and biparametric correlations, with the number n of carbon atoms in the alkane as the additional parameter; linear and nonlinear correlations, with square root as the optimal power in the latter case).

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Numbering of Interior Atoms in Fused Ring Systems

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Received April 8, 1991

Because of the inadequacy of the current rules for numbering interior atoms of fused ring systems, supplementary rules have been developed at Chemical Abstracts Service. These rules are easy to apply, and in most cases, locants can be assigned by inspection.

INTRODUCTION

Existing rules for numbering interior atoms[1,2] of fused ring systems (i.e., atoms common to more than two rings) have proved inadequate. The term "clockwise numbering" is vague in the sense that it could be applied to interior atoms or to a ring system as a whole, resulting in two different sets of numbers for the same ring system. Also, no provisions were made for determining the numbering of complex branched chains of interior atoms, nor were any provisions made for numbering of interior atoms attached to a heteroatom in the interior of a fused ring system. This paper describes the supplementary rules developed at Chemical Abstracts Service (CAS) to resolve these problems, and they have been used successfully since 1980.[3]

CURRENT RULES

The current rules for assignment of orientation and numbering for fused hydrocarbons and heterocycles are applied in sequence as follows:

1. The fused ring system is oriented so that
   a. The largest number of rings are in a horizontal row.
   b. The largest number of rings are above and to the right of the horizontal row (i.e., in the upper right quadrant).
   c. The smallest number of rings are below and to the left of the horizontal row (i.e., in the lower left quadrant).
   d. The largest number of rings are above and to the left of the horizontal row (i.e., in the upper left quadrant).[4]
   e. The smallest number of rings are below and to the right of the horizontal row (i.e., in the lower right quadrant).[4]
2. If two or more orientations meet these requirements, then a unique orientation is determined as follows
   a. Low locants are given to heteroatoms.
   b. Low locants are given to heteroatoms in the priority order O > S > Se > Te > N > P > As > Sb > Bi > Si > Ge > Sn > Pb > B.[5]
   c. Low locants are given to carbon atoms common to two or more rings (i.e., angular carbon atoms).
   d. Low locants are given to atoms that have indicated hydrogen atoms.
3. A locant is assigned to each atom of the ring system as follows
   a. Numeric locants are assigned to all nonangular, peripheral carbon atoms and to all peripheral heteroatoms, whether angular or nonangular. The locants are assigned in a clockwise direction, commencing with the most counter-clockwise, nonangular position of the uppermost ring or, if there is a choice, of the uppermost ring farthest to the right. When all of the peripheral atoms, except the angular carbon atoms, have been numbered, numbering is continued by assigning numeric locants to the interior (i.e., nonperipheral) heteroatoms.
   b. The remaining unnumbered peripheral atoms are angular carbon atoms. Such carbon atoms are designated by adding roman letters "a", "b", "c", etc., to the numeric locant of the position immediately preceding. Interior carbon atoms follow the highest numeric locant, taking a clockwise sequence when there is a choice.

SUPPLEMENTARY RULES

The supplementary rules for numbering interior angular atoms of fused ring systems replace the last sentence of Rule 3b and were developed at CAS in accordance with the principles that (1) they would be an extension of existing rules; (2) they would yield the highest allowable numbering to those atoms; (3) they would eliminate the clockwise numbering sequence of the last sentence of Rule 3b and its ambiguity. Interior atoms can occur as single atoms or as chains of atoms. A single atom is treated as if it were the first atom of a chain. A chain can be branched or unbranched. Noncontiguous chains are numbered completely and in sequence.

Where a choice is necessary because the numbering can proceed by more than one path, the following rules are applied *in sequence* until all of the interior atoms have been numbered.

Rule 1. Longest Primary Chains. Starting from the atom attached to the highest numbered angular, peripheral atom available, an unbranched chain is numbered sequentially,

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beginning with the next available alphanumeric locant. If the chain under consideration has branches of unequal length, the path chosen is the one containing the longer branch. This procedure is continued until the *longest continuous path* of interior atoms is determined. The locants then are sequentially assigned to this chain of atoms. The next chain of interior unnumbered atoms *attached to the periphery* is determined, and the numbering continues from the next highest peripheral atom to which this chain is attached. This procedure is repeated until all of the interior atoms in the ring system are numbered or until a branch of equal length is reached. At this point Rule 1 no longer applies, and the direction taken by the main chain is determined by Rule 2.

Rule 2. Chains with Branches of Equal Length. If more than one chain contains an equal number of interior atoms, the preferred path is determined by considering the two atoms attached to the atom from which the preferred chain is to be determined. The shortest path from these two atoms to the periphery is determined, without the two paths crossing. If more than one path to the periphery is possible for each atom, the path taken in each case is the one leading to the lowest numbered peripheral atom. The atom that is attached to the lowest numbered peripheral atom determines the direction taken by the primary chain.

After all of the interior atoms connected to peripheral atoms with the highest available alphanumeric locants (i.e., connected to an angular atom from which alphanumeric numbering can continue) have been numbered, some atoms may remain unnumbered (i.e., they are not directly connected to a peripheral atom). They may be single atoms ("isolated" atoms, which are regarded as the first atoms of chains) or chains of atoms ("isolated" chains). The following rule is applied to these isolated atoms or chains.

Rule 3. Isolated Atoms and Chains. Isolated atoms and chains are numbered after all of the chains connected to the periphery have been numbered. Because isolated atoms and chains are not directly connected to angular, peripheral atoms from which alphanumeric numbering can continue, they are numbered by first determining the *longest chain* of the unnumbered atoms. The terminal atoms of this chain are compared with the peripheral atoms as described in Rule 2. If these isolated atoms are branched, the preferred chain of isolated atoms is determined by application of Rule 1 or Rule 2 as required. The terminal atoms of this preferred chain then are compared with the peripheral atoms as described in Rule 2, and the numbering continues from the terminal atom closest to the lowest numbered peripheral atom. The *highest alphanumeric locant* available is assigned to this atom, and the rest of the chain is assigned sequential locants. When a ring system contains more than one isolated chain, each chain is numbered in turn—in its entirety—by starting with the isolated chain having a terminal atom of its longest chain connected to the atom with the lowest locant of the compared peripheral atoms. The chain is numbered as described in Rule 1. The second chain is numbered beginning at the atom connected to the peripheral atom with the next lowest locant, and the process continues until all interior atoms are numbered.

Rule 4. Heteroatoms. Heteroatoms present in the interior of a fused ring system are assigned the next highest numeric locants after all of the peripheral atoms have been numbered.

A heteroatom in a unique position in the interior of a fused ring system is assigned the next highest numeric locant. However, if a heteroatom can be placed in either of two equivalent positions of a symmetrical ring system, or if more than one heteroatom is present, then unique numbering for the heteroatoms is determined as follows.

If the heteroatom can have two or more equivalent interior positions in a structure, the numbering is assigned to the peripheral atoms in the usual manner. These equivalent interior positions are compared with the peripheral atoms to determine the most preferred position for the heteroatom (the position closest to the lowest numbered peripheral atom). An orientation of the ring system is chosen that locates the heteroatom in this preferred position, as described in Rule 2, and it receives the next highest numeric locant. Another heteroatom at a position connected to a peripheral atom with a lower locant is assigned the next highest numeric locant, etc. The presence of mixed heteroatoms does not change the numbering unless the numbering of the positions is equivalent; then the lowest locant is assigned to the atom of highest priority,[5] i.e., the most preferred heteroatom is placed in the position connected to the peripheral atom with the lowest locant.

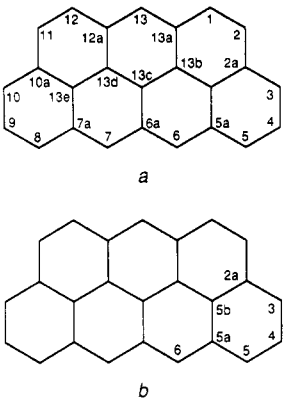

Figure 1.

In fused ring systems containing unnumbered interior carbon atoms in addition to interior heteroatoms, alphanumeric locants are assigned to the latter as described in Rule 5.

Rule 5. Chains Connected to Interior Heteroatoms. The longest chain of carbon atoms attached to the interior heteroatom with the highest locant is determined. Consecutive alphanumeric numbering is assigned to the chain, beginning with the atom attached to the heteroatom. The next longest chain of unnumbered atoms connected to the heteroatom is determined, and the process is repeated until all of the interior atoms attached to the heteroatom have been numbered. If there are two or more chains of equal length, the peripheral atoms to which the atom of each chain farthest from the heteroatom is connected are compared in accordance with Rule 2. The chain with the terminal atom connected to the peripheral atom having the lower compared locant is assigned the next sequence of locants. This procedure is repeated until all of the interior atoms have been numbered.

APPLICATIONS OF RULES

Example 1. Application of Rule 1 to Figure 1 in the numbering of the interior atoms is shown in Figure 1a. The highest numbered angular peripheral atom available is 13a, and the longest continuous path is numbered 13b–13e. The next highest numbered angular peripheral atom available is 5a (vs 3a), and the remaining interior atom is numbered 5b (Figure 1b).

Example 2. The peripheral atoms of Figure 2 are numbered as shown, and numbering continues as follows:

a. Interior numbering starts from peripheral atom 18a and continues as far as possible, i.e., 18b and 18c, in accordance with Rule 1.

b. Proceeding in a counterclockwise direction around the periphery from atom 18a, the next continuity between peripheral and interior atoms exists at peripheral atom 14b. Hence, locants 14c and 14d are assigned to these interior atoms in accordance with Rule 1.

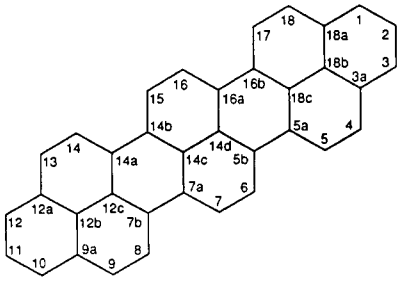

Figure 2.

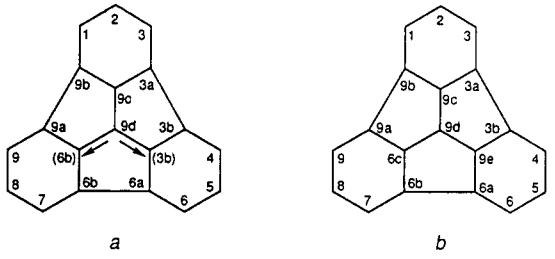

Figure 3.

c. The next continuity exists at atom 12a. The locants 12b and 12c are assigned to these atoms, and the ring numbering is complete.

Example 3. Atoms 9c and 9d of Figure 3a are numbered according to Rule 1. From 9d, however, the numbering can proceed in either of two directions. Rule 2 is then applied as follows:

a. The shortest distance from each of the atoms in question to the periphery is determined; in each case, one atom.

b. The *lowest numbered* peripheral atoms that can be reached by each of these shortest paths are chosen (i.e., 6b vs 9a and 3b vs 6a).

c. Numbering continues in the direction of the lower numbered atom, i.e., the atom connected to 3b is numbered 9e. The remaining interior atom is numbered 6c according to Rule 1. The complete numbering is shown in Figure 3b.

Example 4. In fused ring systems such as those represented in Figure 4, it is necessary to apply Rule 1 at every point from which two paths are possible. In accordance with this rule, interior numbering starts from 18a. Two paths are possible from the first interior atom, 18b. Figure 4a shows that a path can be traced that includes all of the interior atoms.[6] By going in the other direction (Figure 4b), even the best continuous path leaves one isolated interior atom. Hence, application of Rule 1 at 18b effectively determines the rest of the path. However, when point 18t is reached, numbering can proceed in either of two directions, as shown by the arrows in Figure 4c. At this point, Rule 1 no longer applies, and the atom to be numbered 18u is determined by Rule 2, as follows:

a. The shortest paths from each unnumbered atom to peripheral atoms are determined. Figure 4d shows that each of the paths contains three atoms.

b. The lowest numbered peripheral atoms that can be reached by each of these shortest paths are considered (i.e., 2a vs 3a and 14a vs 15a).

c. Locant 18u is assigned to the atom in the direction of the lower numbered peripheral atom, i.e., 2a, and the numbering is completed as shown in Figure 4a.

Example 5. The peripheral atoms of Figure 5 are numbered as shown, and numbering continues as follows:

a. After all of the peripheral atoms have been numbered, two atoms remain (a 2-atom chain) that cannot be numbered consecutively from the periphery. Thus, Rules 1 and 2 do not apply.

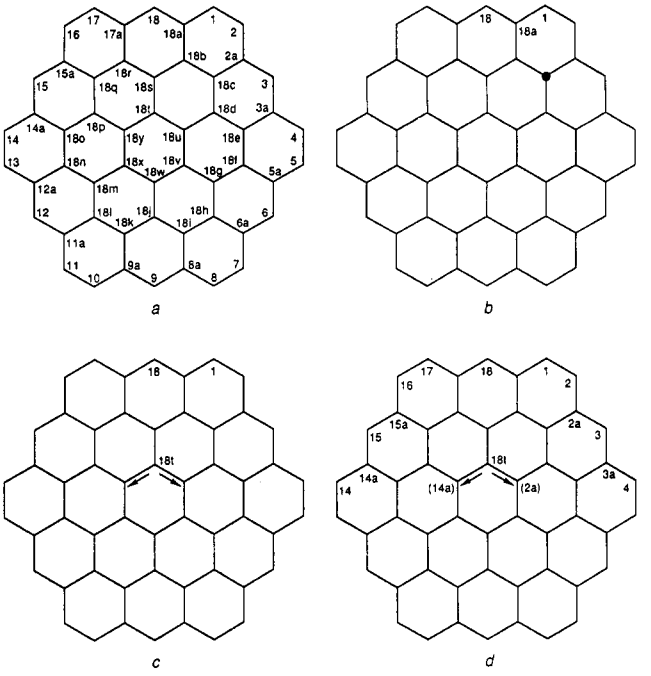

Figure 4.

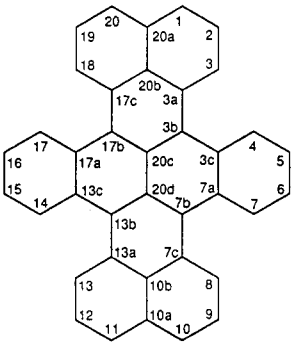

Figure 5.

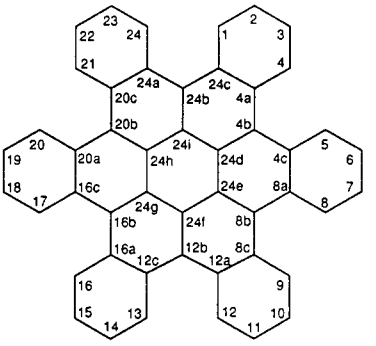

Figure 6.

b. As described in Rule 3, the two ends of the isolated unnumbered interior atoms are given the next higher locant sequence (20c and 20d), beginning, as before, at the end connected to the lower numbered peripheral atom, i.e., 3b.

Example 6. The peripheral atoms of Figure 6 are numbered as shown. Two things are immediately evident when attempting to assign locants to this structure: it is highly symmetrical (12 positions can be assigned the locant 1), and no interior atom is connected to the periphery in such a way that consecutive locants can be assigned to the interior atoms from the periphery.

a. Assignment of the locant 1 to the structure determines the peripheral numbering and orientation of the structure as shown above.

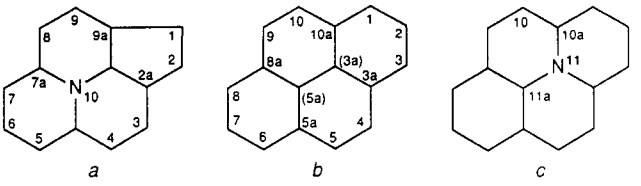

Figure 7.

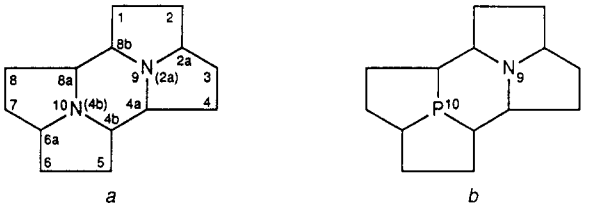

Figure 8.

b. The interior atoms form a cyclic chain of six atoms. From Rule 3, the next highest locant is assigned to the interior atom closest to the lowest numbered peripheral atom. Thus, the locant 24d is assigned to the atom connected to atom 4b of the periphery.
c. Rule 2 determines the direction of the rest of the locants assigned to the other atoms in sequential order around the chain. For numbering purposes these cyclic structures are considered chains whose cyclic nature is considered broken between the two atoms having the lowest and highest number.

Example 7. The single heteroatom in Figure 7a is in a unique position. After the peripheral locants have been assigned in accordance with Rule 1, the heteroatom is assigned the next higher locant, 10, in accordance with Rule 4.[7]

The two equivalent positions in Figure 7b are compared in terms of the lower numbered peripheral atoms (3a and 5a) to which they are attached, in accordance with Rule 2. An orientation of the ring system then is chosen so that the heteroatom is in the position that is closest to the lowest numbered peripheral atom, 3a, in accordance with Rule 4, and is assigned locant 11. The remaining unnumbered interior atom is numbered 11a, as shown in Figure 7c.

Example 8. Figure 8a illustrates a ring system containing two heteroatoms of the same element in equivalent positions. The next higher locant, 9, is assigned to the nitrogen attached to 2a, and locant 10 is assigned to the nitrogen attached to 4b, in accordance with Rule 4.

Figure 8b illustrates a ring system containing two heteroatoms of different elements in equivalent positions. The more preferred heteroatom, N, is assigned to the position closest to the peripheral atom 2a, and the less preferred heteroatom, P, is assigned to the atom connected to 4b, in accordance with Rule 4. The heteroatoms are then assigned locants 9 and 10 respectively, also in accordance with Rule 4.

Example 9. The presence of a heteroatom in the interior of a ring system influences the numbering of the other interior atoms attached to it. The highest peripheral locant is 12a, so the arsenic atom is assigned the next highest numeric locant, 13, in accordance with Rule 4. The remaining interior atoms are considered as one-atom chains directly connected to the arsenic, which is the highest numbered atom in the structure. By Rule 5, the (one-atom) chain connected to peripheral atom

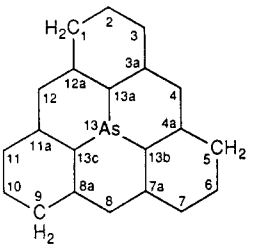

Figure 9.

3a is given locant 13a; the next locant, 13b, is assigned to the atom connected to 4a, and the final unnumbered atom is assigned locant 13c. The complete numbering is shown in Figure 9.

CONCLUSION

The purpose of this paper is to formulate a unique and reproducible procedure for numbering the interior atoms of fused ring systems. The rules are easy to apply, and in most cases, locants can be assigned by inspection.

The examples used in this paper have been chosen to illustrate the range of complexity of ring systems that can be encountered. The interior atoms in these examples have been numbered in such a way as to assist the reader in understanding and applying the rules.

REFERENCES AND NOTES

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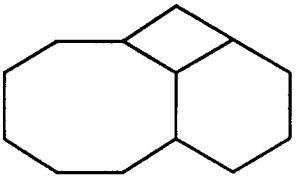
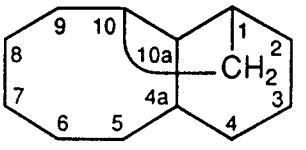
(2) *Nomenclature of Organic Chemistry; Sections A, B, C, D, E, F, and H*, 1979 ed.; Pergamon Press: Oxford, 1979; pp 25–6.
(3) This paper does not consider ring systems that are named as bridged fused systems because, in such systems, the bridge is considered only after the ring system has been named. For example, the ring system



appears to have an interior atom. However, no method exists for describing the fusion of the 4-atom ring to both the 6- and the 8-atom ring. The ring system is therefore named as a bridged fused system.



1,10-methano-1*H*-benzocyclooctene

The interior atom has now become a peripheral atom during the naming process.
(4) Although not explicitly stated in ref 1, these rules were deemed to be an extension of Patterson's Rules.
(5) *Nomenclature of Organic Chemistry; Sections A, B, C, D, E, F, and H*, 1979 ed.; Pergamon Press: Oxford, 1979; p 53.
(6) Note that the path spirals from the exterior toward the interior of this ring system.
(7) The second interior atom remains unnumbered because it cannot be numbered by Rules 1–4. Application of Rule 5 yields the permanent locant 10a (cf. Figure 9).