[Contribution from the Polarimetry Section, Bureau of Standards, United States Department of Commerce]

RELATIONS BETWEEN ROTATORY POWER AND STRUCTURE IN THE SUGAR GROUP. V.[1] THE CHLORO- AND BROMO-ACETYL DERIVATIVES OF ARABINOSE. THE NOMENCLATURE OF ALPHA AND BETA FORMS IN THE SUGAR GROUP. SOME DERIVATIVES OF 1,6-BROMO-ACETYL GLUCOSE, GENTIOBIOSE AND MALTOSE[2]

By C. S. Hudson and F. P. Phelps

Received August 8, 1924 Published November 5, 1924

It was shown in Part I[3] that the values of the specific rotation of chloro- and bromo-acetyl *l*-arabinose in chloroform solution that have been recorded by Chavanne[4] ($[\alpha]_D$ = —225 and —283, respectively) are of opposite sign to those predicted by theory (+231 and +264), and it was stated that "this complete disagreement obviously requires further experimental study." We have now prepared these crystalline derivatives by Chavanne's directions from both *l*- and *d*-arabinose and have measured the rotations of the resulting four halogen-acetyl arabinoses in chloroform solution. From these measurements it appears that Chavanne has mistaken the sign of the rotation of his compounds. The revised rotations are recorded in Table I.

Table I

The Rotations of the β-Chloro- and β-Bromo-acetyl Derivatives of Arabinose

Substance	$[\alpha]^{20}_D$ in $CHCl_3$	Molecular rotation $[M]_D$	Rotation of end carbon $A = [M]^{20}_D - B$[a]	
β-Chloro-acetyl *d*-arabinose	−244	−72,000	−41,900	A_{Cl}
β-Chloro-acetyl *l*-arabinose (mol. wt. 295)	+244	+72,000	+41,900	
β-Bromo-acetyl *d*-arabinose	−288	−97,600	−67,500	A_{Br}
β-Bromo-acetyl *l*-arabinose (mol. wt. 339)	+288	+97,600	+67,500	

[a] The value of B, the rotation of the acetylated basal chain of arabinose is $B_{l\text{-arabinose}}$ = +30,100 from the observed rotations of the alpha and beta forms of *l*-arabinose tetra-acetate (see Part I, p. 466) and consequently $B_{d\text{-arabinose}}$ = —30,100.

As these values agree with those calculated in sign and approximately so in magnitude, the exception that was strikingly apparent from Chavanne's data disappears and the halogen-acetyl derivatives of arabinose fall into

---

[1] Part IV was published in This Journal, **46,** 979 (1924).

[2] Published by permission of the Director of the Bureau of Standards, U. S. Department of Commerce.

[3] This Journal, **46,** 466 (1924).

[4] Chavanne, *Compt. rend.*, **134,** 661 (1902).

line with those of the other sugars by conforming, in first approximation at least, to the van't Hoff principle of optical superposition.

The observed specific rotations are larger than those that were calculated by the use of the average values $A_{Cl} = 37,800$[5] and $A_{Br} = 59,300$, from Part I, Table II. However, the value of A_{Cl} for chloro-acetyl maltose is 41,400 and for chloro-acetyl glucose is 40,200, which agrees well with the value now found for chloro-acetyl arabinose. The value $A_{Br} = 67,500$ for bromo-acetyl arabinose is considerably larger than those found for this coefficient in Part I from the similar derivatives of four other aldoses, the largest previous value being 61,700 for bromo-acetyl xylose. An explanation of this exceptionally large value of A_{Br} for the arabinose derivative is not directly apparent but there are several facts relating to the question which may here be recorded because they will probably be involved in any solution of the problem. The alpha and beta forms of the tetra-acetate of *l*-arabinose show a difference in molecular rotation of 33,400,[6] a value which is decidedly less than those found for the similar acetates of most other sugars, which range from 36,200 for the xylose tetra-acetates to 40,500 for the maltose octa-acetates. It is to be observed, however, that the mannose penta-acetates differ by only 31,200 and the first and second galactose penta-acetates by 32,700, this last value being quite near that found for the arabinose tetra-acetate. Hudson and Dale[6] have shown that the observed rotation of β-triacetyl methyl *l*-arabinoside (+182) differs considerably from the calculated value (+197). It has been shown in Part I that the observed rotation of the first chloro-acetyl galactose is exceptionally large, and Hudson and Yanovsky[7] have shown that both arabinose and galactose exhibit an anomaly in their mutarotation which distinguishes them from other sugars. Since *d*-galactose and *l*-arabinose are closely similar in configuration, differing only by the interposition of Carbon 5 in galactose, it may be that the deviations from the principle of optical superposition that have now been found for certain of their derivatives and the anomaly in their mutarotation are in some manner related to the possession by them of a common type of structure. In

---

[5] This value should be 37,900 and the values of the molecular rotations of the chloro-acetyl derivatives of xylose, glucose, mannose, lactose, maltose and cellobiose of Part I, Table II, should be 48,700, 60,900, 33,000, 47,200, 104,100 and 47,800 respectively, because the molecular weights of these compounds are one unit larger than the values used in the table. These corrections are so slight that they do not affect any of the conclusions. This opportunity may be taken to correct some misprints. The calculated specific rotation of β-chloro-acetyl glucose (Part I, p. 475) should be —47 rather than +47, as is evident from the context. The reference to the preparation of the fluoro-acetyl derivatives of xylose, glucose and cellobiose by D. H. Brauns (p. 464) should be 6 rather than 7. In Part III, p. 485, β-methyl gentiobiose should read β-methyl gentiobioside.

[6] Hudson and Dale, THIS JOURNAL, **40,** 992 (1918).

[7] Hudson and Yanovsky, *ibid.*, **39,** 1013 (1917).

any explanation of these peculiarities it should not be overlooked that the existence of four penta-acetates of galactose proves that at least two types of ring structure are to be expected among its derivatives. Possibly similar ring types occur among the derivatives of arabinose.[8]

In Part I it was shown that the synthesis of Koenigs and Knorr involves a Walden inversion on the asymmetric carbon atom that is concerned in the substitution, α-bromo-acetyl glucose ($[\alpha]_D = +198$) passing by this reaction to β-glucose penta-acetate or β-tetra-acetyl methyl glucoside. No exception to this rule was found among the many cases that were considered. The arabinose derivatives also follow this rule since the molecular rotation of bromo-acetyl *l*-arabinose, +97,600, is *more positive* than that of the acetylated *l*-arabinose chain, +30,100, while that of the tetra-acetyl *l*-arabinose that results from the bromo derivative by Koenigs and Knorr's synthesis is *less positive*, +13,400 (Hudson and Dale[6]), showing that the rotation of the end asymmetric carbon atom has become reversed in sign during the course of the synthesis.

The Nomenclature of Alpha and Beta Forms in the Sugar Group

It was shown in Part I that the numerous aldose halogen-acyl derivatives therein mentioned are alpha forms with the exception of the second chloro-acetyl galactose, which was classed as a beta compound, though the first chloro-acetyl galactose was shown to be an alpha form. As the halogen-acetyl derivatives of arabinose are classed in the present article as beta compounds it may appear at first sight that arabinose differs from the other aldoses in the respect that a beta derivative rather than an alpha one is produced when it passes through the usual reactions by which halogen-acetyl sugars are formed. However, it can be shown that this difference is really only a consequence of the conventional system of nomenclature for alpha and beta forms, and that arabinose resembles the other sugars in typical reactions provided the comparisons are made by the use of the configurations established by Fischer, which is of course the logical method. His structure for *l-arabinose* is identical with that for *d-galactose* with the exception of the added presence of Carbon 5 in galactose, and as this carbon has little influence on the rotation[9] it is to be expected that structurally similar derivatives of the two sugars will have rotations of similar sign and magnitude. On the other hand, since the sugars belong to opposite (*d* and *l*) series the conventional naming of these structurally similar forms is

---

[8] In support of this idea it is recalled that Hudson and Dale (Ref. 6) have remarked concerning the large proportion of sirupy arabinose acetate that was obtained along with a small yield of crystalline α-arabinose tetra-acetate from the acetylation of arabinose with acetic anhydride and sodium acetate. This material may represent an arabinose tetra-acetate of new ring structure. The third galactose penta-acetate was discovered in an analogous acetylation of galactose. The subject will be investigated.

[9] Hudson, THIS JOURNAL, **33**, 409 (1911).

done by opposed ways; it thus results that β-*l*-arabinose ($[\alpha]_D = +175$, mol. wt. 150) and α-*d*-galactose ($[\alpha]_D = +144$, mol. wt. 180) are the names given to structurally similar forms of these sugars having molecular rotations nearly alike (+26,200 and +25,900). On structural ground, therefore, a β-halogen-acetyl *l*-arabinose is the analog of an α-halogen-acetyl *d*-galactose. The reason for naming the forms of the sugars of the dextro and levo series in these opposed ways was explained when the present system of nomenclature was proposed;[10] it follows as a direct consequence of designating the optical antipode of α-methyl *d*-glucoside as α-methyl *l*-glucoside, a designation which Fischer[11] originally applied to these enantiomorphic substances. It further follows logically that the known forms of the halogen-acetyl derivatives of *l*-arabinose, which are to be designated beta compounds on account of their rotations, are to be considered structurally similar to the alpha forms of the halogen-acetyl derivatives of *d*-galactose, as mentioned, and that the pentose conforms with the behavior of the hexose in yielding halogen-acetyl derivatives of this type of structure by the reactions that are customarily employed. In a similar manner the acetylation of *l*-arabinose with acetic anhydride and sodium acetate (Hudson and Dale[6]) yields the alpha form of the tetra-acetate where *d*-galactose yields its β-penta-acetate, and the reaction between *l*-arabinose and acidified methyl alcohol yields β-methyl *l*-arabinoside where *d*-galactose yields α-methyl *d*-galactoside; in these cases again the difference is only an apparent one due to a convention of nomenclature and when the comparison is made on structural grounds the two sugars of similar structure react alike. It seems important to emphasize these matters in order to prevent the drawing of erroneous conclusions when the differences of reactivity of the alpha and beta forms of the various sugars and their derivatives are compared, an interesting experimental study which has already received considerable attention[12] and will doubtless be greatly extended. An example may serve to illustrate the pitfalls that may be expected in such studies unless the necessary caution concerning nomenclature is used. From a comparison of the configurations of *d*-glucose and *l*-idose (Rosanoff's nomenclature) it is evident that the hypothetical β-methyl *l*-idoside is the structural relative of α-methyl *d*-glucoside rather than of β-methyl *d*-glucoside.[13] The configurations of the two compounds

---

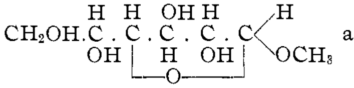
[10] Hudson, *ibid.*, **31**, 66 (1909).

[11] (a) Fischer, *Ber.*, **28**, 1145 (1895). See also (b) Fischer and Armstrong, *Ber.*, **34**, 2887 (1901), Footnote 3.

[12] Compare Svanberg and Josephson, *Ber.*, **57B**, 297 (1924).

[13] In naming the forms of methyl *l*-idoside, which as yet have not been prepared, the more dextrorotatory one is to be designated beta because the sugar belongs in the *levo* series, but the rotation of this form will in all probability, on account of the similarity of structure between *d*-glucose and *l*-idose, and the small rotation of Carbon 5, be found to be very near that of α-methyl *d*-glucoside.

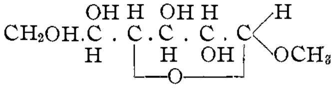
are to be written



$$\mathrm{CH_2OH.\underset{OH}{\overset{H}{C}}.\underset{|}{\overset{H}{C}}.\underset{H}{\overset{OH}{C}}.\underset{OH}{\overset{H}{C}}.\underset{|}{C}{<}^{H}_{OCH_3}}$$

α-Methyl *d*-glucoside, I

and



$$\mathrm{CH_2OH.\underset{H}{\overset{OH}{C}}.\underset{|}{\overset{H}{C}}.\underset{H}{\overset{OH}{C}}.\underset{OH}{\overset{H}{C}}.\underset{|}{C}{<}^{H}_{OCH_3}}$$

β-Methyl *l*-idoside, II

On account of the close similarity between the structures of these substances there is a possibility that the enzyme α-glucosidase may hydrolyze the idoside and if such prove to be the case it might possibly be inferred that an alpha enzyme hydrolyzes a derivative belonging in the beta series. Such a conclusion would be incorrect because the idoside is not a structural relative of β-methyl glucoside.

Svanberg and Josephson[12] have recently criticized the customary naming of alpha and beta forms on the basis of comparative rotations with the general statement that this system is of "hypothetical character" and have suggested that a comparison of the chemical or biochemical reactivities of the two forms of a given sugar furnishes a preferable basis of nomenclature.

The ambiguities and exceptions which one meets at the present time in trying to found such a new system are well illustrated, however, by several of the experimental facts which they record and are further emphasized by the difficulty which Freudenberg and Doser[14] have mentioned in the case of di-acetone glucose, where one cannot decide whether the greater reactivity of β- over α-glucose in combining with acidified acetone should be referred to a faster rate of reaction in a homogeneous system or to the greater solubility of β-glucose in the solvent. A requirement of a satisfactory system of nomenclature is that it shall not lead to ambiguity, and it does seem that the system now in use meets this demand; the precision with which classifications can be made under it is well shown in the articles of this series. It is true that it is founded upon a theoretical basis, which is van't Hoff's principle of optical superposition, but the applicability of this principle to a large number of substances of the sugar group has been firmly established by many experimental investigations during the past fifteen years. *The numerical relations which have been found among the rotations of the sugars and their derivatives are not hypotheses but are facts obtained from physical measurements of rotations, and the theory which so simply and clearly accounts for the signs and magnitudes of these rotations is the one upon which the present system of naming the alpha and beta forms is founded. It seems very desirable that any system of nomenclature in the sugar group should have this kind of theoretical foundation.* One recalls in this connection that the facts from which the configurations of the sugars were established by Fischer prove these configurations only because they can be directly deduced from a theory, namely, the van't Hoff-LeBel

---

[14] Freudenberg and Doser, *Ber.*, **56B**, 1246 (1923).

hypothesis of an asymmetric carbon atom of definitely assumed characteristics.[15] To attempt the replacement of the present system of naming alpha and beta forms by any plan which bases its distinctions upon vaguely definable conceptions of relative chemical or biochemical reactivity seems a step backward. The ascertainment of these relative reactivities is a useful study of the dependence of reactivity upon structure but the matter of a logical system of nomenclature is a separate subject.

In connection with this topic reference may be made to the recent article by R. Kuhn[16] in which he proposes to classify glucosides on the basis of an experimental identification of the form of the parent sugar that is liberated when the glucoside is hydrolyzed by an enzyme. He would base the classification upon the rotatory power, the comparison of "other physical constants," or upon empirical rules of synthesis, only when the method of enzymotic hydrolysis cannot be applied. It does not seem warranted to place the deductions that can be drawn from the comparison of rotatory powers in the sugar group as of no greater value than the uncertain conclusions that are at times obtained from comparisons of melting points, refractive indices, heats of combustion, etc., or even the conclusions that are derived from rules of synthesis, though it is not to be denied that these last are often of considerable importance as indications, as has frequently been emphasized in the articles of this series in the case of the rule for Koenigs and Knorr's reaction. The large difference between the rotations of the members of an α-β pair of compounds in the sugar group is dependent upon the oppositely directed rotations of a single carbon atom (Carbon 1 of the aldoses) and it is the opposed form of the arrangement in space of the groups attached to this same carbon that makes possible the existence of two isomers in place of a single substance. There is here, accordingly, a simple relationship between the two space-structures of this determinative or "key" carbon atom present in the isomers and the difference between their rotations, and this relationship is not confused by the influence of secondary factors, as may probably be the case when structures are inferred from the relative values of other physical constants.[17] Al-

---

[15] The matter cannot be expressed more clearly than by Fischer's introductory sentence in the immortal article that records the proof of the configuration of glucose and originates a theoretical chemistry of the sugars [*Ber.*, **24,** 1836 (1891)]: "Alle bisherigen Beobachtungen in der Zuckergruppe stehen mit der Theorie des asymmetrischen Kohlenstoffatoms in so vollkommener Uebereinstimmung, dass man schon jetzt den Versuch wagen darf, dieselbe als Grundlage für die Klassification dieser Substanzen zu benutzen."

[16] Kuhn, *Ber.*, **56B,** 857 (1923).

[17] It seems very probable that the position of the ring in a sugar or its derivatives may eventually become an important consideration in the classification of alpha and beta forms and it may be advisable from theoretical considerations of the space relationship of asymmetric Carbon 1 to different types of ring structure to reverse in a few instances the present names, but such possible changes would constitute a development of

though E. F. Armstrong's method of enzymotic hydrolysis has been of much importance in showing the relationship of a few glucosides to definite forms of their parent sugars, its applicability is so limited on account of the specific nature of enzyme actions that its main value lies in its occasional use as a control upon the classifications that can nearly always be readily made on the basis of rotatory powers. Moreover, while such hydrolyses can at times show the existence of common structural features in a glucoside and one form of its parent sugar they fail when an attempt is made to extend the comparisons to show correlations of structure among the glucosidic derivatives of different sugars. On the other hand, the comparison of rotatory powers gives important evidence on this question, as was shown in Part IV[1] for the members of the complicated group of acetates of galactose and α-mannoheptose.

The present system of naming alpha and beta forms on the basis of rotatory powers is so definite in its classifications, the experimental determinations which are required for its application (measurements of rotation) are so readily made, and such important information regarding structural types in the sugar group is disclosed by it, that it seems most advisable to continue its use. It should be borne in mind, however, that since the system is founded in part upon the *dextro* and *levo* classification of the sugars that Fischer introduced, its classifications are arbitrary in the same sense as are those of Fischer, and at times they are at first sight somewhat confusing, as in the case where an alpha form of one sugar is evidently of closer structural relationship to a beta form of another sugar than to its alpha form.

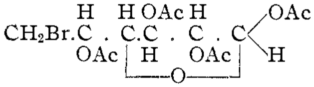
The Calculated Rotations of Fischer and Armstrong's Dibromo-acetyl Glucose (1,6-Bromo-2,3,5-acetyl α-Glucose), its β-Methyl Glucoside (6-Bromo-2,3,5-acetyl β-Methyl Glucoside) and α-Tetra-acetate (6-Bromo-1,2,3,5-acetyl α-Glucose)

In Part I the specific rotation of the first of these compounds, which has the structural formula XVI (p. 474), was calculated from the rotations of two benzyl glucosides that are related to it to be +169. This result is in error, however, because the molecular weight of dibromo-acetyl glucose was taken as 474. The correct weight is 432 and consequently the calculated rotation becomes +186 in place of +169. In the calculation there is the uncertainty that the rotation of one of the benzyl glucosides was measured in alcohol rather than in chloroform. There has now been found an independent way by which this calculation can be made. Fischer, Helferich and Ostmann[18] have observed the specific rotation of

the present system of nomenclature by the addition of new theoretical ideas, not its abandonment, and the need for such changes can only be determined after the ring structures are more definitely known than at present.

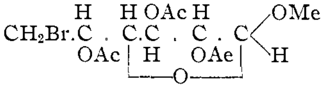
[18] Fischer, Helferich and Ostmann, *Ber.*, **53**, 873 (1920).

6-bromo-1,2,3,5-acetyl β-glucose (mol. wt., 411) to be +12.1 in acetylene tetrachloride; hence its molecular rotation is (12.1) (411) = +4970. The structure of the substance, which is considered to be a beta form because it is derived from dibromo-acetyl glucose by Koenigs and Knorr's synthesis, is III, and accordingly its molecular rotation is to be written $B'_{glucose} - A_{Ac} = +4970$. Since $A_{Ac} = +19{,}100$ (Part I, p. 470) the rotation of the basal chain is $B'_{glucose} = +24{,}100$. This is an important determination because from it there can be calculated by the addition or subtraction of the known values of A_{Me}, A_{Ac}, etc., the rotations of many 6-bromo substitution products derived from glucose and from many other sugars. The specific rotation of *dibromo-acetyl glucose* becomes thus $[\alpha]_D = (B'_{glucose} + A_{Br}) \div \text{mol. wt.} = (24{,}100 + 59{,}300) \div 432 = 193$ in chloroform. The two calculated values for this substance, 186 and 193, agree fairly well. The latter one seems more reliable because the measurements from which it is derived were made throughout in chloroform or acetylene tetrachloride solution.[19]



$CH_2Br.\underset{OAc}{\overset{H}{C}}\,.\,\overset{H}{C}.\underset{H}{\overset{OAc}{C}}\,.\,\underset{OAc}{\overset{H}{C}}\,.\,C\begin{smallmatrix}OAc\\H\end{smallmatrix}$ (ring —O—)

III



$CH_2Br.\underset{OAc}{\overset{H}{C}}\,.\,\overset{H}{C}.\underset{H}{\overset{OAc}{C}}\,.\,\underset{OAe}{\overset{H}{C}}\,.\,C\begin{smallmatrix}OMe\\H\end{smallmatrix}$ (ring —O—)

IV

---

[19] This example illustrates the importance attached to the selection of a solvent in the measurement of the rotations of new compounds. When Hudson and Dale [This Journal, **37**, 1264 (1915)] determined the coefficients $B_{glucose}$, A_{Ac} and A_{Me}, they measured the rotations of the glucose penta-acetates and methyl glucoside tetra-acetates in six solvents to learn which one was best suited for general use in testing the applicability of the principle of optical superposition. Benzene was shown to be quite unsuitable, methyl alcohol and acetic acid somewhat unsatisfactory, while chloroform and ethyl alcohol (absolute) gave good results. Chloroform was selected for the subsequent measurements of many acetylated derivatives of the sugars, from which the coefficients now in use have been derived, on account of the fact that it is an excellent general solvent and that the rotations in the literature pertaining to sugar derivatives that are insoluble in water refer in the majority of cases to their chloroform solutions. Unfortunately, the sugars and some of their derivatives are not soluble in chloroform; water has accordingly been used as the solvent for these substances with good results, as it appears that optical superposition holds fairly closely for both aqueous and chloroform solutions of many substances belonging in the sugar group. A more precise study of the question of the solvents suitable for such studies and also a comparison of the rotations for light of various wave lengths would be very useful. Until better recommendations can be made, rotations should be compared in water or in chloroform solution wherever possible. A large number of compounds which were prepared in Fischer's laboratory during the later years of his life were measured in acetylene tetrachloride solutions. Fortunately this solvent appears to give values almost identical with those of chloroform solutions, doubtless on account of the close chemical relationship of the two liquids, but even so it would seem advisable in future research work to discard the use of acetylene tetrachloride or preferably to measure the rotations in chloroform as well. It is to be hoped that investigators who have rare sugar derivatives in hand may measure the rotations in chloroform where the solubility is sufficient, as an aid to the development of such studies as are being described in the present series of articles.

Brigl and Wrede[19a] have reported the preparation of a substance which is probably the alpha form of *6-bromo-1,2,3,5-acetyl glucose* (that is, the alpha form corresponding to the beta derivative that is represented by III), but there appears to be no record so far of its rotation. The value obtained by calculation is $(B'_{\text{glucose}} + A_{\text{Ac}}) \div 411 = 105$.

Fischer, Helferich and Ostmann[18] have prepared 6-bromo-2,3,5-acetyl β-methyl glucoside (mol. wt. 383, Structure IV) but its rotation was not recorded. The calculated value is $[\alpha]_D = (B'_{\text{glucose}} - A_{\text{Me}}) \div 383 = (24{,}100 - 26{,}900)$[20] $\div 383 = -7$ in chloroform.

The Rotation of α-Bromo-acetyl Gentiobiose Observed by Zemplén

The specific rotation of this substance was calculated in Part I to be +108 in chloroform. Zemplén[21] has recently succeeded in preparing the compound in crystalline form and has found the value $[\alpha]_D^{19} = +112$ in chloroform, which agrees well with the predicted rotation. As the calculation was based on the assumption that the substance belongs in the alpha series, this allocation may now be considered established. Since this alpha derivative has been found[22] to yield β-methyl gentiobioside hepta-acetate by Koenigs and Knorr's synthesis, it is evident that the usual Walden inversion here takes place. The value of $B_{\text{gentiobiose}}$ has been found to be +15,900 from the rotations of the two forms of gentiobiose octa-acetate (Part I, p. 477). The molecular rotation of α-bromo-acetyl gentiobiose is $(112)(699) = +78{,}300 = (B_{\text{gentiobiose}} + A_{\text{Br}})$; hence $A_{\text{Br}} = +62{,}400$, which agrees with the values of this coefficient found previously. This confirmation of theory by Zemplén's recent measurement lends strong support to the assumptions upon which the calculations have been based, as do likewise the newly measured rotations of the halogen-acetyl derivatives of arabinose, and the recent proof by Haworth and Wylam that the biose of amygdalin is gentiobiose, a conclusion that was reached in Part III from data on rotatory powers.[23]

The Calculated Rotations of Some Acyl Derivatives of Maltose and Gentiobiose

On account of the recent demonstration that maltose and gentiobiose constitute the first known α-β pair of compound sugars (Haworth and Wylam, Hudson) the comparison of the various properties of these sugars and their derivatives becomes a subject of interest. As a beginning in

---

[19a] Brigl and Wrede, *Z. physiol. Chem.*, **116**, 13 (1921).

[20] The value of A_{Me} is taken from Part I, p. 470.

[21] Zemplén, *Ber.*, **57B**, 698 (1924).

[22] Hudson and Johnson, THIS JOURNAL, **39**, 1272 (1917).

[23] The article by Haworth and Wylam [*J. Chem. Soc.*, **123**, 3120 (1923)] was received for publication Nov. 3, 1923 and Part III of this series Nov. 14, 1923. These independently conducted researches have led to the same conclusion, as regards the identity of the biose of amygdalin with gentiobiose, by quite different methods of study.

this field there are recorded in Table II the calculated rotatory powers in chloroform solution of a number of their acyl derivatives. The method that is followed in the calculations has been illustrated so often that a tabulation of the data may here suffice. The values of the various coefficients used in the calculations are taken from Part I, A_{Cl} being corrected as mentioned. The uniformly good agreement between the observed and the calculated rotations of the five compounds that have already been investigated seems a reliable indication that the calculated rotations of the remaining substances are near the true values.[27]

TABLE II

THE ROTATIONS OF SOME ACYL DERIVATIVES OF MALTOSE AND GENTIOBIOSE

Substance	Mol. wt.	Calculated molecular rotation	$[\alpha]_D$ In chloroform Calc.	Obs.
α-Fluoro-acetyl maltose	638	$B_{maltose} + A_F = 62{,}700 + 9800$	114	?
α-Chloro-acetyl maltose	655	$B_{maltose} + A_{Cl} = 62{,}700 + 37{,}900$	154	159[24]
α-Bromo-acetyl maltose	699	$B_{maltose} + A_{Br} = 62{,}700 + 59{,}300$	175	?[25]
α-Iodo-acetyl maltose	746	$B_{maltose} + A_I = 62{,}700 + 85{,}400$	199	?
α-Nitro-acetyl maltose	681	$B_{maltose} + A_{NO_3} = 62{,}700 + 37{,}100$	147	149[24]
β-Hepta-acetyl methyl maltoside	650	$B_{maltose} - A_{Me} = 62{,}700 - 26{,}900$	55	54[26]
α-Fluoro-acetyl gentiobiose	638	$B_{gentiobiose} + A_F = 15{,}900 + 9800$	40	?
α-Chloro-acetyl gentiobiose	655	$B_{gentiobiose} + A_{Cl} = 15{,}900 + 37{,}900$	82	?
α-Bromo-acetyl gentiobiose	699	$B_{gentiobiose} + A_{Br} = 15{,}900 + 59{,}300$	108	112[21]
α-Iodo-acetyl gentiobiose	746	$B_{gentiobiose} + A_I = 15{,}900 + 85{,}400$	136	?
α-Nitro-acetyl gentiobiose	681	$B_{gentiobiose} + A_{NO_3} = 15{,}900 + 37{,}900$	78	?
β-Hepta-acetyl methyl gentiobioside	650	$B_{gentiobiose} - A_{Me} = 15{,}900 - 26{,}900$	−17	−19[22]

---

[24] From Part I.

[25] Bromo-acetyl maltose was crystallized by Fischer and Armstrong [*Ber.*, **35,** 3153 (1902)] but they did not measure its rotation.

[26] Hudson and Sayre, THIS JOURNAL, **38,** 1867 (1916).

[27] In connection with the subject of the related structures of maltose and gentiobiose attention is called to the fact that the rates of mutarotation of these sugars that are recorded in the literature are closely the same. When it was shown from rotatory data that lactose and cellobiose possess the same linkage between their respective hexose constituents [Hudson, THIS JOURNAL, **38,** 1573 (1916)], which was subsequently proved by Haworth and his co-workers to be the 1–5 union, it was mentioned that the rates of mutarotation of lactose and cellobiose have practically identical values. These facts, taken in conjunction with some unpublished comparisons of a similar nature, indicate that *the comparative rates of mutarotation of substances of the sugar group can be correlated quite directly with structures.* This will be further developed in a subsequent article, and in particular the rates of mutarotation of glucosamine and chondrosamine will be used to throw light on their structures, which are at present not definitely known.

Postscript

After the manuscript of the present article was completed, a publication by D. H. Brauns[28] has appeared in which the rotations in chloroform solution of fluoro-, chloro-, bromo- and iodo-acetyl *l*-arabinose are recorded. Brauns has corrected the sign of the rotation of Chavanne's two compounds but has evidently not read the remarks on that subject that were published in Part I of this series (p. 466), as he does not refer to that previous indication of the error in Chavanne's signs. Our values for the rotations of chloro- and bromo-acetyl *l*-arabinose agree closely with those of Brauns and there can be no longer any doubt regarding the correct signs. It may be added that our experimental work was performed in the latter months of 1923 and that we had no knowledge that Brauns was measuring the same compounds. It seems well worth while that there should have been this partial duplication of work because of the theoretical importance attached to the correction of Chavanne's signs. The rotations found by Brauns are here tabulated in the usual manner to show the values of the coefficients that may be derived from the molecular rotations.

TABLE III

THE ROTATIONS OF THE HALOGEN-ACETYL DERIVATIVES OF *l*-ARABINOSE (BRAUNS' MEASUREMENTS)

Substance	Mol. wt.	$[\alpha]^{20}_D$ in $CHCl_3$	Molecular rotation $[M]_D$	Rotation of end carbon $A = [M]_D - B_{l\text{-arabinose}}$
β-Fluoro-acetyl *l*-arabinose	278	+138	38,400	8,300 (A_F)
β-Chloro-acetyl *l*-arabinose	295	+244	72,000	41,900 (A_{Cl})
β-Bromo-acetyl *l*-arabinose	339	+287	97,300	67,200 (A_{Br})
β-Iodo-acetyl *l*-arabinose	386	+339	130,800	100,700 (A_I)

The very large differences between A_I for iodo-acetyl arabinose and iodo-acetyl glucose (from Part I, Table II), 100,700−85,600 = 15,100, corresponding to about 36° in their specific rotations, seems to be evidence of considerable weight that there is a difference between the ring structures of the substances, which supports the similar view that has been suggested earlier in this article on account of the rather large rotation of bromo-acetyl arabinose. The value of A_F is not appreciably different from that obtained from fluoro-acetyl xylose (8400) in Part I. The four halogen-acetyl derivatives of arabinose are to be classed as beta compounds on the basis of their rotations for the reasons mentioned earlier in the present article.[29]

---

[28] THIS JOURNAL, **46**, 1484 (1924).

[29] It was mentioned in Part I (p. 475) that "the values for the rotations of the terminal asymmetric carbon atom now known for so many types of derivatives allow the calculation of the rotations of a large number of halogen-acyl, nitro-acyl and mixed acyl derivatives of various sugars and glucosides," and that "it does not seem desirable to burden the literature with these calculated values, as the typical examples which have

Experimental Part

Preparation of Chloro-acetyl *d*-Arabinose.—The directions of Chavanne were followed. Five g. of levorotatory *d*-arabinose ($[\alpha]_D^{20} = -105$) was dissolved in 10.5 g. of acetyl chloride by shaking the mixture in a machine during about 14 hours, using a flask fitted with a calcium chloride outlet tube. The resulting solution was taken up with dry chloroform, washed first with ice water containing a little sodium bisulfite, then with ice water made slightly alkaline with sodium carbonate, and then with ice water alone. The chloroform solution was dried with sodium sulfate and diluted with petroleum ether. On evaporation in a current of dry air crystallization took place. The crystals were washed with dry ether, recrystallized from benzene, again washed with ether and dried in a desiccator over sulfuric acid and potassium hydroxide to constant weight. The $[\alpha]_D^{20}$ value in chloroform solution was -227. These crystals were recrystallized from chloroform solution by the addition of ether and the substance then showed $[\alpha]_D^{20} = -245$ and two subsequent recrystallizations gave products with rotations of -242 and -246, respectively. The average value $[\alpha]_D^{20} = -244$ is taken to be the specific rotation of chloro-acetyl *d*-arabinose in chloroform solution. An estimation of chlorine by dissolving the substance in dil. nitric acid and titrating according to the Volhard method showed the theoretical value for chloro-triacetyl arabinose.

Preparation of Chloro-acetyl *l*-Arabinose.—Starting with dextro-rotatory *l*-arabinose and acetyl chloride, chloro-acetyl *l*-arabinose was prepared similarly. The values for the recrystallized substance obtained in two experiments were $[\alpha]_D^{20} = +243.1$ and $+243.7$ in chloroform.

Preparation of Bromo-acetyl *d*-Arabinose.—This was readily prepared from levorotatory *d*-arabinose and acetyl bromide by interaction at zero in an ice-bath. The crystals were recrystallized from chloroform by adding ether and the first crop showed $[\alpha]_D^{20} = -284$. After several recrystallizations a constant value of -290 in chloroform was found. A bromine estimation by the Volhard method gave the theoretical value for bromo-triacetyl arabinose.

Preparation of Bromo-acetyl *l*-Arabinose.—This was prepared similarly from dextrorotatory *l*-arabinose and acetyl bromide and recrystallized several times. The values found were $[\alpha]_D^{20} = -287$ and -285. The average value 288 is selected as the magnitude of the rotation of both forms of bromo-acetyl arabinose. In all the measurements the readings were made in a Bates type saccharimeter with white light and a dichromate filter, which gives a light of effective wave length about 585 instead of the 589 sodium line; in consequence the values may be one or two degrees too large. The rotatory dispersion of the solutions is enough different from that of quartz to make the setting somewhat uncertain and it is probably for this reason that the agreement between the values of the rotations of the dextro and levo forms of bromo-acetyl arabinose

---

been given will illustrate the method of applying the appropriate coefficients in particular cases." The fluoro- and iodo-acetyl derivatives of arabinose are such cases and since Brauns has not referred to the values that may be so calculated they are here recorded from the data of Part I.

Fluoro-acetyl *l*-arabinose, $[\alpha]_D = (B_{l\text{-arabinose}} + A_F) \div \text{Mol. wt.} = (30{,}100 + 9800) \div 278 = +144.$

Iodo-acetyl *l*-arabinose, $[\alpha]_D = (B_{l\text{-arabinose}} + A_I) \div \text{Mol. wt.} = (30{,}100 + 85{,}400) \div 386 = +299.$

The calculated and observed values for the fluoro derivative agree fairly well and, as indicated previously, the agreement is almost exact if the value of A_F from fluoro-acetyl xylose is used in the calculation. The calculated value for the iodo compound is much lower than the observed, a fact which may prove to be of much theoretical importance, as has been mentioned.

is not better. However, a precision measurement of the rotations has not been the object of the present investigation. The results recorded in the table are probably correct within 2°.

The four halogen-acetyl derivatives appear to be quite stable if kept dry, even when exposed to diffused sunlight. They have been kept for months at room temperature in a desiccator over sulfuric acid and potassium hydroxide, and in some cases over potassium hydroxide alone, without apparent deterioration. They form relatively large, perfect and colorless crystals when grown slowly from solution.

Summary

An experimental revision of the rotations of the chloro- and bromo-acetyl derivatives of arabinose confirms the calculations made in Part I, as it is shown that the correct signs are the reverse of those previously recorded by Chavanne. In the meantime D. H. Brauns has confirmed this deduction from theory through his preparation and measurement of the rotations of fluoro-, chloro-, bromo- and iodo-acetyl *l*-arabinose. The rotation of fluoro-acetyl arabinose agrees well with the calculated value. Iodo-acetyl arabinose exhibits a rotation about 36° larger than that calculated by the use of the coefficient A_I derived from the rotation of iodo-acetyl glucose and it is suggested that this large difference may indicate the presence of a new ring type of structure in the arabinose compound. This indication is supported by the rather large rotation of bromo-acetyl arabinose. The rotation of chloro-acetyl arabinose is somewhat, but not considerably, larger than the calculated value. On the basis of rotatory powers it is shown that the known halogen-acetyl arabinoses, which have hitherto not been classified, are to be named beta compounds. It is emphasized that the synthesis of Koenigs and Knorr involves a Walden inversion on the end asymmetric carbon atom in all cases now known. A discussion of the nomenclature of alpha and beta forms in the sugar group brings out the importance of following the system of nomenclature that one of us suggested in 1909, now in general use; a number of arguments are presented which lead us to reject the recent suggestions of Svanberg and Josephson and of Kuhn, who have favored the substitution of other methods of naming. The specific rotation of α-bromo-acetyl gentiobiose calculated in Part I, +108, has now been verified through Zemplén's recent preparation of this substance; he records the value +112. The conclusions of Part III, based upon rotations, that the biose of amygdalin is gentiobiose and that gentiobiose and maltose constitute the first known α-β pair of compound sugars, have been proved independently by Haworth and Wylam through conventional methods, as described in their article published concurrently with Part III. Calculations are recorded of the rotations of *1,6-bromo-2,3,5-acetyl α-glucose* and the related *6-bromo-1,2,3,5-acetyl α-glucose* and *6-bromo-2,3,5-acetyl β-methyl glucoside;* these substances have been described in the literature without records of their rotations. From the recorded rotation of *6-bromo-1,2,3,5-acetyl β-glucose*

the value of the coefficient $B'_{\text{glucose}} = +24{,}100$ has been found. It is shown that the calculated and observed rotations of five acyl derivatives of gentiobiose and maltose agree closely; the rotations of seven related derivatives have now been calculated (Table II). Arguments are presented in support of the recommendation that measurement of the rotations of new optically-active compounds, particularly those of the sugar group, be made in water or in chloroform solution wherever possible.

WASHINGTON, D. C.

NEW BOOKS

The Structure of Crystals. By RALPH W. G. WYCKOFF. American Chemical Society Monograph Series. The Chemical Catalog Company, Inc., 19 East 24th Street, New York, U. S. A., 1924. 462 pp. 213 figs. 24 × 15 cm. Price $6.00 net.

In all the history of science there is no more brilliant page covering a period of only ten years than the development of X-ray analysis of crystal structure. Up to January 1, 1924, the positions of atoms in some 200 crystalline substances were determined with a considerable degree of exactness. One of the chief contributors to the field, and one of whose work America should be justly proud, is R. W. G. Wyckoff. His painstaking experimental work, authoritative interpretations, and now the exceptionally high caliber of his new book, justify completely his selection as the author of an American Chemical Society Monograph.

Dr. Wyckoff has been, during the past four years, the chief expositor and proponent of the theory of space groups as applied to crystal structures. His belief in this theory is so profound that it is only natural that the monograph should reflect a strongly individualistic point of view. Consequently, it is admittedly in no sense an impartial handbook of methods and results of X-ray analysis compiled by an unprejudiced editor.

> "It is rather intended to give (in Part I) the reaction of a single point of view towards the material of crystal analysis as it now exists. All of the tools that are available are here considered, but all of the different ways of using them are not touched upon. It is the purpose of the second part to treat all existing diffraction data from the point of view outlined in Part I."

This strongly individualistic quality of the monograph may, in some important particulars, militate against its general usefulness as a source of information or as a textbook. One finds, for example, in Ewald's excellent monograph "Kristalle und Röntgenstrahlen," which appeared recently and constitutes the only real competitor, a much more liberal point of view. On the other hand, it must be admitted that the successes of the space group theory justify a very favorable attitude towards it. It has within a few months been adopted by the Braggs and others who did not formerly utilize it. Further advances into the field of more complex structures seem now to be hopeless without its application. This