

In 1952 (2) the IUPAC recommended a somewhat synthetic structure-based system which interposed an abbreviated organic bivalent radical name between "poly" and "amer."

~CH₂~
polymethamer
~CH₂CH₂O~
polyethoxamer
~NH(CH₂)₆NHCO(CH₂)₄CO~
poly(azihexazamer-*alt*-adipylamer)
or poly(hexamer-*alt*-adipamidamer)
or polyhexiadipamidamer

This system at the present time is too poorly defined and too incompatible with conventional nomenclature to be adopted for general use, and it has not been accepted by the average polymer chemist.

Other systems have been proposed from time to time. For example, every linear polymer could be conceived of having been derived by the removal of hydrogen from each end of a compound, which, minus the hydrogen, is the repeating unit. Such a system would lead to some of the same problems as resulted from names based on source, such as multiple monomers giving a single polymer.

CONCLUSION

There is little doubt but that polymer nomenclature is fraught with problems, if not near-chaos. While names such as polystyrene are unambiguous and will certainly not be discarded in the near future, it must be realized that even the unambiguous names of current practice generally are simply nouns. If you know their meanings, they are part of your vocabulary. There is little that can be done to extend such names to other structures without introducing new ambiguity.

To assure rational communication in the polymer field, a structure-based nomenclature system is necessary. Such systems have been devised. As in the case of organic compounds, complex polymer structures will be given complex names. The rules for the formation of these names will be complex, also, and this acts as a deterrent to use. Usage of nomenclature in this field not only depends upon the polymer chemist, but perhaps more importantly, absolutely depends upon journal editors and the indexers in the polymer field.

LITERATURE CITED

- (1) Huggins M. L., Natta, G., Desreux, V., Mark, H., *Pure and Appl. Chem.* **12**, 645 (1966).
- (2) *J. Polymer Sci.* **8**, 272 (1952).

Carbohydrate Nomenclature*

M. L. WOLFROM†

Department of Chemistry, The Ohio State University, Columbus, Ohio 43210

Received March 24, 1967

The history and development of the Carbohydrate Nomenclature Committee of the Division of Carbohydrate Chemistry of the American Chemical Society is reviewed briefly and its present status is outlined. The work of this committee has been carried out jointly with a corresponding committee of The Chemical Society (London). The rules currently approved are presently under consideration by the Organic Nomenclature Commission of the International Union of Pure and Applied Chemistry. Extensions of these rules are currently needed and are under consideration.

The nomenclature of carbohydrate chemistry presents many problems. The carbohydrates are the only organic compounds which have an array of adjacent asymmetrically substituted carbon atoms of established configurational relationship. Their basic nomenclature was established by Emil Fischer in his classic work on carbohydrate structure. Fischer rejected a completely rational system, based upon the Geneva conventions, as being

too cumbersome. He devised instead a system of common or trivial names denoting configurations of adjacent asymmetric centers through a series of four such centers.

It has become necessary to extend his system to meet structural conditions experimentally established after the work of this great master was closed; we may mention here such points as ring size, anomerism, and oligosaccharide structure. To accomplish this end, a set of basic or stem names are used, to which suitable prefixes or suffixes are added. It was in these needed extensions that great confusion resulted in the carbohydrate organic chemical literature. This situation became especially apparent in the editing of the "Advances in Carbohydrate

* Based on a paper presented before the Division of Chemical Literature, Symposium on Chemical Nomenclature, 152nd National Meeting of the American Chemical Society, New York, N. Y., Sept. 15, 1966.

† Chairman, Nomenclature Committee, Division of Carbohydrate Chemistry, American Chemical Society.

Chemistry," an annual publication now in its twenty-first volume. There was needed a codification of reasonable, rational nomenclature not too far removed from the main current practice and based upon established organic chemical usage.

This need was first recognized by Charles D. Hurd, and a carbohydrate nomenclature committee was established in 1939, under his chairmanship, as a joint activity of the American Chemical Society's Divisions of Sugar Chemistry and Technology (later known as the Division of Sugar Chemistry and now as the Division of Carbohydrate Chemistry), Chemical Education, and Biological Chemistry. This effort resulted in the formulation of many useful concepts and codifications. A final report of this committee was made at the April, 1944 Meeting of the American Chemical Society.

These activities were then continued as a sole effort of the Division of Sugar Chemistry and Technology by a new committee consisting of R. Max Goepf, Jr., chairman, G. H. Coleman, R. C. Hockett, and M. L. Wolfrom. R. C. Hockett became chairman after the untimely death of R. Max Goepf, Jr., in an airplane accident in 1946. This committee eliminated those parts of the mimeographed report of the first committee which were considered controversial, and produced a report which was approved by the American Chemical Society Committee on Nomenclature, Spelling, and Pronunciation, then under the chairmanship of E. J. Crane. On the recommendation of this committee, the report was approved by the Council of the American Chemical Society in April, 1948 and was published (1) in *Chemical and Engineering News* on a one-year tentative basis. This procedure was followed in two later revisions and extensions (2, 3, 4) of the rules, except that the last was published in the *Journal of Organic Chemistry*.

The new committee was then enlarged to include L. T. Capell, G. H. Coleman, W. Z. Hassid, R. C. Hockett, W. Pigman, N. K. Richtmyer, J. C. Sowden, R. S. Tipson, R. L. Whistler, and M. L. Wolfrom. Until his death on December 27, 1952, C. S. Hudson was also an influential member. In 1951, M. L. Wolfrom assumed the committee chairmanship. R. S. Tipson has been an active member of the committees since their inception in 1939, and has rendered especially valuable service in the codification of the rules in proper English language form. W. Z. Hassid has represented biochemical interests and L. T. Capell, of the Chemical Abstracts Service staff, has guided the committee in its desire to conform to the recognized principles of organic chemical nomenclature. J. C. Sowden was a member until his death in 1963; R. C. Hockett has recently withdrawn because of the pressure of other interests. The present membership of the committee consists, in addition to those named, of H. S. Isbell, R. W. Jeanloz, J. K. N. Jones, Kurt L. Loening, and R. David Nelson, the last two being from the staff of the Chemical Abstracts Service.

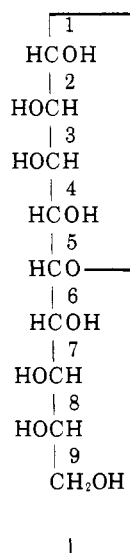
After the first published committee report (1), the enlarged committee published a second, more extensive set of Rules of Carbohydrate Nomenclature in 1953 (2). This publication was a joint report from the American committee and a corresponding group of British chemists consisting of S. Peat, W. Baker, H. Burton, E. L. Hirst, J. Honeyman, C. K. Ingold, W. H. Linnell, Mrs. E. E.

Percival, M. Stacey, A. R. Todd, B. Lythgoe, D. J. Bell, W. Klyne, T. S. Work, and the editors of the *Journal of the Chemical Society*, R. S. Cahn, editor-in-chief, A. D. Mitchell, and L. C. Cross. This committee functioned as a subcommittee of the Publication Committee of the Chemical Society. M. Stacey and R. S. Cahn were influential in effecting this cooperative effort, notable for the participation of the editors of the Chemical Society with the cooperation of representatives of the Editorial Board of the Biochemical Society. The Publication Committee of the Chemical Society "instructed that they should be used forthwith in the Society's publications." These rules were published in the *Journal of the Chemical Society* (3). Final agreement had been obtained at a notable meeting held in New York City and attended by a majority of the members of the American Committee and by R. S. Cahn, A. D. Mitchell, and M. Stacey from the British Committee. A revised and extended set of rules was again the subject of a cooperative British-American effort. These were published in the *Journal of Organic Chemistry* (4) and in the *Journal of the Chemical Society* (5).

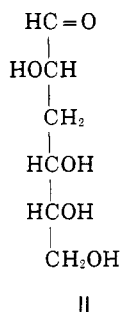
In 1963, R. S. Cahn, a member of the Organic Nomenclature Commission of the International Union of Pure and Applied Chemistry, was requested to submit proposals on carbohydrate nomenclature for consideration by the Organic Commission. He submitted the British-American rules and requested their adoption since they had been widely used and found to be satisfactory in English language journals over a period of years. These included non-British-American journals using the English language, such as many of those published in Japan and in the Scandinavian countries. This solution was considered to be far too simple, and a Special Committee on the Nomenclature of Carbohydrates under the chairmanship of P. E. Verkade (Holland), also the chairman of the Organic Commission of the International Union, was appointed. This committee consisted of R. S. Cahn (Great Britain), J. E. Courtois (France), O. Hoffmann-Ostenhof (Austria), W. Klyne (Great Britain), L. T. Capell (U. S. A.), N. Lozac'h (France), F. Micheel (Germany), T. Reichstein (Switzerland), J. Staněk (Czechoslovakia), W. J. Whelan (Great Britain), and M. L. Wolfrom (U. S. A.). After the official retirement of R. S. Cahn and L. T. Capell, they were replaced by L. C. Cross and K. L. Loening, respectively. This committee was to review the British-American rules with a view to their adoption or modification. Two meetings were held in Basel, Switzerland, one in 1964 and one in 1965. The British-American rules were devised for the English language, but this presented no problem, as it was understood that alterations, especially as regards word endings and language forms, would be allowable in adapting them to other languages. Some rearrangements and condensations of the rules were made, and such points as were restricted to purely English language forms were eliminated. Agreement on all of the essential points of the British-American rules was attained except for three:

(1) The international committee wished to eliminate most of the valuable illustrative examples, which in our opinion are essential in applying these rules to the complicated nomenclatural situations encountered by the carbohydrate chemist.

(2) The naming of anomers in the higher sugars presents problems, and some members of the international committee favor changing the rules back to a system long ago discarded by the carbohydrate chemists working in this area. This can be illustrated by the following example. The anomeric sugar form I is named according to Rule 22 (4, 5) as *L-arabino-α-D-manno-nonopyranose*, but many of the international committee would prefer *β-L-arabino-D-manno-nonopyranose*. In the first name the reference carbon atom for anomeric designation is C-5 and in the second it is C-8. The functioning part of this molecule is certainly the upper portion, while the lower is merely a side chain on the pyranose ring. The sugar will have chemical properties very similar to those of *α-D-mannose* and not to those of *β-L-arabinose*.

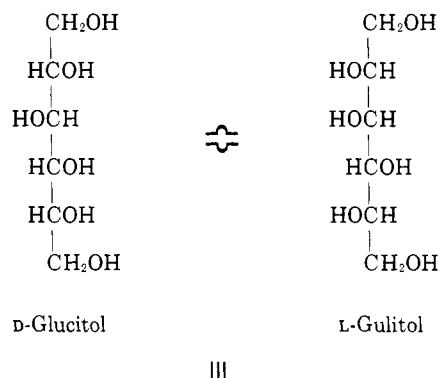


(3) The third point in disagreement is the number of configurational prefixes to be used in designating deoxy sugars. The sugar II is named according to Rule 8 (4, 5) as 3-deoxy-D-*arabino*-hexose. In this designation the consecutive, but not contiguous, asymmetric centers are named in one prefix. Some of the international committee members consider that the centers designated by a configurational prefix must be contiguous, and would name sugar II as 3-deoxy-D-*erythro-L-glycero*-hexose. We believe that this name is unnecessarily cumbersome. Another meeting of the international committee is contemplated for the near future.

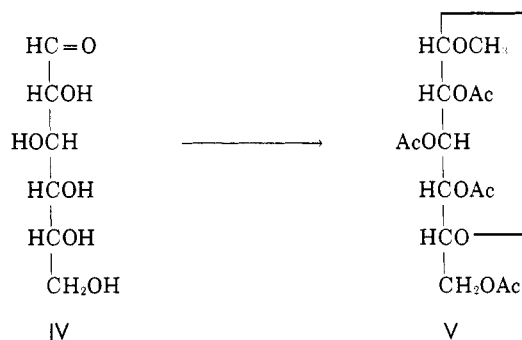


The international committee adopted a useful principle to eliminate occasional alternative names arising when a carbohydrate derivative possesses like end groups. Thus,

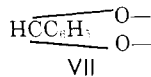
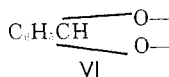
according to the British-American Rule 23 (4, 5), the alditol III (common name sorbitol) can be designated either as *D-glucitol* or *L-gulitol*. The new modification would eliminate the second name by the principle of alphabetic selection.



The logical steps required to arrive at a name from a formula are to be detailed in the international rule formulation. Thus, in the rather simple case of methyl tetra-*O*-acetyl-*α-D*-glucopyranoside (V), the first step is to write the conventional Fischer projection formula (IV) for the parent sugar and obtain the stem name *D-glucose*. Then this structure is operated upon to obtain the derivative. The first operation is to insert the pyranose ring in the *α-D* anomeric form. Then this is glycosidated to yield the methyl glycoside and finally the remaining hydroxyl groups are acetylated. All these operations are designated by suitable nomenclatural forms. The projection formula may then be transformed to a Haworth ring-form depiction or even to a conformational formula. In this way, all prefixes and suffixes, separable or inseparable, are considered as operational.



Extensions to the published British-American rules (4, 5), presently under consideration by both the British and American Committees, are suitable forms for naming polysaccharides, unsaturated sugars, branched chain sugars, acyclic derivatives, and for designating certain asymmetric centers not configurationally relatable to the sugar stem. Examples of the latter are designations for the absolute configurations of the benzylidene carbon atoms in the two possible forms (VI, VII) of a benzylidene cyclic acetal. This problem has recently been solved experimentally by the isolation of such pairs and the assignment to them of absolute configurations, by A. B. Foster and associates (6), in a brilliant application of proton magnetic resonance spectroscopy.



Formulas VI and VII are good examples of a single isolated, asymmetric center whose forms would appear to be best named according to the Cahn, Ingold, Prelog sequence rule (7, 8, 9, 10). Otherwise, assignments based on the sequence rule should not be given to the sugars (11). The sequence rule was never meant to be extended to them. To quote the originators of this rule (7): "... the present carbohydrate nomenclature is simpler than that which follows from the sequence rule, and need not be changed..." It is to be regretted that some writers of American college textbooks have mistakenly attempted to do this. Depending upon the valence bonds, adjacent centers of the same configurational form may receive different designations, and substitution of oxygen by sulfur on a center will immediately reverse its designation. This will not lead to rational classifications in such a well-related series of asymmetric centers as are found in the carbohydrates.

The modern organic "polymer" chemists would appear to have preempted the term "polymer" and to have limited it to strictly synthetic products. They thus overlook the fact that the carbohydrate group, and also the protein family, contain a great multiplicity of polymers, all fabricated by enzymes in a strictly isotactic manner. The carbohydrate polymers are much more simply constructed than are the proteins, and in many cases their structures are well established. Attempts to codify nomenclature in the area of polysaccharides have been under way for some time in an active subcommittee of the American group. The membership of the subcommittee consists of R. L. Whistler, chairman, R. W. Jeanloz, J. K. N. Jones, Karl Meyer, W. Pigman, and M. L. Wolfrom.

In addition to impinging on polymer nomenclature, the carbohydrates also impinge upon the biochemical area. Both the British and American committees have always endeavored to work with the biochemists, and have appointed to their committees biochemists of recognized scientific status. The biochemists hold an enviable position in that their journal editors have led a movement to improve nomenclature. However, their main editorial efforts so far have been centered on codifying an immense array of collations of initials. Initials are not names, and without names there is no true nomenclature. Nevertheless, the modern biochemist insists that initials are required in his publications. The nomenclature of biochemistry presents many difficult problems, but the exact naming of carbohydrate substances on a rational

basis would not appear to be one of them. The biochemical literature is replete with incorrect and faultily constructed names for carbohydrate substances.

Finally, a few comments may be in order as to the general acceptance of the published British-American Rules of Carbohydrate Nomenclature. It is apparent that their publication met a real need, and acceptance and usage have been wide in the English literature, including, as was noted above, many foreign journals publishing in this language. In addition to the "Advances in Carbohydrate Chemistry," Section 43 (Organic-Carbohydrates) of *Chemical Abstracts* adheres to these rules, as does the Abstracts of Meeting Papers of the Carbohydrate Division of the American Chemical Society. At this point, remarks are in order in respect to the impingement of the machine age upon these activities. Adaptation to computer composition by the Chemical Abstracts Service has presented problems to the nomenclaturist, some of which have been overcome. The recent change of the American Chemical Society from the printing of their Meeting Abstracts to an offset process requiring exact copy has presented more problems. It is believed by us that the machine should be made to work for the science; science should not be required to work for the machine.

The editors of the new journal, *Carbohydrate Research*, enforce a rigid standard of nomenclatural form. It is to be regretted that the editors of the fundamental journals of the American Chemical Society do not seem to be "nomenclature-minded" in the least degree. This includes *Chemical Abstracts*, with the exception of their indexes. As the complexity of science increases, a plea may be made here for some standardization of nomenclatural form; or do we all speak and write in different tongues?

LITERATURE CITED

- (1) Crane, E. J., *Chem. Eng. News* **26**, No. 22, 1623 (1948).
- (2) Crane, E. J., *ibid.*, **31**, No. 17, 1766 (1953).
- (3) *J. Chem. Soc.*, **1952**, 5108.
- (4) *J. Org. Chem.*, **28**, 281 (1963).
- (5) *J. Chem. Soc.*, **1962**, 5307.
- (6) Baggett, N., Buck, K. W., Foster, A. B., Randall, M. H., and Webber, J. M., *ibid.*, **1965**, 3394.
- (7) Cahn, R. S., and Ingold, C. K., *J. Chem. Soc.* **1951**, 612.
- (8) Cahn, R. S., Ingold, C. K., and Prelog, V., *Experientia* **12**, 81 (1956).
- (9) Cahn, R. S., *J. Chem. Educ.* **41**, 116; erratum 508 (1964).
- (10) Cahn, R. S., Ingold, C. K., and Prelog, V., (a) *Angew. Chem.* **78**, 413 (1966); (b) *Angew. Chem. Intern. Ed. Engl.* **51**, 385 (1966).
- (11) Ref. 10b, p. 404.