[CONTRIBUTION FROM THE CARBOHYDRATE DIVISION, BUREAU OF CHEMISTRY AND SOILS, U. S. DEPARTMENT OF AGRICULTURE]

OPTICAL ROTATION AND ATOMIC DIMENSION. VIII. HALOGENO-HEPTA-ACETYL DERIVATIVES OF MELIBIOSE AND MALTOSE. THE STRUCTURES OF BIOSES AND CELLULOSE

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In preceding articles of this series it was reported that the relation between the specific rotational values and the atomic dimensions of the halogeno-hepta-acetyl derivatives of cellobiose, glucosido-mannose and gentiobiose deviate from the regular relationship for the monose sugars and that an agreement is obtained only by excluding the values for the fluoro derivatives. In this relationship these three bioses behave in the same manner, although their structure is not alike. In celloboise and glucosido-mannose the first carbon of the one monose is connected by an oxygen atom to the *fourth* carbon of the second, whereas in gentiobiose the first carbon of the one monose is connected by an oxygen atom to the *sixth* carbon of the other.

The preparation and rotational values of the pure crystalline fluoro-, chloro- and bromo-hepta-acetyl derivatives[1] of melibiose, which are described in the present article, have revealed the astonishing fact *that an exact agreement with the regular relationship for the monose sugars exists for these biose derivatives.* The recent establishment of the structure of melibiose[2] has shown that in this biose the first carbon of the one monose, galactose, is attached by an oxygen atom to the sixth carbon atom of the other, glucose, and, further, that melibiose is an *α-biose.*[3] Melibiose is therefore α-galactosido-6-glucose. *The bioses which have been investigated before,* cellobiose, glucosido-mannose and gentiobiose, are *β-bioses.*

Before making deductions from this striking difference in behavior of these α-and β-bioses, it seemed desirable to check this result. This pointed directly to the necessity of preparing the halogen derivatives of maltose, as it has been established that maltose[4] is α-glucosido-4-glucose and it was considered probable that an α-6-biose and an α-4-biose would behave in the same way. In addition to the melibiose derivatives this paper describes

[1] The crystalline iodo derivative was too unstable to allow a process of recrystallization. The rotational value of the yellowish crystals was found to be close to the value required by the atomic dimension relationship.

[2] Haworth, and co-workers, *J. Chem. Soc.*, 1527, 3146 (1927); Helferich and Bredereck, *Ann.*, **465**, 166 (1928).

[3] Bioses in which the reducing or first carbon atom of the one monose is connected by an α-glucosidic bond to one of the non-reducing carbons of the second monose are called α-bioses. The reducing (first) carbon of the second monose allows the substitution of its hydroxyl for halogen.

[4] Haworth, Loach and Long, *J. Chem. Soc.*, 3146 (1927).

the preparation of pure crystalline fluoro- and bromo-hepta-acetylmaltose[5] and gives their rotational values. The rotational value for the crystalline chloro derivative has been checked with that reported in the literature. The iodo derivative could not be obtained in crystalline condition. The data for the specific rotations of the melibiose and maltose derivatives together with those for the other bioses are given in Table I for comparison with the regular relationship of the monose sugars.

TABLE I

COMPARISON OF SPECIFIC ROTATIONS OF α- AND β-BIOSE DERIVATIVES[a] WITH REPRESENTATIVE MONOSE DERIVATIVES (INCLUDING FLUORO DERIVATIVES)

	α-Bioses Deriv. of		β-Bioses Deriv. of			Resp. sp. rot. diff.					Resp. sp. rot. diff. reduced				Sp. rot. diff., monoses
	Melibiose	Maltose	Gentiobiose	Cellobiose	Glucomannose	α		β			α		β		
F	149.7	111.1	43.8	30.6	13.6	42.8	48.4	36.7	41.1	37.6	41	41	41	41	41
Cl	192.5	159.5	80.5	71.7	51.2	17.4	20.6	20.6	24.1	26.7	17	17	23	24	29	17
Br	209.9	180.1	101.1	95.8	77.9	..	..	25.0	29.9	33.6	..	..	28	30	37	21
I	..	..	126.1	125.7	111.5										

[a] All rotations recorded in Tables I and II are positive.

TABLE II

COMPARISON OF SPECIFIC ROTATIONS OF β-BIOSE DERIVATIVES WITH REPRESENTATIVE MONOSE DERIVATIVES (EXCLUDING FLUORO DERIVATIVES)

	β-Bioses Derivatives of			Resp. sp. rot. diff.			Resp. sp. rot. diff. reduced			Sp. rot. diff., monoses
	Gentiobiose	Cellobiose	Glucomannose							
Cl	80.5	71.7	51.2	20.6	24.1	26.7	17	17	17	17
Br	101.1	95.8	77.9	25.0	29.9	33.6	21	21	21	21
I	126.1	125.7	111.5							

The foregoing data adequately support the conclusion that the α-biose derivatives follow the atomic dimension relationship, whereas the β-biose derivatives agree with this relationship only when the fluorine derivatives are excluded.

Directed by the atomic dimension relationship, I thus concluded that a fundamental difference between the finer structures of these α- and β-bioses must exist, as the numerical deviation of the atomic dimension relationship for each of the β-bioses must be an expression of this difference in structure.

[5] The preparation of pure crystalline bromo-hepta-acetylmaltose, which has been intermittently attempted by the author during many years, has revealed peculiarities which may be of interest from a chemical and crystallographical standpoint. The results are given under "Experimental Part."

Discussion of Results

Two postulates have been used for arriving at an insight into the finer structure of the bioses. The first postulate is the basis of stereo-chemistry of carbon compounds. The second postulate is based on the present view of the stereo-chemical behavior of oxygen.

Postulate I.—The directions of the four equal valences of the carbon atom are the same as the directions of the lines connecting the four corners of the regular tetrahedron with its center.

Postulate II.—Two possibilities exist for the oxygen atom: (*a*) The directions of the four valences (two primary and two secondary) of oxygen are the same as those for the valences of the carbon atom. The oxygen atom displays valences of this kind in the ring system of the monoses. (*b*) The two primary valence directions of oxygen are nearly opposite each other. (In the present discussion it is *assumed* that valences of these types are displayed by the oxygen atom which connects the two monoses of α- and of β-bioses.)

For support of the second postulate I quote Huggins,[6] who states that "for one reason or another a valence may be forced away from its normal position. Thus in the quartz crystal the angle subtended at the atomic center by the two bond electron pairs around each oxygen atom is considerably greater than it would be if the pairs were in their normal positions at the corners of a regular tetrahedron (about 109°)."

Allowing these postulates, let us consider first one carbon atom to which four different single atoms are attached and call the first valence the α-valence and the second the β-valence. These α- and β-valences are symmetrically arranged with respect to the plane going through the other two valences, in which plane the centers of the carbon atom and the third and the fourth atoms are also situated. The α- as well as the β-valence makes with this plane an angle of $109.5°/2 = 54.75°$, whereas the α-valence makes with the β-valence an angle of $109.5°$.

This regularity does not hold, however, for a ring system, as, for example, the amylene-oxide structure of the monose sugars. Using the facts laid down in the written formula of glucose, we will systematically build up in space the structure formula for this sugar and in this way bring out some peculiar differences in structure between the α- and β-forms of the monoses.[7]

Suppose we first make a row of the six carbons of glucose. The valence

[6] Huggins, *Phys. Rev.*, **19**, 352 (1922).

[7] Dowel pins and wooden cubes with 26 holes (Bool Furniture Co., Ithaca, N. Y.) are recommended for making models. The rigid angles and the close connection of the blocks prevent the errors that are easily made when wire is used for the bonds. Tetrahedrons are easily constructed from the cubes. Oxygen is indicated by a black triangle on each face.

connecting the first with the second carbon is directed at a definite angle *upward* (with regard to a horizontal plane), whereas the valence connecting the second to the third carbon must necessarily be directed the *same angle downward*, and so on. The centers of these six carbons are thus situated in two horizontal lines, one above the other, the first, third and fifth in the lower and the second, fourth and sixth in the higher. We will call this the zig-zag chain of six carbons. The attaching of the hydroxyl groups to the carbons is not *directly* given by the conventional glucose formula of Fischer–Tollens–Haworth, because it must be realized which agreement had to be made in order that space relations could be expressed in a *plane* (of the paper). It follows from these agreements that if the model of the zig-zag chain of carbons is placed on a horizontal plane and viewed from above, *each* carbon must be viewed in succession and from such a side that the extension of the valences connecting this carbon to the former and to the next are *crossing this plane*. Therefore, if the second carbon in the zig-zag chain is situated in a horizontal plane *above* that of the first carbon, we can directly put the OH group at the right without being obliged to turn the model.[8] For the OH group of the third carbon, however, which should have a left position according to the written formula, we have to turn the zig-zag model around in order to view this carbon from the correct side (in which the extension of the valences connecting this carbon to the former and the next are crossing the horizontal plane on which the model is placed). Consequently the OH of the third carbon comes in the zig-zag chain model at the *same side* as the OH of the second carbon. The OH of the fourth carbon will come in the zig-zag model also under the OH of the preceding carbons, whereas the OH of the fifth carbon (represented by an oxygen block) will be situated at the *other* side of the zig-zag model, as will be easily seen by consulting the written formula for glucose.

In order to make the amylene-oxide ring we leave the connection between the first carbon and the second as it is, and turn the third carbon around the 2–3 axis until its OH group is opposite that of the second. Now we turn the fourth carbon around the 3–4 axis until its OH is opposite that of the third. At last the fifth carbon is turned around the 4–5 axis until its oxygen (represented by an oxygen block) closes the six-numbered ring by also turning the first carbon around the 1–2 axis.

The ring is formed without strain and the model has much regularity. If viewed from the side of the ring a perfect representation of Fischer's written glucose formula is given, the agreements being taken into account. The place of the sixth carbon, however, which is below the plane of the

[8] It is convenient to indicate the OH groups of the second, third and fourth carbons by dowel pins and omit the indication of the H atoms. However, the OH group of the fifth carbon is indicated by a block representing oxygen.

ring and which assumed this position by the turning of the 4–5 axis, could not be so easily found without the preceding logical deduction.[9]

I will give now a brief description of the finished model, bringing out peculiarities for the direction of the α- and β-valences. If the model is so placed that the ring is horizontal and the first carbon be situated farthest away from the observer with the second carbon at the left and the oxygen atom at the right, then the valence connecting the first carbon to the second is directed at a definite angle upward and that from the second to the third at the same angle downward, and so on. Consequently the centers of the first, third and fifth carbons will be in one horizontal plane, and those of the second and fourth carbons and the oxygen will be in a second horizontal plane slightly above the first. The unoccupied valences of the first carbon are always designated as α- and β-valence. It has been established that the α-valence for all *d*-sugars must be at the top of this carbon in accord with the requirement[10] that for *d*-glucose it must be near the OH group of the second carbon which is at the top of the second carbon. Now we observe that *the α-valence is directed slightly upward to the front, making an angle with the horizontal ring system of about 19.5°, whereas the β-valence is directed about perpendicularly down, making therefore an angle of about 90° with that ring system.*[11] This result is entirely different from that obtained for a single carbon atom, to which four different atoms are attached and for which the α- and β-valences are *symmetrically* placed with regard to the plane in which the third and fourth atoms are situated. The explanation of this peculiarity for the monoses is that the directions of the α- and β-valences are not *primarily* dependent on the direction of the parallel planes of the ring systems, *but on the direction of the valence connecting the first carbon to the second* (or the first to the sixth).

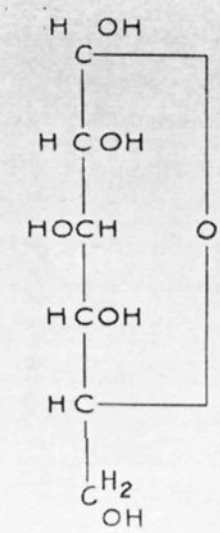
Before we show how the experimental facts regarding the rotational relationship of the halogeno-acetyl derivatives of the bioses are well explained by structural peculiarities of the bioses, it seems well to point out plainly the two *assumptions* on which these *finer* stereo-chemical structures are based.

I. The particular ring structure of the monoses developed above is

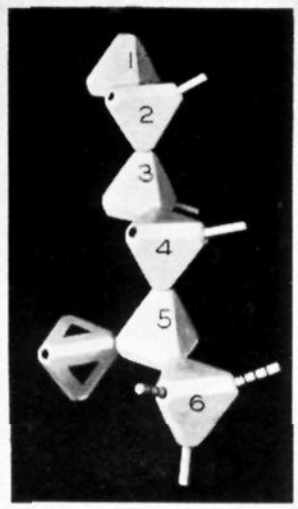
[9] I am indebted to Prof. W. H. Dore of Berkeley (California) for valuable remarks establishing this place of the sixth carbon atom.

[10] Boëseken, *Ber.*, **46**, 2612 (1913); Pictet, *Helv. Chim. Acta*, **3**, 649 (1920); Hudson, THIS JOURNAL, **31**, 66 (1909). For the *l*-sugars the β-valence is that of the top as required by the nomenclature.

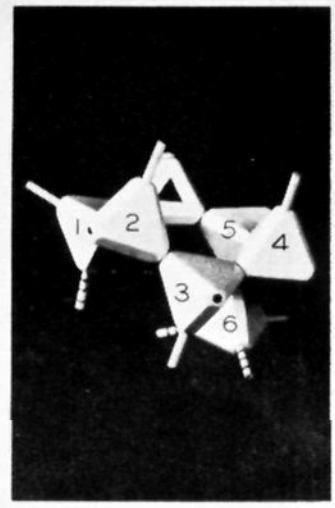
[11] The difference in direction of the α-valence and the β-valence with respect to the ring system has been logically derived from the tetrahedral orientation of the four valences of the carbon atom. The anisotropy of the carbon atom [see the interesting study on this subject by Mrs. K. Lonsdale-Yardley, *Phil. Mag.*, **6**, 433 (1928)] may also have a *minor* influence on this different behavior of the α- and β-valences.



WRITTEN FORMULA

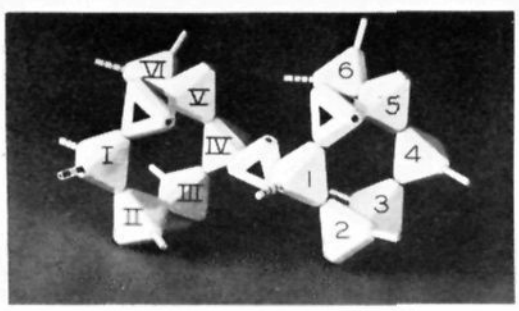


ZIG-ZAG FORMULA
ALDEHYDE GROUP OMITTED

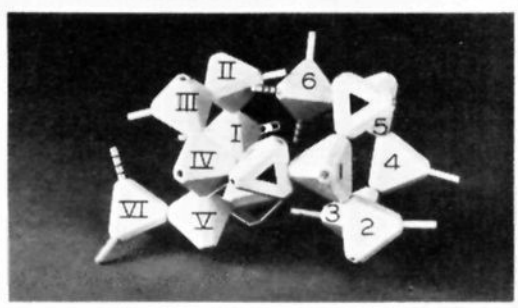


STEREO FORMULA

α-GLUCOSE

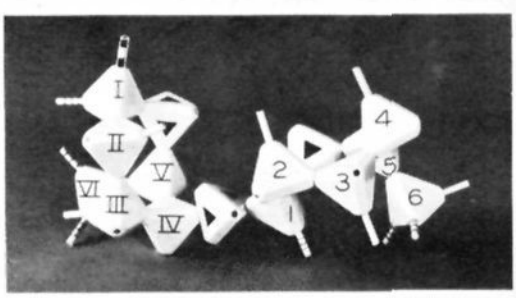


HALOGENO-HEPTA-ACETYL
CELLOBIOSE
NON-FACING FORMULA

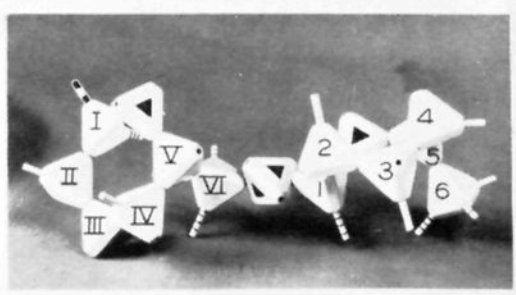


HALOGENO-HEPTA-ACETYL
CELLOBIOSE
FACING FORMULA

β-BIOSE DERIVATIVES



HALOGENO-HEPTA-ACETYL
MALTOSE



HALOGENO-HEPTA-ACETYL
MELIBIOSE

α-BIOSE DERIVATIVES

CARBON ATOM

OXYGEN ATOM

HYDROXYL OR ACETYL GROUPS

HALOGEN (ALWAYS IN α-POSITION)

HYDROGEN ATTACHED TO THE FIRST AND SIXTH CARBON, ALL OTHERS OMITTED.

THE CARBON ATOMS OF THE HALOGEN CONTAINING MONOSE ARE NUMBERED BY ROMAN FIGURES; THE CARBON ATOMS OF THE OTHER MONOSE BY ARABIC FIGURES.

only one of the several possible spacial arrangements of the atoms in the amylene oxide ring.[12]

II. It is assumed that the linking oxygen between the monose units has its valences opposite each other and that a free rotation of the monose units around this oxygen linkage can take place.

Important deductions can now be made regarding the structure of α- and β-bioses, which were studied in the forms of their halogen derivatives. We will apply a free rotation around the axis which connects the one monose by an α-(or β-) valence by means of an oxygen atom to the second monose for the α- and β-bioses, respectively. Taking into account the small angle (19°) which the α-valence makes with the ring system, it can be seen even without a model that for the α-bioses (melibiose and maltose) the halogen atom is too far away from the other monose to be influenced by secondary valences. We can turn the second monose entirely 360° around the connecting α-valence axis without an appreciable approach of the ring systems. With the investigated β-bioses, however, it is quite different. We will first connect the two ring systems through the β-valence and an oxygen atom to the fourth carbon (cellobiose and glucosido-mannose) in such a way that the second ring is situated in *front* of the other in a parallel horizontal plane below the first. When the second monose is turned from 90 to 180° around the β-biosidic axis, it is seen *that the halogen attached to the α-valence of the second monose faces the atoms attached to the ring system of the first monose. The same result* is obtained by connecting the two ring systems through the β-valence and an oxygen atom to the sixth carbon (gentiobiose). These model studies, directed by experimental results, clearly explain *that the halogens of the β-bioses are influenced by secondary valences, whereas the halogens of the α-bioses are not.* Further, these model studies indicate that some β-bioside derivatives, as β-glucosido-4-galactose, must follow entirely the atomic dimension relationship. Investigations will be taken up later for checking this result and also for determining more exactly which are the selectively influencing atoms of the second monose.

This insight into the finer structure of the bioses, resulting from the application of the atomic dimension relationship, gives also a suggestion regarding the structure of such important polysaccharides as *cellulose.* The old formula for cellobiose cannot be used for constructing the formula for cellulose, as the x-ray picture of cellulose fiber shows a diffraction pattern requiring C_{12} units, whereas the above old formula of cellobiose in chain formation would require a pattern of C_6 units.[13]

[12] See, *e. g.*, Lowry, *Chem. Industry*, **47**, 1149 (1928).

[13] See Sponsler and Dore, "Colloid Symposium Monograph," Chemical Catalog Co., New York, p. 174, and THIS JOURNAL, **50**, 1941 (1928); also, Hauser, *Ind. Eng. Chem.*, **21**, 120 (1929). Nor does a ring formula of three units, for example, satisfy the requirements on account of the low molecular weight and weak secondary bonds of

However, the new structure formula for cellobiose in chain formation, in which one glucose of the cellobiose molecule is facing the other, *fulfils the pattern requiring* C_{12} *units*, although at this stage of the investigations it would also allow larger units such as C_{18}. An examination of a model of this chain of C_{12} units shows further that the oxygen atoms connecting the successive glucose units are alternately *well protected* and *partly protected* by surrounding groups[14] (especially by acetyl groups of the first and second carbon atoms), *which fact explains why cellobiose is produced on acetolysis of cellulose fiber,* as the one oxygen union will be hydrolyzed more quickly than the next.

These peculiarities, revealed by a study of the atomic dimension relationship, lead to a conclusion regarding the possibility of considering cellobiose as a building stone of cellulose opposite that heretofore adopted. We now see that the former conclusion was erroneous because a formula for cellobiose had been adopted for which sufficient detail in structure was lacking.

Experimental Part

General Remarks.—For all determinations of the specific rotation U. S. P. or purified chloroform[15] was used. The volume of the solution was made up in the same flask to 24.9767 cc. at 20°, which requires multiplication by the factor 4.0038 for obtaining 100 cc. The reading, which was made in the same 4-dm. tube at 20°, is given in circular degrees.

Melibiose.—A supply of β-melibiose dihydrate was prepared from raffinose according to the method of Hudson and Harding.[16] After one recrystallization the preparation gave a specific rotation in water of +128.9°, agreeing with the value obtained by Hudson and Yanovsky[17] of +129.5°.

β-Octa-acetylmelibiose was prepared by acetylating melibiose with acetic anhydride and anhydrous sodium acetate. It was recrystallized four times from 95% alcohol, yielding a product of constant specific rotation in chloroform of +102.6° and m. p. 177°. Hudson and Johnson[18] report specific rotation in chloroform +102.5°; m. p. 177.5° (corr.).

Fluoro-hepta-acetylmelibiose was prepared from β-octa-acetylmelibiose in the manner previously described.[19] The distillation was finished in about twenty to twenty-five minutes and the reaction product was directly worked up. The sirup resulting from the extraction with chloroform did not crystallize readily. Crystallization was

the chain in contradiction to the tensile strength [Meyer and Mark, *Ber.*, **61**, 593 (1928); Hess and Trogus, *ibid.*, **61**, 1982 (1928)].

[14] Acetyl or acyl groups are, of course, not extending from a carbon atom of the ring system in a straight line connecting the corner of the tetrahedron with its center, but are curved out from the ring system by the O—CO—C bond. As to the 50% yield of cellobiose octa-acetate from cellulose, see Friese and Hess, *Ann.*, **456**, 42 (1927).

[15] Brauns, THIS JOURNAL, **46**, 1486 (1924).

[16] Hudson and Harding, *ibid.*, **37**, 2734 (1915).

[17] Hudson and Yanovsky, *ibid.*, **39**, 1027 (1917).

[18] Hudson and Johnson, *ibid.*, **37**, 2752 (1915).

[19] Brauns, *ibid.*, **45**, 834 (1923).

started by adding some 70% methyl alcohol and scratching the walls of the dish. When crystallization started more 70% methyl alcohol was added gradually. The yield of impure crystals was 8 g. from 15 g. of β-octa-acetate. It was recrystallized several times by being dissolved in boiling 70% methyl alcohol with addition of decolorizing carbon and filtered through an ordinary folded filter. The filtrate was seeded and allowed to cool gradually. The first separations of the recrystallizations of the impure substance contain most of the impurities. The pure product crystallizes in small prismatic needles and is stable, colorless and tasteless. It is very soluble in most solvents except water and petroleum ether; m. p. 135°. The determination of the specific rotation in chloroform solution gave the following result.

Rotation.—Third recrystallization; first and second fractions, respectively. Subs., 0.5247, 0.6429: $\alpha = +12.445°, +15.374°$; $[\alpha]^{20}_{D} = +148.12°, +149.31°$. Fourth recrystallization: first and second fractions, respectively. Subs., 0.6225, 0.3722: $\alpha = +14.923°, +8.900°$; $[\alpha]^{20}_{D} = +149.69°, +149.36°$. Fifth recrystallization: first and second fractions, respectively. Subs., 0.6412, 0.2132: $\alpha = +15.374°, +5.098°$; $[\alpha]^{20}_{D} = +149.71°, +149.31°$. Therefore +149.70° is taken as the specific rotation of the pure substance.

Anal. Subs., 0.1679: CO_2, 0.2999; H_2O, 0.0847. Subs., 0.5000: CaF_2, 0.0269. Subs., 0.5000: 98.54 cc. of 0.25 *N* H_2SO_4, 246.35 cc. of 0.1 *N* NaOH. Calcd. for $C_{26}H_{35}O_{17}F$: C, 48.88; H, 5.53; F, 2.98; 62.67 cc. of 0.1 *N* NaOH for AcOH + F. Found: C, 48.71; H, 5.64; F, 2.62; 61.95 cc. of 0.1 *N* NaOH.

Chloro-hepta-acetylmelibiose was prepared by following the method described for chloro-hepta-acetylgentiobiose.[20] The sirup resulting from the concentration of the chloroform solution did not crystallize readily, a difficulty which was observed for all the halogen derivatives of melibiose. The following method was employed for obtaining the chloro derivatives in a crystalline condition. The sirup was kept first for a few hours in a vacuum desiccator. A small quantity of ether mixed with about one-fourth of its volume of petroleum ether was then added and the mixture was continually stirred while the sides of the crystallizing dish were scratched; the solid masses separating at the walls of the dish were broken down. Gradually a cloudiness appeared. A small quantity of ether was then added and the stirring was continued until small crystals separated. At this stage more ether was added, accelerating the crystallization. The crystals were separated on a suction filter. The yield of impure crystals was 6 g. from 20 g. of β-octa-acetate. A small quantity of crystals was always put aside for seeding the solution of the next recrystallization. Recrystallization was produced by dissolving in dry ether, filtering and slowly evaporating the solution under a bell jar with a current of dry air. The concentrated solution was seeded and the slow evaporation continued. The current of air was interrupted after fifteen minutes and the solution was allowed to stand undisturbed for ten to twenty minutes. In this way well developed crystals were obtained. The determination of the specific rotation in chloroform gave the following results.

Rotation.—Second recrystallization: first and second fractions, respectively. Subs., 0.6626, 0.6261: $\alpha = +20.416°, +19.238°$; $[\alpha]^{20}_{D} = +192.39°, +191.86°$. Third recrystallization: first and second fractions, respectively. Subs., 0.6327, 0.6299: $\alpha = +19.498°, +19.422°$; $[\alpha]^{20}_{D} = +192.42°, +192.52°$.

Therefore, 192.50° is taken as the specific rotation of the pure substance. The pure compound crystallizes in small prisms; m. p. 127°. It is slightly bitter and stable when kept in a vacuum desiccator over sodium hydroxide in the ice box. It is readily soluble in ordinary solvents except petroleum ether and water, and slightly soluble in ether.

[20] Brauns, THIS JOURNAL, **49**, 3173 (1927).

Anal. Subs., 0.2019: CO_2, 0.3504; H_2O, 0.0990. Subs., 0.2315: AgCl, 0.0514. Subs., 0.5000: 98.54 cc. of 0.25 *N* H_2SO_4, 306.95 cc. of 0.1 NaOH. Calcd. for $C_{26}H_{35}O_{17}Cl$: C, 47.65; H, 5.39; Cl, 5.41; 61.10 cc. of 0.1 *N* NaOH. Found: C, 47.33; H, 5.48; Cl, 5.49; 60.60 cc. of 0.1 *N* NaOH.

Bromo-hepta-acetylmelibiose.—Twenty-five grams of octa-acetylmelibiose was dissolved in 85 cc. of acetic acid and 62 cc. of a saturated solution of hydrogen bromide in acetic acid was added. The mixture was kept in a stoppered Erlenmeyer flask at room temperature for one and one-half hours. It was then poured into a separatory funnel containing ice water, cracked ice and chloroform and shaken out five times with ice water. The chloroform extract was dried with calcium chloride, filtered and evaporated to a sirup at low temperature. The sirup was stirred with 15 cc. of petroleum ether and the petroleum ether solution was poured off. This process was repeated once. The petroleum ether solution crystallized overnight by evaporation in the air. The quantity of crystals was small but it was useful for seeding the ether solution of the sirup. The process for obtaining well-defined pure crystals was the same as that described for chloro-hepta-acetylmelibiose. The yield was small, being 4 g. from 25 g. of octa-acetate. The solutions for the rotations were prepared with purified chloroform.

Rotation.—First recrystallization. Subs., 0.6184: $\alpha = +20.642°$; $[\alpha]_D^{20} = +208.42°$. Second recrystallization. Subs., 0.6127: $\alpha = +20.538°$; $[\alpha]_D^{20} = +209.30°$. Third recrystallization. Subs., 0.6336: $\alpha = +21.297°$; $[\alpha]_D^{20} = +209.88°$. Fourth recrystallization. Subs., 0.4256: $\alpha = +14.293°$; $[\alpha]_D^{20} = +209.70°$.

Therefore, +209.90° is taken as the specific rotation of the pure substance. The pure substance crystallizes in short prisms; m. p. 116°. It is slightly bitter and can be kept in a vacuum desiccator over sodium hydroxide in the ice box. It is readily soluble in most solvents, less soluble in ether and slightly soluble in petroleum ether and water.

Anal. Subs., 0.2360: CO_2, 0.3842; H_2O, 0.1090. Subs., 0.1960: AgBr, 0.0529. Subs., 0.5000: 98.54 cc. of 0.25 *N* H_2SO_4, 303.46 cc. of 0.1 *N* NaOH. Calcd. for $C_{26}H_{35}O_{17}Br$: C, 44.62; H, 5.05; Br, 11.43; 57.20 cc. of 0.1 *N* NaOH. Found: C, 44.40; H, 5.17; Br, 11.48; 57.11 cc. of 0.1 *N* NaOH.

β-Octa-acetylmaltose was prepared by acetylating maltose with anhydrous sodium acetate and acetic anhydride. It was recrystallized twice from 95% alcohol, yielding in chloroform a product of constant specific rotation +62.87° and m. p. 159–160°. Hudson and Johnson[21] report $[\alpha]_D^{20} = +62.59°$ and m. p. 159–160°.

Fluoro-hepta-acetylmaltose.—Ten grams of β-octa-acetylmaltose was treated with anhydrous hydrofluoric acid in the manner previously described.[17] The distillation was finished in about twenty to twenty-five minutes and the reaction product was worked up directly. The sirup resulting from the extraction with chloroform was crystallized by stirring with petroleum ether, the yield of impure crystals being 7.5 g. from 10 g. of octa-acetate. It was recrystallized several times by dissolving in about 80 cc. hot 95% alcohol, filtering and cooling gradually, at last with ice. The pure product crystallizes in small prisms and is stable, colorless and tasteless. It is soluble in the ordinary solvents except petroleum ether and water; m. p. 174–175°. The determination of the specific rotation in chloroform gave the following results.

Rotation.—First recrystallization. Subs., 0.7097: $\alpha = +12.574°$; $[\alpha]_D^{20} = +110.62°$. Second recrystallization. Subs., 0.7208: $\alpha = +12.806°$; $[\alpha]_D^{20} = +110.93°$. Third recrystallization. Subs., 0.7143: $\alpha = +12.709°$; $[\alpha]_D^{20} = +111.10°$. Fourth recrystallization. Subs., 0.6975: $\alpha = +12.411°$; $[\alpha]_D^{20} = +111.10°$. Therefore, +111.1° is taken as the specific rotation of the pure substance.

Anal. Subs., 0.2066: CO_2, 0.3717; H_2O, 0.1062. Subs., 0.5067; CaF_2, 0.0251.

[21] Hudson and Johnson, THIS JOURNAL, **37**, 1276 (1915).

Subs., 0.5000: 106.18 cc. of 0.25 *N* H_2SO_4, 328.35 cc. of 0.1 *N* NaOH. Calcd. for $C_{26}H_{35}O_{17}F$: C, 48.88; H, 5.53; F, 2.97; 62.67 cc. of *N* NaOH. Found: C, 49.06; H, 5.75; F, 2.41; 62.90 cc. of 0.1 *N* NaOH.

Chloro-hepta-acetylmaltose has been obtained in crystalline condition by Foerg[22] by saturating an acetic anhydride suspension of maltose with hydrochloric acid at low temperature. The container was sealed and kept for two weeks at room temperature. Foerg separated from the reaction product crystalline chloro-hepta-acetylmaltose, but made an error in recording the sign of the specific rotation, which was corrected by Schliephacke,[23] who found for the specific rotation in chloroform solution +158.68°. By applying the chlorination method of von Arlt, modified by Skraup and Kremann,[24] described for the preparation of chloro-tetra-acetylmannose,[25] I prepared pure chloro-hepta-acetylmaltose in a few days.

The reaction product, a colorless sirup, crystallized when stirred with petroleum ether. The yield of impure crystals was 9 g. from 15 g. of β-octa-acetate. Recrystallization was produced by dissolving in warm ether, filtering and adding so much petroleum ether that seeding or scratching started the crystallization. Recrystallization was repeated until a constant-rotating substance was obtained. The pure product crystallizes in small prisms and is stable when kept in a desiccator over sodium hydroxide in the ice box. It is soluble in the ordinary solvents except petroleum ether and water; m. p. 125°. Foerg and Schliephacke report m. p. 118–120°. The determination of the specific rotation in chloroform gave the following results.

Rotation.—First recrystallization. Subs., 0.6044: $\alpha = +15.370°$; $[\alpha]_D^{20} = +158.79°$. Second recrystallization. Subs., 0.6471: $\alpha = +16.504°$; $[\alpha]_D^{20} = +159.25°$. Third recrystallization. Subs., 0.6484: $\alpha = +16.549°$; $[\alpha]_D^{20} = +159.36°$. Fourth recrystallization. Subs., 0.6145: $\alpha = +15.693°$; $[\alpha]_D^{20} = +159.46°$. Therefore +159.50° is taken as the specific rotation of the pure substance.

Anal. Subs., 0.1878: CO_2, 0.3263; H_2O, 0.0899. Subs., 0.2733: AgCl, 0.0605. Calcd. for $C_{26}H_{35}O_{17}Cl$: C, 47.65; H, 5.39; Cl, 5.41. Found: C, 47.39; H, 5.36; Cl, 5.47.

Bromo-hepta-acetylmaltose.—Crystalline bromo-hepta-acetylmaltose has been described by Fischer and Armstrong[26] in a short communication. They obtained it by the action of liquid hydrobromic acid on octa-acetylmaltose under high pressure at room temperature, evaporating the hydrobromic acid and crystallizing the reaction product from hot ligroin. Prismatic needles were obtained melting at 84°. A bromine determination gave correct figures for a monobromo derivative, but no other properties were recorded. In a later paper Fischer[27] stated that by repeating this method of preparation an amorphous product resulted, which was largely the monobromo derivative, as a high percentage of crystalline hepta-acetyl-

[22] Foerg, *Monatsh.*, **23**, 45 (1902).

[23] Schliephacke, *Ann.*, **377**, 184 (1910).

[24] Von Arlt, *Monatsh.*, **22**, 144 (1901); Skraup and Kremann, *ibid.*, **22**, 376 (1901).

[25] Brauns, THIS JOURNAL, **44**, 404 (1922).

[26] Fischer and Armstrong, *Ber.*, **35**, 3153 (1902).

[27] Fischer, *ibid.*, **44**, 1898 (1911); also E. Fischer and H. Fischer, *ibid.*, **43**, 2522 (1910).

maltose could be obtained from it. Later investigators have always used this amorphous product, for example, Karrer.[28] In the course of the present investigation the following facts were brought out which are important for preparing the crystalline bromo derivative.

1. The use of liquid hydrobromic acid, which requires the cooling with liquid air, yields a crude product which does not differ from the crude products of more simple methods of preparation.

2. It is advantageous to prevent so far as possible the formation of the dibromo derivative (which is not easily separated from the monobromo derivative) by shortening the time of reaction.

3. The crude amorphous product crystallizes from hot ligroin *only* if the cooling or concentrating is extremely slow. This slow cooling was produced by the use of unsilvered Dewar flasks and slow evaporation by a very weak current of dry air.

Preparation.—Five grams of octa-acetylmaltose was dissolved in 17 cc. of acetic acid which had been cooled to about 15°. Then 11 cc. of a saturated solution of hydrogen bromide in acetic acid was added and the whole was cooled to about 0°. The mixture was kept in a stoppered Erlenmeyer flask in ice water for half an hour and was then poured into a separatory funnel containing ice water and cracked ice and shaken out five times with ice water, yielding a neutral chloroform solution. This was dried with calcium chloride, filtered and evaporated to a sirup at low temperature by a current of dry air. The sirup was allowed to stand in a vacuum desiccator for two hours, after which it was converted to a sticky white powder by stirring with ligroin (b. p. 70–90°). This powder was boiled on the steam-bath in an Erlenmeyer flask with about 100 cc. of ligroin for some five minutes, forming a sticky substance which was stirred with a glass rod. The hot solution was then poured without filtering into an unsilvered Dewar flask, the sticky sediment remaining in the Erlenmeyer flask. This process was repeated. The wall of the Dewar flask was then scratched with a glass rod, which was first rubbed in some crystalline bromo derivative (obtained by repeatedly pouring off a ligroin solution from amorphous separations). After standing overnight crystalline material separated at the walls and amorphous substance at the bottom of the Dewar flask. The mother liquor was poured into beakers and very slowly evaporated under a bell jar by a weak current of air. By seeding and scratching the walls of the beakers brilliant short prisms of about one mm. in thickness and length were obtained. The amorphous product, which separates at the bottom of the Dewar flasks, can be converted to crystals by repeating the foregoing process. The analysis of the amorphous substance yields figures which are near those required for the monobromo derivative and its specific rotation is only a few degrees lower than that for the pure crystalline compound. Its melting point, however, is different as it melts at 80–83°. Heated quickly to near its melting point it was found that crystalline bromo-hepta-acetylmaltose melts at 112–113°, whereas Fischer reported a melting point of 84°. As crystallization seems to be connected with an orientation of the molecules before they separate out of solution, it is likely that for a quick separation the many secondary valences present in the α-biose derivatives prevent an *orientated or crystalline separation*, whereas for the β-bioses this difficulty does not exist in this measure, as their secondary valences have been largely saturated. Crystalline bromo-hepta-acetylmaltose was obtained in pure condition by regulating the time of reaction as described above, thus preventing the

[28] Karrer, *Helv. Chim. Acta*, **4**, 169, 263, 678 (1921).

formation of the dibromo derivative, which could not be removed from the monobromo derivative by recrystallization. Analysis proved that the pure compound had been separated. The crystalline compound is easily soluble in ordinary solvents except petroleum ether and water. It is slightly bitter and was kept for many months without decomposition in a desiccator over sodium hydroxide in the ice box.

Rotation.—Subs., 0.6101: $\alpha = +17.640°$; $[\alpha]_D^{20} = +180.54°$. Recrystallization. Subs., 0.3872: $\alpha = +11.177°$; $[\alpha]_D^{20} = +180.24°$.

Other preparations gave values near $+180.10°$, which is taken as the specific rotation of the pure substance.

Anal. Subs., 0.1718: CO_2, 0.2827; H_2O, 0.0808. Subs., 0.2177: AgBr, 0.0581. Calcd. for $C_{26}H_{35}O_{17}Br$: C, 44.62 H, 5.05; Br, 11.43. Found: C, 44.88; H, 5.26; Br, 11.36.

Summary

The pure crystalline fluoro, chloro and bromo derivatives of acetylated melibiose and maltose have been prepared and described. The specific rotational values of these α-biose derivatives show an agreement with the atomic dimension relationship of the monose sugars, whereas the values for the halogen derivatives of the β-bioses, investigated before, agree with this relationship only by excluding the values for the fluoro derivatives. An explanation of this behavior is obtained by model studies, which show that the *direction* of the β-valence allows the constituting monoses to face each other, with a resulting selective influence, whereas the direction of the α-valence does not allow this position. The new (more detailed) structure formula for cellobiose suggests a structure formula for cellulose. As compared with formulas heretofore suggested this new formula gives a better interpretation of the chemical and physical properties of cellulose.

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[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF THE COLLEGE OF LIBERAL ARTS, NORTHWESTERN UNIVERSITY]

THE MERCURATION OF NAPHTHALIC ACIDS

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While the replacement by mercury of one of the carboxyl groups in phthalic acid has long been known,[1] the effect of changes in structure on this reaction has not been studied extensively.

In the present study naphthalic acid, 3-nitronaphthalic acid and 4-nitronaphthalic acid have been submitted to the reaction of Pesci. In each case one of the carboxyl groups was replaced by mercury. Naphthalic acid gave anhydro-8-hydroxymercuri-1-naphthoic acid. With 3-nitronaphthalic acid the carboxyl in the 8-position was replaced more than that in the 1-position. With 4-nitronaphthalic acid the replacement was almost entirely in the 8-position, only a small amount of replacement taking

[1] Pesci, *Atti. accad. Lincei*, [5] **10, I**, 362 (1901).