fourth, etc.) set of concentrations of products can be used to further improve the precision. More than two distributions should be used in particular when one (or more) of the rate constants is substantially different from unity, that is, if the concentration of one component in the resulting mixture is very low.

In the acetylation of "A" already mentioned, when using the values $c_{\text{"A"}}$ 18.8, $c_{\text{"B"}}$ 23.7, and $c_{\text{"C"}}$ 7.1% for the first distribution (d.s. = 1.31), and the values $c_{\text{"A"}}$ 4.6, $c_{\text{"B"}}$ 13.8, and $c_{\text{"C"}}$ 2.1% for the second distribution (d.s. = 1.75; obtained analogously by reaction of "A" with 1.8 equivalent of acetyl chloride in pyridine), together with $c_{\text{"A}_0\text{"}}$ 100%, the minimum for $|\mathbf{q} - \mathbf{q}'|$ was found approximately at $\mathbf{k} = 3.0$. Calculation according to procedure I.*a* gave then the same results for both distributions as obtained in I.*a*.

II.*a Calculation of the maximum yield of the monosubstituted derivative* **B** *together with the required amount of reagent.* — Equation *12* gives the dependence of concentration of the monosubstituted derivative **B** on the concentration of the starting compound **A**. The maximum concentration of **B** is thus obtained at the point where $dc_B/dc_A = 0$. Differentiation of (*12*) with respect to c_A yields equation (*18*) which, after rewriting in the form (*19*), gives the value of the concentration of compound **A**,

$$\frac{\mathbf{p}}{(\mathbf{q}-1)}\left(1 - \mathbf{q}c_{A_0}^{(1-\mathbf{q})} c_A^{(\mathbf{q}-1)}\right) = 0 \qquad (18)$$

$$c_A = \left(\frac{1}{q c_{A_0}^{(1-q)}}\right)^{1/(q-1)} \qquad (19),$$

at the maximum concentration of **B**. By substituting this concentration into the relation (*12*), the value of $c_B^{\max}$ is obtained. The concentration of **C** at this point is obtained similarly by substitution in equation (*13*). The concentration, calculated from the distribution of the compounds obtained, d.s. $= (c_B + c_C + 2c_D)/100$, can be used as the criterion of the consumption of reagent, assuming quantitative reaction.

Thus, in the present example (Scheme II), 24.9% is the maximum yield of methyl 3-acetamido-2-*O*-acetyl-3,6-dideoxy-*β*-D-glucopyranoside ("**B**") that can be obtained, if the reaction conditions employed for the calculation of the constants **p**, **q**, **k** (see I.*a*) are used. The concentrations of other components at this point are the following: $c_{\text{"A"}}$ 29.0, $c_{\text{"C"}}$ 9.6, and $c_{\text{"D"}}$ 36.5%. The d.s. value corresponding to this distribution (d.s. 1.08) requires the net consumption of 1.09 equivalent of acetyl chloride, under anhydrous conditions (usually, 5–10% excess of the reagent over the calculated value should be employed).

II.*b* *Calculation of the maximum yield of the monosubstituted derivative* **C**, *together with the required amount of reagent.* — Calculation as in II.**a** can also be performed for the second monosubstituted derivative **C**. By differentiating equation (*13*) ($dc_C/dc_A = 0$) there is obtained equation (*20*) for the concentration of diol **A** at $c_C^{\max}$,

$$c_A = \left(\frac{1}{kq c_{A_0}^{(1-kq)}}\right)^{1/(kq-1)} \qquad (20)$$

and this concentration is then used for evaluating c_B (eq. *12*) and $c_C^{\max}$ (eq. *13*). The d.s. value and the consumption of reagent is then calculated according to procedure II.*b*.

Thus, the following concentrations of individual compounds at $c_{\text{"C"}}^{\max}$ are obtained for the reaction of "**A**" with acetyl chloride in pyridine: $c_{\text{"A"}}$ 49.3, $c_{\text{"B"}}$ 21.9, $c_{\text{"C"}}^{\max}$ 11.4, and $c_{\text{"D"}}$ 17.4%. This indicates that no more than 11.4% of methyl 3-acetamido-4-*O*-acetyl-3,6-dideoxy-*β*-D-glucopyranoside ("**C**") can be obtained under these conditions, and that in order to achieve this maximum yield, 0.68 equivalent of acetyl chloride must be used.

II.*c* *Calculation of the composition of the reaction mixture at any given concentration of unreacted starting compound.* — Equations (*12*) and (*13*) may be employed also for the calculation of c_B and c_C, that is, for the estimation of the composition of a reaction mixture at any given c_A value, if the values **p**, **q**, and **k** are known (normal substitution). This procedure permits a better comparison of an experimental result with one performed on another compound to a different degree of substitution.

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REFERENCES

1 J. M. SUGIHARA, *Advan. Carbohyd. Chem.*, 8 (1953) 1; D. H. BALL AND F. W. PARRISH, *ibid.*, 23 (1968) 233.

2 H. OHLE AND E. DICKHÄUSER, *Ber.*, 58 (1925) 2593.

3 E. L. ELIEL AND C. A. LUKACH, *J. Amer. Chem. Soc.*, 79 (1957) 5986; K. W. BUCK, A. B. FOSTER, A. R. PERRY, AND J. M. WEBBER, *J. Chem. Soc.*, (1963) 4171; K. W. BUCK, J. M. DUXBURY, A. B. FOSTER, A. R. PERRY, AND J. M. WEBBER, *Carbohyd. Res.*, 2 (1966) 122; J. M. KNOBLICH, J. M. SUGIHARA, AND T. YAMAZAKI, *J. Org. Chem.*, 36 (1971) 3407.

4 R. D. GUTHRIE, A. M. PRIOR, AND S. E. CREASEY, *J. Chem. Soc.*, C, (1970) 1961; G. J. F. CHITTENDEN AND J. G. BUCHANAN, *Carbohyd. Res.*, 11 (1969) 379; S. E. CREASEY AND R. D. GUTHRIE, *ibid.*, 22 (1972) 487; R. W. JEANLOZ AND D. A. JEANLOZ, *J. Amer. Chem. Soc.*, 79 (1957) 2579. J. J. WILLARD, J. SADOWSKI, AND W. VITALE, *Can. J. Chem.*, 41 (1963) 1223; C. P. J. GLAUDEMANS AND H. G. FLETCHER, JR., *Carbohyd. Res.*, 7 (1968) 480; A. C. MAEHLY AND T. REICHSTEIN, *Helv. Chim. Acta*, 30 (1947) 496; F. A. CAREY AND K. O. HODGSON, *Carbohyd. Res.*, 12 (1970) 463, N. L. HOLDER AND B. FRASER-REID, *Synthesis*, (1972) 83; D. HORTON AND J. H. LAUTERBACH, *J. Org. Chem.*, 34 (1969) 86; H. B. BORÉN, P. J. GAREGG, L. KENNE, L. MARON, AND S. SVENSSONS, *Acta Chem. Scand.*, 26 (1972) 644; S. UMEZAWA, T. TSUCHIYA, AND H. HINENO, *Bull. Chem. Soc. Japan*, 43 (1970) 1212; E. J. ROBERTS AND S. P. ROWLAND, *Carbohyd. Res.*, 5 (1967) 1; W. M. DOANE, B. S. SHASHA, E. I. STOUT, C. R. RUSSELL, AND C. E. RIST, *ibid.*, 4 (1967) 445.

5 J. J. WILLARD, J. S. BRIMACOMBE, AND R. P. BRUETON, *Can. J. Chem.*, 42 (1964) 2560.

6 P. J. GAREGG, *Acta Chem. Scand.*, 16 (1962) 1849; E. J. REIST, L. V. FISHER, AND D. E. GUEFFROY, *J. Org. Chem.*, 31 (1966) 226.

7 S. J. ANGYAL AND P. T. GILHAM, *J. Chem. Soc.*, (1957) 3691; T. SUAMI AND K. YABE, *Bull. Chem. Soc. Japan*, 39 (1966) 1931; S. J. ANGYAL AND R. J. HICKMAN, *Carbohyd. Res.*, 20 (1971) 97.

8 K. ČAPEK, J. ČAPKOVÁ-ŠTEFFKOVÁ, AND J. JARÝ, *Collect. Czech. Chem. Commun.*, 35 (1970) 321; K. KEFURT, Z. KEFURTOVÁ, AND J. JARÝ, *ibid.*, 38 (1973) 2627; K. KEFURT, J. STANĚK, JR., Z. KEFURTOVÁ, AND J. JARÝ, *ibid.*, in press; H. F. G. BEVING, H. B. BORÉN, AND P. J. GAREGG, *Acta Chem. Scand.*, 24 (1970) 919.

9 K. ČAPEK, J. ŠTEFFKOVÁ, AND J. JARÝ, *Collect. Czech. Chem. Commun.*, 31 (1966) 1854; K. ČAPEK, J. ŠTEFFKOVÁ, AND J. JARÝ, *ibid.*, 32 (1967) 2491; K. ČAPEK, J. ŠTEFFKOVÁ, AND J. JARÝ, *ibid.*, 33 (1968) 781; K. ČAPEK, J. ŠTEFFKOVÁ, AND J. JARÝ, *ibid.*, 33 (1968) 1750; K. ČAPEK, J. ŠTEFFKOVÁ, AND J. JARÝ, *ibid.*, 35 (1970) 107; A. C. RICHARDSON, *Carbohyd. Res.*, 4 (1967) 415; A D. BARFORD AND A. C. RICHARDSON, *ibid.*, 4 (1967) 408.

10 K. ČAPEK, J. STANĚK, JR., AND J. JARÝ, *Collect. Czech. Chem. Commun.*, in press.

11 R. U. LEMIEUX AND A. G. MCINNES, *Can. J. Chem.*, 38 (1960) 136.

12 J. PACÁK, J. PODEŠVA, Z. TOČÍK, AND M. ČERNÝ, *Collect. Czech. Chem. Commun.*, 37 (1972) 2589; R. W. JEANLOZ, A. M. C. RAPIN, AND S.-I. HAKOMORI, *J. Org. Chem.*, 26 (1961) 3939; D. SHAPIRO, A. J. ACHER, AND E. S. RACHAMAN, *J. Org. Chem.*, 32 (1967) 3767; J. M. MACLEOD, L. R. SCHROEDER, AND P. A. SEIB, *Carbohyd. Res.*, 30 (1973) 337.

13 J. F. CODINGTON, I. L. DOERR, AND J. J. FOX, *J. Org. Chem.*, 29 (1964) 558; A. R. TODD AND T. L. V. ULBRICHT, *J. Chem. Soc.*, (1960) 3275.

14 P. J. GAREGG, *Acta Chem. Scand.*, 17 (1963) 1343.

15 G. C. WOLF, E. L. FOSTER, AND R. T. BLICKENSTAFF, *J. Org. Chem.*, 38 (1973) 1276.