

when the proposals fail to gain approval. On the other hand, the widest possible consideration of proposals is desirable. Committee members often need the opinions of others. This question has never been settled and perhaps never will be. It is very desirable for proposed nomenclature (as contrasted with accepted nomenclature) to be regarded as tentative and used with discretion. Sometimes the interval between proposal and official action is rather long. This is not always avoidable.

Even approved nomenclature rules are often published as tentative for a year or so to give potential users an opportunity to discover and report objections. This is healthy practice.

Nomenclature development is not easy. The hard work required takes much time, study, criticism, correlation, and original thinking, and it calls for a truly comprehen-

sive knowledge of the scientific field involved as well as of word structure. The widest possible nomenclature picture often needs to be kept in mind for the sake of consistency. It is wise to keep branches of chemistry from developing nomenclature systems out of step with each other as to general planning whenever the good of the whole of chemistry is better served by a consideration of the needs of all.

Once official agreement on nomenclature rules has been reached the widest possible distribution of the information is desirable. Then all scientists have an opportunity to help, not only in the good cause of nomenclature development, but also in the development of affected scientific fields through the use of the most effective scientific language. Is it not a duty to try to use standard nomenclature?

Inorganic–Organic Nomenclature

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Some of the overlapping areas between inorganic and organic chemistry and their nomenclatures have been no-man's land and some have been both men's land, without any real truce, although it is increasingly recognized that there is no fundamental distinction between these branches of chemistry that have been separated by historical developments. With the rapid growth of organometallic chemistry and the quickly disappearing border between the two disciplines, it is the purpose of this paper to examine the nomenclature systems used in inorganic and organic chemistry, to look at the similarities and differences in the two systems, and to point out some of the problems arising as the result of these differences.

When we compare organic and inorganic nomenclature some of the basic differences between organic and inorganic chemistry must be kept in mind:

1. Inorganic chemistry is concerned with many elements, while organic chemistry is basically concerned with just one element, carbon.
2. Inorganic chemistry deals with oxidation states.
3. Different types of bonding are much more frequently encountered in inorganic chemistry.
4. Structures with alternating atoms (that is bonding between different kinds of atoms) occur more often in inorganic molecules.

5. Organic chemists were concerned at an earlier stage with structure—inorganic chemists only more recently. Thus, some inorganic compounds of silicon, germanium, and boron analogous in formula to organic compounds were at one time given organic-sounding names like disilicoethane, germanoethane, and boroethane.

An encouraging development is the increasing cooperation between inorganic and organic nomenclature committees. In the International Union of Pure and Applied Chemistry (IUPAC), at least in recent years, there has often been an organic observer at meetings of the Commission on Nomenclature of Inorganic Chemistry, and *vice versa*. In 1959 at Munich, the two commissions set up a joint subcommission consisting of an equal number of members from each to study the whole field of nomenclature of organometallic compounds. The subcommission consisted of four, and later three, members each from the organic and inorganic commissions. In the American Chemical Society there has been good cooperation between inorganic and organic nomenclature committees in some cases, while in others more would have been highly desirable; fortunately, there is promise of better cooperation in the future.

Reports of special nomenclature subcommittees under the Division of Organic Chemistry of the American Chemical Society, dealing in some cases in part with inorganic as well as organic compounds, are those published on silicon,¹ fluorine and other halogens,² and

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phosphorus,³ and the still unpublished ones on boron and organometallic compounds. More recently appointed committees under the Division of Inorganic Chemistry are those on boron, halogen, and phosphorus compounds.

In this connection a careful and exhaustive study should be made as to whether there is a need for special nomenclature systems for each element or group of elements, or whether it is possible to develop a general uniform system. Could extension of the oxa-aza system for carbon compounds fill this need? Or coordination-type names? Within a given area is it necessary to have separate systems for inorganic and organic compounds? We have such a situation now in the phosphorus field.

In the discussion that follows, reference will be made to the 1957 IUPAC Definitive Rules for Nomenclature of both Inorganic and Organic Chemistry which have been published separately in book form⁴ and reprinted together in the United States with committee comments in the *Journal of the American Chemical Society*.⁴

Before proceeding further we want to point out two differences between organic and inorganic nomenclature rules which are general in scope:

1. *Substitution*. The organic chemist substitutes for hydrogen. For example, the name chloromethane indicates that a chlorine atom has replaced a hydrogen atom. The inorganic chemist, on the other hand, may substitute for a hydroxyl group, an oxygen atom, or both. For example, in the name chlorophosphoric acid, a chlorine atom is considered to have replaced an OH group.
2. *Sequence of substituents*. Organic substituents are cited in alphabetical order (for example, bromochlorofluoroiodomethane). This practice is recommended in the IUPAC organic rules and it has been used by *Chemical Abstracts*. A different order of citing ligands is given in the IUPAC inorganic rules. It is not quoted here, since the matter is to be discussed again by the Commission on Nomenclature of Inorganic Chemistry.

The general areas of overlapping between inorganic and organic nomenclature include the naming of inorganic compounds that have organic derivatives, organic compounds that have inorganic derivatives (as salts), coordination compounds, organometallic compounds, and isotopically labeled compounds. Running through all these areas are the problems of harmonizing differences between inorganic and organic names for radicals and ions, and for prefixes and suffixes. Some encouraging progress has already been made along these lines.

In the matter of names for radicals and ions, a simple example of inorganic-organic rapprochement is the designation of fluorine as a substituent. Organic practice has been pretty consistently fluoro (fluoromethane), but until recently inorganic practice has usually favored fluo (for example, fluoborate). The IUPAC inorganic rules now give only fluoro.

For the ion H_3O^+ and its organic derivatives, organic chemists have used the term oxonium by analogy with sulfonium rather than with ammonium. Although hydronium was recommended for this ion in the 1940 IUPAC inorganic rules, oxonium is the choice in the 1957 rules.

Again, take SO_2 and SO , called sulfonyl and sulfinyl, respectively, in inorganic names, and sulfonyl and sulfinyl in organic names. At a joint meeting of the Inorganic and Organic Commissions of the IUPAC in 1951, it was agreed

that the preferred names would be sulfonyl and sulfinyl except that "the trivial names of sulfonyl halides and thionyl halides be retained for these cases only." Sulfonyl is not, however, a completely unsystematic name, but an acid radical name regularly formed from the trivial name sulfuric acid, analogous to nitryl, phosphoryl, etc. Thionyl, of course, is an unfortunate but well-established exception. From the inorganic point of view, the name sulfurosyl has been suggested for SO ; it would be analogous to nitrosyl.

In the other direction, there are a few changes from organic names to inorganic names. One is that from triazo to azido for the group N_3^- , and triazo is not even given as a synonym in the latest IUPAC and *Chemical Abstracts* lists of organic groups and radicals. Another change is from thiocyno to thiocyanato.

A valuable step has been taken by the inclusion at the end of the 1957 IUPAC inorganic rules of a list (even though not complete) of names for ions and radicals, with columns for comparing names of groups as neutral molecules, cations or cationic radicals, anions, ligands, and prefixes for substituents in organic compounds. A parenthetical statement at the head of the list reads: "In inorganic chemistry substitutive names are seldom used, but the organic-chemical names are shown to draw attention to certain differences between organic and inorganic nomenclature." This is elaborated on in the rules themselves, together with a brief paragraph on "conjunctive names" such as hydrazinesulfonic acid, which "according to the principles of inorganic chemical nomenclature should be called hydrazidosulfuric acid."

One general difference in usage is that of the ending -ido in inorganic names but not usually in organic ones: sulfido as well as thio, nitrido instead of nitrilo, imido and amido instead of amino and imino (though of course prefixes for organic acid radicals like acetamido end in -ido). The extension of this practice to hydrido to replace hydro as a ligand name has met considerable opposition from American and British inorganic nomenclature committees.

Another general difference in the IUPAC rules not yet accepted widely involves the invariable use of -o as an ending for anionic ligands or those regarded as such: peroxo, hydroxo, methoxo, by analogy with oxo.

In the naming of organic derivatives of inorganic compounds, there exists a problem due to the fact that hydrides of certain elements have trivial names such as silane, phosphine, and germane, and we name their derivatives by substitution (for example, tetramethylsilane), while other hydrides such as AlH_3 and HgH_2 do not have widely accepted trivial names, and we name their derivatives by addition (example, triethylaluminum), as indicated in rule 48 of the 1930 Definitive Report of the Commission on the Reform of Nomenclature of Organic Chemistry of the International Union of Chemistry⁵; thus, to name the compound AlEt_2H , we are forced to say diethylaluminum hydride, while if we had a trivial name for AlH_3 such as alane (used in some German papers) or alumane, we could name the above compound by substitution, that is, diethylalane or diethylalumane. For this reason new trivial names for hydrides of more elements or in some cases reactivation of older names would seem highly desirable.

Next to hydrides, organic derivatives of inorganic acids have probably presented the most problems in this area

of overlapping. With esters, the chief question is the indication of partial and complete substitution in polybasic acids. Shall we say dimethyl sulfate, as recommended in the inorganic rules, or methyl sulfate, in line with much organic practice? For so-called acid esters, is diethyl hydrogen phosphate, for example, acceptable to everyone (though not in the fused form of hydrogenphosphate as one word adopted throughout the IUPAC inorganic rules)?

More troublesome is the naming of amides, imides, and nitriles or nitriles, particularly the amides in which some of the hydroxyl groups of a polybasic acid have not been replaced. The prefix amido- has generally been used in inorganic names, as amidophosphoric acid for $\text{NH}_2\text{PO}(\text{OH})_2$, whereas the suffix -amic acid is favored in organic names, as succinamic acid. The 1957 IUPAC inorganic rules recognize the use of either the prefix amido- or the suffix -amidic acid, as in phosphoramidic acid (in line with the organic phosphorus report³).

Some of the greatest confusion in overlapping inorganic-organic naming lies in -onic and -inic acids. It stems at least in part from opposing organic and inorganic approaches. If the systems of (1) substitutive names or (2) additive or conjunctive names that are common in organic but not inorganic nomenclature are followed, then chlorosulfonic acid for ClSO_3H can be considered as (1) derived from a hypothetical sulfonic acid HSO_3H by substitution of a hydrogen attached to sulfur, or (2) made up of chlorine and the sulfonic group SO_3H . According to inorganic principles, on the other hand, ClSO_3H would be named chlorosulfuric acid and regarded as (1) derived from sulfuric acid by substitution of hydroxyl instead of hydrogen or (2) made up of chlorine and three oxygens coordinated to sulfur, with "sulfuric acid" considered to be an abbreviated form of trioxosulfuric(VI) acid.⁶ If chlorosulfonic acid is taken as a type name (as some British organic chemists at one time did), one system of naming -onic and -inic acids results; if chlorosulfonic acid is taken as an exception, another system results. A closely related question is the use of hydrocarbon *vs.* radical names for organic -onic and -inic acids; benzenesulfonic acid and benzenesulfinic acid are well established, but phenylphosphonic and diphenylphosphinic acids are now preferred by *Chemical Abstracts* following the organic phosphorus report. Finally, it must be pointed out that -inic and -onic acids seem to indicate different oxidation states; this is indeed true for sulfinic-sulfonic acids, but not for borinic-boronic and phosphinic-phosphonic acids.

For acids in which sulfur has replaced part or all of the oxygen, inorganic chemists prefer to use simply thio rather than the thio- and thiono once favored by some organic chemists but now dropped from the *Chemical Abstracts* lists. Since in the free acids, salts, and some partial esters and amides containing both oxygen and sulfur, the position of hydrogen or other cation with reference to oxygen and sulfur is indeterminate, the use of thio- and thiono to indicate replacement of oxygen in hydroxyl or doubly bound oxygen, respectively, is more specific than the structure itself. The location of ester groups can be indicated by the use of *O*- and *S*-; thus, the insecticide parathion is *O,O*-diethyl *O*-*p*-nitrophenyl phosphorothioate (or (mono)thiophosphate).

In the naming of inorganic derivatives of organic compounds, salts of organic acids and organic bases do not

seem to have received marked divergent treatment by inorganic and organic chemists, unless perhaps in the case of salts of bases inorganic chemists have shown greater preference for cation names like phenylhydrazinium chloride over names like phenylhydrazine hydrochloride.

However, in the naming of metal derivatives of alcohols and phenols, there has again been a fundamental disagreement between the organic and inorganic views of the nature of these derivatives and also between the attitudes toward the sometimes similar naming of hydrates, alcoholates, and like "addition compounds." For metal derivatives the organic rules and also *Chemical Abstracts* used oxide names such as sodium alkoxide, ethoxide, phenoxide, or benzyl oxide. According to the IUPAC inorganic rules, on the other hand, alcoholates are salts of alcohols and hence should be given names with -ate endings, as ethanolate (hence "ethanethiolato" for the $\text{C}_2\text{H}_5\text{S}$ - group as a ligand in the inorganic rules list, in contrast to the organic "ethylthio"). For addition compounds, organic chemists do not seem to object to hydrate, alcoholate, and the like, whereas inorganic chemists, at least as represented by the IUPAC rules, wish to reserve the ending -ate for anions and so favor discarding the terms alcoholate (to indicate alcohol of crystallization), etherate, ammoniate, etc., and even hydrate, and instead favor simply naming the compounds (ethanol, diethyl ether, ammonia, water, etc.) after the name of the other component of the addition compound: thus calcium chloride-6-water (or calcium chloride hexahydrate). This disagreement over naming of metal derivatives of alcohols and phenols and also over naming of addition compounds should be resolved as soon as possible.

The groups of compounds discussed so far have been dealt with for the most part by organic committees rather than inorganic up until the 1957 inorganic rules.

Coordination compounds, on the contrary, have been studied and named more by inorganic chemists⁷ than by organic, in spite of the fact that there is much of organic interest in organic ligands. In general, there is evidence (as indicated, for example, in the 1957 inorganic rules) of a growing tendency among inorganic chemists to broaden the application of coordination-type names. Thus complex compounds like the polyphosphorus compounds can be systematically named as coordination compounds, as suggested by Professor George W. Schaeffer. Many organic chemists, on the other hand, favor extending the oxa-aza or "a" system⁸ to such compounds. A thorough study of the application of both systems to these compounds as well as possible alternatives seems indicated.

In particular for coordination compounds (as already pointed out in connection with the names for ions and radicals), if -o is used for all anionic ligands, divergencies from the organic use of -y will result: hydroxo, hydroxy; methoxo, methoxy; acetato, acetoxy. Another question is the use of trivial or systematic names for organic ligands: acetylacetonato or 2,4-pentanediono (or -dionato); 1,2,3-triaminopropane or 1,2,3-propanetriamine?

A new field of organometallic chemistry which presents challenging nomenclature problems was opened by the discovery of di(or bis)(cyclopentadienyl)iron (ferrocene) in 1951. The rapid extension of the field to compounds of nearly 30 transition and rare earth metals with cyclopentadienyl radicals and related structures has shown that

there are at least several types: di(or bis)(cyclopentadienyl) compounds of the metals ("sandwich" compounds) ionic cyclopentadiene derivatives ("cyclopentadienides") of some metals, cyclopentadienyl metal halides, carbonyl and nitrosyl compounds of metals with either one or two cyclopentadienyl groups, and complex ions involving cyclopentadienyl radicals bonded to metals. The diversity of chemical behavior even exceeds that of type formula so that two substances [like $(C_5H_5)_2Mn$ and $(C_5H_5)_2Fe$] may have similar empirical compositions but widely different properties. A whole series of trivial names have begun to appear in the literature for these systems: ferrocene, ruthenocene, cobaltocene, osmocene, benzoferrocene, etc. Thus, it becomes imperative to decide whether a systematic nomenclature can adequately handle all these compounds. The alternative is a multitude of trivial names. An additional complicating factor is the great number of organic derivatives that can be obtained from these systems. Thus, taking ferrocene as an example, organic substituents have been introduced into the molecule by Friedel-Crafts acylation, metalation, arylation with diazonium salts, and syntheses *via* Mannich bases of ferrocene. This makes the nomenclature problem that much more acute.

Finally, recommendations for the designation of special isotopes in names of compounds have been considered by both inorganic and organic committees. The earliest work on such naming was very naturally on deuterium. In the now familiar modified Boughton system⁹ introduced by Dr. E. J. Crane into *Chemical Abstracts* indexing of both inorganic and organic compounds some 20 years ago, a small italic *-d* follows the common name or part of the name: ammonia-*d* for NH_3D and acetic-*d*₂ acid-*d* for CH_2D_2COOH . Tritium can be similarly indicated by *-t*. For other labeled compounds in *CA* the symbol in italics (with mass number at the upper right) is attached by a hyphen to the end of the part of the name that is modified: ammonia- N^{15} for $N^{15}H_3$; acetic-1- C^{14} acid for $CH_3C^{14}OOH$. (In 1964 *CA* changed its practice to put the mass number

to the upper left in conformity with the IUPAC inorganic rules.)

No IUPAC rules for naming isotopically labeled organic compounds have been published, but the 1957 inorganic rules stipulate that the symbol(s) with mass number as left superscript should follow in parentheses the name or part of the name designating the group in which the labeled atom occurs, with indication (if necessary for clarity) of the whole group containing the labeled atom: ^{32}P phosphorus(^{32}P) trichloride; $^2H^{35}SO_4$ sulfuric(^{35}S) acid(2H); $^{15}NO_2NH_2$ nitramide($^{15}NO_2$). Italics are not specified. [Although 2H is shown in this section (1.32) of the rules, deuterium and tritium are approved in an earlier section (1.15) and D^- deuteride ion is in a later section (3.21).] Since the current differences in practice are chiefly in form only, it should not take lengthy arbitration to achieve much-to-be desired uniformity in naming isotopically labeled compounds.

In conclusion, it is our hope that by pointing out some of the similarities and differences between organic and inorganic nomenclatures and by examining briefly some of the problems, this paper will contribute in a small way to a greater mutual understanding between chemists active in the two fields.

REFERENCES

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