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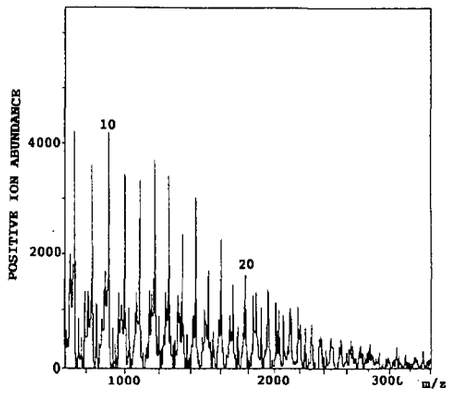

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Nomenclature of Organic Polycycles out of the Computer – How to Escape the Jungle of the Secondary Bridges

Gerta Rücker and **Christoph Rücker***

Chimia 44 (1990) 116–120

Abstract. A computer program is described which generates *IUPAC* names (*von Baeyer* names) and the corresponding numbering schemes for polycyclic hydrocarbons of any size and complexity. The program thoroughly uses constitutional symmetry which may be present. Parts of *IUPAC* rule *A-32* had to be formulated more precisely than codified hitherto. The names and the elapsed CPU times are given for some polycycles.

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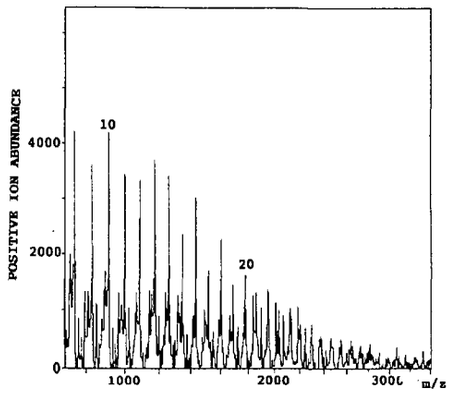

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synthesising more and more complex unusual polycyclic organic structures [3]. The primary problem is not the lack of nomenclature rules but the chemists' lacking ability or willingness to apply the long-established *IUPAC* rules [4] to compounds of ever-increasing size and complexity. As a result incorrect *IUPAC* names for polycyclic compounds are found throughout the literature up to the present time [5]. A graphic method [6] and computer programs [7] put forward several years ago could not change this situation due to their severely limited scope. By developing a computer program capable of *naming and numbering polycyclic compounds of any size and complexity*, we hoped *i)* to demonstrate that a rather complex part of organic nomenclature is open to generation by machine, *ii)* to provide the practising chemist with a tool to relieve him from a time-consuming, error-prone, and, thus, unpopular task. In the course of the work, it became obvious that a powerful program for symmetry perception was likewise in demand and that the nomenclature rule *A-32* itself had to be further developed. We here report on the program POLCYC (polycyclics) which (conveniently, but not necessarily in combination with the symmetry-perception program TOPSYM [8] (topological symmetry)) meets the stated aims, and on our tentative extensions to *IUPAC* rule *A-32* included therein. To give the reader an impression of the program's capability, in *Fig. 1* compounds **1–12** are shown whose names were generated by POLCYC (see *Table 1*).

Both programs are written in FORTRAN 77 and require the constitutional formula of the compound under investigation as the only input information (the *n* C-atoms being numbered arbitrarily). The symmetry perception program TOPSYM, using a purely mathematical approach, partitions both the atoms and the pairwise relationships between atoms into equivalence classes. The lowest-numbered representative of each equivalence class of bridgehead pairs is listed to be treated by POLCYC.

The nomenclature program POLCYC closely mimics a chemist's trial-and-error approach in that it tries to line up atom by atom on a string, in a cycle or a bicycle under certain restrictions. It consists of several principal features. First, there is a section generating for a given *n* a so-called *compatibility table*, *i.e.* an ordered (ranked) list of all possible fundamental bicycle sizes, separated in two sections for *Hamilton* cases (all *n* C-atoms on one closed circuit) and non-*Hamilton* cases. Such a table is shown in *Table 2*. Each entry consists of a sequential number and a pair of square brackets containing three numbers which characterise the bicycle size [*l.s.m*] (for *l*arger branch of main ring. *s*maller branch. *m*ain bridge). In the construction procedure, the *IUPAC* rules *A-32.31a–c* are incorporated, so it is ascertained that any entry (addressed by its sequential number) is better in the sense of rule *A-32* than all entries having higher sequential numbers.

Second, a procedure is included (the *path algorithm*) which generates for a given structure, a given bridgehead pair (i, j) and a given entry [*l.s.m*] all possible bicycles of size [*l.s.m*], in that it tries to construct a pathway from *i* over a sequence of *m* atoms to *j*, back over a sequence of *s* atoms to *i*,

Table 1. *IUPAC Names of Compounds* **1–15** *and the CPU Times Elapsed in Generating These Names and the Corresponding Numbering Schemes*

1	Heptacyclo[7.5.1.$0^{2,14}$.$0^{5,12}$.$0^{5,15}$.$0^{8,10}$.$0^{11,13}$]pentadecane; 0.176 s.
2	Decacyclo[12.5.1.$0^{2,7}$.$0^{2,13}$.$0^{4,11}$.$0^{5,10}$.$0^{7,18}$.$0^{8,13}$.$0^{8,16}$.$0^{15,19}$]icosane; 0.569 s.
3	Nonacyclo[11.7.1.$1^{6,18}$.$0^{1,16}$.$0^{2,11}$.$0^{3,8}$.$0^{4,19}$.$0^{8,17}$.$0^{10,15}$]docosane; 0.802 s.
4	Nonadecacyclo[25.22.1.$1^{5,23}$.$1^{9,19}$.$1^{31,46}$.$1^{35,42}$.$0^{2,26}$.$0^{4,24}$.$0^{6,22}$.$0^{8,20}$.$0^{10,18}$.$0^{12,16}$.$0^{13,39}$.$0^{15,38}$.$0^{28,49}$.$0^{30,47}$.$0^{32,45}$.$0^{34,43}$.$0^{36,41}$]tetrapentacontane; 27.3 min.
5	Nonadecacyclo[41.11.1.$1^{7,19}$.$1^{10,52}$.$1^{16,28}$.$1^{25,37}$.$1^{34,46}$.$0^{3,53}$.$0^{5,9}$.$0^{8,12}$.$0^{14,18}$.$0^{17,21}$.$0^{23,27}$.$0^{26,30}$.$0^{32,36}$.$0^{35,39}$.$0^{41,45}$.$0^{44,48}$.$0^{50,54}$]hexacontane; 63.0 min.
6	Undecacyclo[9.9.0.$0^{2,9}$.$0^{3,7}$.$0^{4,20}$.$0^{5,18}$.$0^{6,16}$.$0^{8,15}$.$0^{10,14}$.$0^{12,19}$.$0^{13,17}$]icosane; 0.237 s.
7	Tetracyclo[29.29.0.$0^{11,41}$.$0^{21,51}$]hexacontane; 0.345 s.
8	Heptadecacyclo[16.14.0.$0^{2,5}$.$0^{3,28}$.$0^{4,9}$.$0^{6,17}$.$0^{7,14}$.$0^{8,13}$.$0^{10,27}$.$0^{11,26}$.$0^{12,23}$.$0^{15,22}$.$0^{16,19}$.$0^{20,31}$.$0^{21,24}$.$0^{25,30}$.$0^{29,32}$]dotriacontane; 2.885 s.
9	Henicosacyclo[17.16.0.$0^{1,10}$.$0^{2,7}$.$0^{2,32}$.$0^{3,20}$.$0^{3,29}$.$0^{4,27}$.$0^{5,30}$.$0^{6,31}$.$0^{8,33}$.$0^{9,34}$.$0^{11,14}$.$0^{12,35}$.$0^{13,18}$.$0^{15,19}$.$0^{16,22}$.$0^{17,23}$.$0^{20,24}$.$0^{21,26}$.$0^{25,28}$]pentatriacontane; 18.50 s.
10	Tricosacyclo[20.18.0.$0^{1,25}$.$0^{2,6}$.$0^{2,21}$.$0^{3,13}$.$0^{4,11}$.$0^{5,9}$.$0^{7,20}$.$0^{8,18}$.$0^{10,17}$.$0^{12,16}$.$0^{14,21}$.$0^{15,19}$.$0^{22,32}$.$0^{23,30}$.$0^{24,28}$.$0^{26,39}$.$0^{27,37}$.$0^{29,36}$.$0^{31,35}$.$0^{33,40}$.$0^{34,38}$]tetracontane; 34.71 s.
11	Hentriacontacyclo[29.29.0.$0^{2,60}$.$0^{3,5}$.$0^{4,25}$.$0^{6,8}$.$0^{7,19}$.$0^{9,11}$.$0^{10,58}$.$0^{12,14}$.$0^{13,52}$.$0^{15,17}$.$0^{16,46}$.$0^{18,20}$.$0^{21,23}$.$0^{22,43}$.$0^{24,26}$.$0^{27,29}$.$0^{28,40}$.$0^{30,32}$.$0^{33,35}$.$0^{34,55}$.$0^{36,38}$.$0^{37,49}$.$0^{39,41}$.$0^{42,44}$.$0^{45,47}$.$0^{48,50}$.$0^{51,53}$.$0^{54,56}$.$0^{57,59}$]hexacontane; 9.91 min.
12	Hentriacontacyclo[29.29.0.$0^{2,14}$.$0^{3,12}$.$0^{4,59}$.$0^{5,10}$.$0^{6,58}$.$0^{7,55}$.$0^{8,53}$.$0^{9,21}$.$0^{11,20}$.$0^{13,18}$.$0^{15,30}$.$0^{16,28}$.$0^{17,25}$.$0^{19,24}$.$0^{22,52}$.$0^{23,50}$.$0^{26,49}$.$0^{27,47}$.$0^{29,45}$.$0^{32,44}$.$0^{33,60}$.$0^{34,57}$.$0^{35,43}$.$0^{36,56}$.$0^{37,41}$.$0^{38,54}$.$0^{39,51}$.$0^{40,48}$.$0^{42,46}$]hexacontane; 181.8 min.
13	Heptacyclo[18.12.10.$4^{22,31}$.$0^{5,32}$.$0^{16,21}$.$0^{25,45}$.$0^{28,44}$]hexatetracontane; 24.63 s.
14	Hexacyclo[5.4.0.$0^{2,10}$.$0^{3,9}$.$0^{4,6}$.$0^{8,11}$]undecane; 0.057 s.
15	Pentacyclo[3.3.0.$0^{2,4}$.$0^{3,7}$.$0^{6,8}$]octane; 0.080 s.

Table 2. *Compatibility Table for* n = *14* (*e.g.* diamantane). *a) Hamilton* cases, *b)* non-*Hamilton* cases.

a)	*b)*	Main bridge size			
		4	3	2	1
1 [6.6.0]	Main ring size				1[6.5.1]
2 [7.5.0]	13				2[7.4.1]
					3[8.3.1]
3 [8.4.0]					4[9.2.1]
					5[10.1.1]
4 [9.3.0]					
	12			6[5.5.2]	10[5.5.1]
5 [10.2.0]				7[6.4.2]	11[6.4.1]
				8[7.3.2]	12[7.3.1]
6 [11.1.0]				9[8.2.2]	13[8.2.1]
					14[9.1.1]
	11		15[5.4.3]	17[5.4.2]	20[5.4.1]
			16[6.3.3]	18[6.3.2]	21[6.3.1]
				19[7.2.2]	22[7.2.1]
					23[8.1.1]
	10	24[4.4.4]	25[4.4.3]	27[4.4.2]	30[4.4.1]
			26[5.3.3]	28[5.3.2]	31[5.3.1]
				29[6.2.2]	32[6.2.1]
					33[7.1.1]
	9		34[4.3.3]	35[4.3.2]	37[4.3.1]
				36[5.2.2]	38[5.2.1]
					39[6.1.1]
	8		40[3.3.3]	41[3.3.2]	43[3.3.1]
				42[4.2.2]	44[4.2.1]
					45[5.1.1]
	7			46[3.2.2]	47[3.2.1]
					48[4.1.1]
	6			49[2.2.2]	50[2.2.1]
					51[3.1.1]
	5				52[2.1.1]
	4				53[1.1.1]

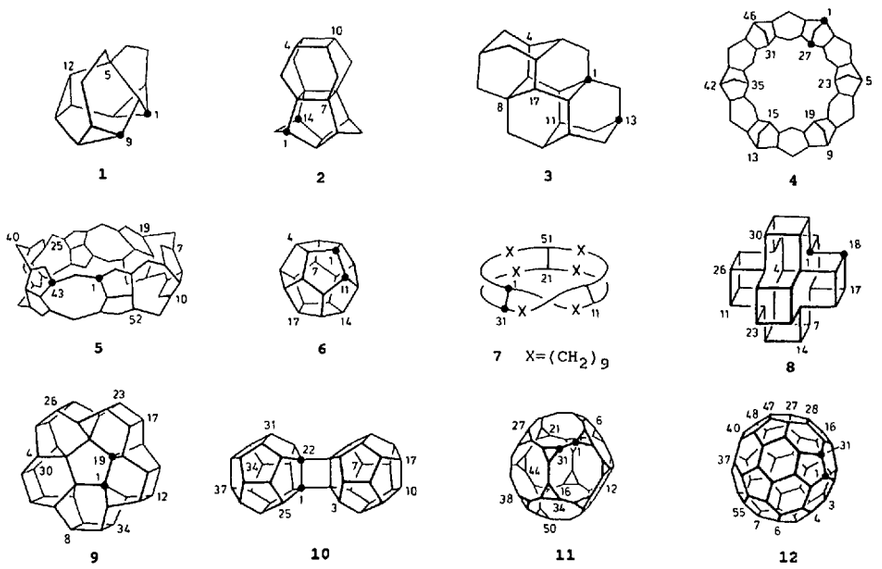


Fig. 1. *Some polycycles named and numbered by POLCYC* [9]. The bridgeheads are marked by dots.

and again from i over l atoms to j, so that no atom (except i and j) appears in the sequence more than once. The symmetry recognition ensures that any pathway which will turn out to be equivalent by symmetry to one already traced is cut off in its initial step. The path algorithm is guided by the compatibility table to look for a bicycle corresponding to the first entry first, and only after failing to find such a bicycle the second entry is tried, and so on. Therefore, as soon as a bicycle is found, it surely corresponds to the best [*l.s.m*] for the given (i, j). For later bridgehead pairs the compatibility table is worked through not further than to the sequential number successful for an earlier bridgehead pair.

Once the fundamental bicyclic system has been identified and systematically numbered, the secondary bridges are found by a modified path algorithm. Since secondary bridges often are not independent of one another (see *Fig. 2*), in order to fulfill the requirements of rules *A-32.23* and *A-32.31d*, we had to introduce a procedure to establish a hierarchy of secondary bridges based on the criteria length, complexity, and systematic numbering of the points of anchoring at the fundamental bicycle. Details of the secondary bridge finding procedure cannot be given here.

Surprisingly even the unambiguous selection of the fundamental bicycle required a few additions to the codified rules, and these will now be discussed in some detail.

In the case of more than one best bicycle being identified *IUPAC* rule *A-32.31d* ('smallest locants') has to be used, which is, however, insufficient as was noticed earlier [6a]. For instance, it is possible that different choices of a bicycle out of a set of equally good ones (same[*l.s.m*]) lead to different patterns of secondary bridge lengths. For this case, hitherto overlooked, we tentatively introduced the following rule, which we deem justified by analogy: 'The first secondary bridge shall be as large as possible. If no decision is arrived at by this rule, the second secondary bridge shall be as large as possible, and so on'. For illustration consider hydrocarbon **13** [10] (*Fig. 3*), where four possible choices of the fundamental bicycle ([18.12.10] in all cases) lead to patterns of lengths 4.0.0.0.0, 2.2.0.0.0 (two possibilities), or 2.1.1.0.0 for the secondary bridges. By the above rule the first possibility is chosen as the best.

In other cases where there is no difference in secondary bridge lengths but in secondary bridge location, we apply rule *A-32.31d* in the form suggested and used by *Chemical Abstracts Service* (which will be included in the next edition of the official rules [11]): that name is chosen which has the lowest locants *regardless of the order of citation*. For illustration see hydrocarbon **14** (homobasketane) in *Fig. 4*, where name **14b** is chosen.

Unfortunately, in many cases application even of this rule does not result in unambiguous discrimination. In *Fig. 5*, the pentacyclic hydrocarbon cuneane (**15**) is shown with two possible fundamental bicycles which cannot be differentiated by the rules mentioned hitherto: both represent a [3.3.0] system, and both comprise the same set of locants 2,3,4,6,7,8. In such cases we propose to adopt the following

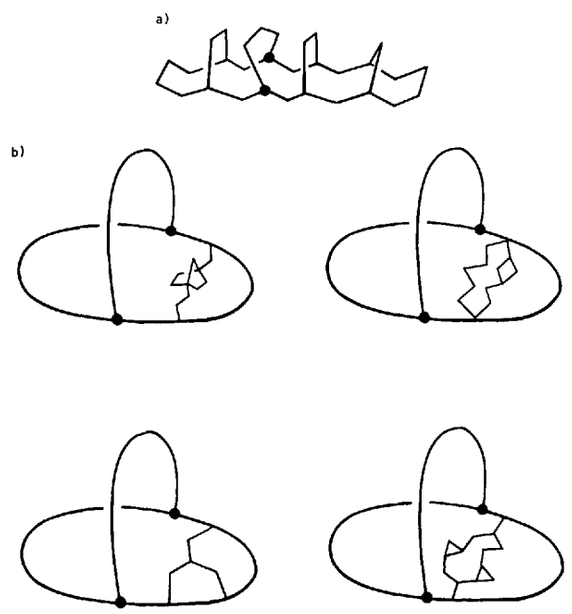


Fig. 2. *Some situations with several secondary bridges:* a) *independent of one another*, b) *mutually dependent*

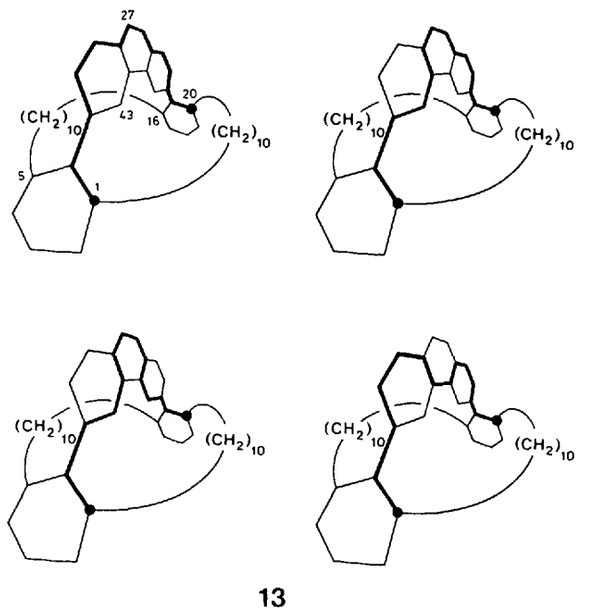
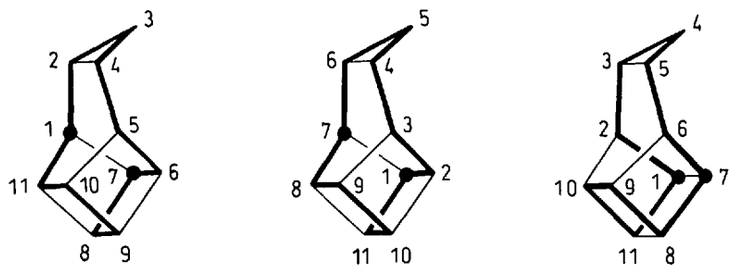


Fig. 3. *A hydrocarbon for which there is a choice between several fundamental bicycles* (all of the same [*l.s.m*]) *differing in the secondary bridges lengths pattern*



14a [5.4.0.$0^{2,4}$.$0^{5,10}$.$0^{6,9}$.$0^{8,11}$]: 2,4,5,6,8,9,10,11

14b [5.4.0.$0^{2,10}$.$0^{3,9}$.$0^{4,6}$.$0^{8,11}$]: 2,3,4,6,8,9,10,11

14c [5.4.0.$0^{2,10}$.$0^{3,5}$.$0^{6,9}$.$0^{8,11}$]: 2,3,5,6,8,9,10,11

Fig. 4. *In homobasketane* (**14**) *a choice between fundamental bicycles differing in the set of locants is made by the 'CAS procedure'* [11]

15a [3.3.0.$0^{2,4}$.$0^{3,7}$.$0^{6,8}$] 15b [3.3.0.$0^{2,8}$.$0^{3,7}$.$0^{4,6}$]

Fig. 5. *In cuneane* (**15**) *a choice between fundamental bicycles not differing in the set of locants is made by the 'first cited differing position procedure'*

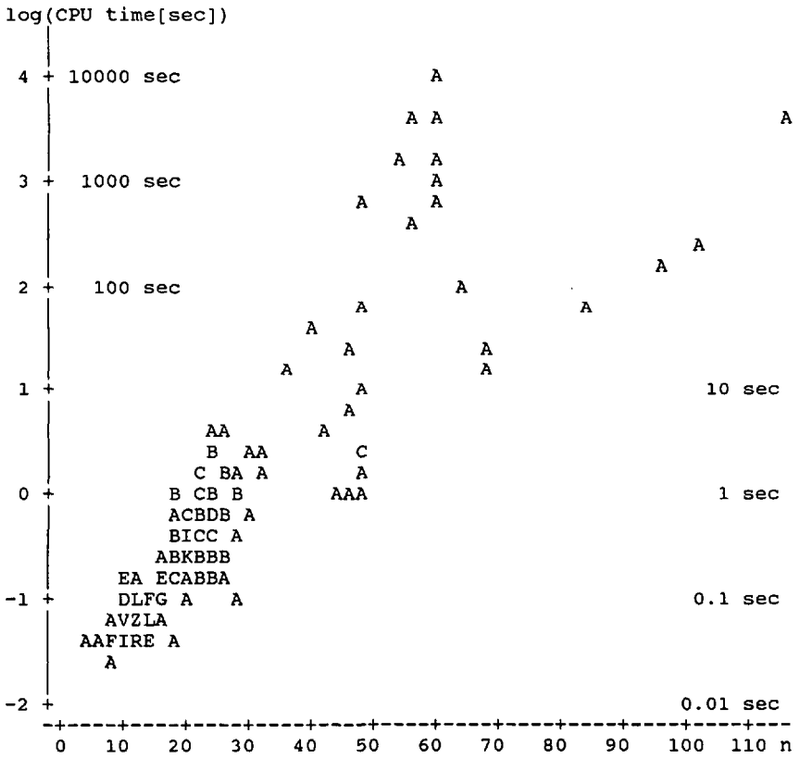


Fig. 6. *Plot of log(CPU time [sec])* vs. n *for compounds of complexity* c/n *between 0.1 and 0.6* ($c = 1 + t/2 + q$ where t = number of tertiary centers, q = number of quarternary centers). A = 1 observation, B = 2 observations, *etc.*

interpretation of rule *A-32.31d:* 'That name is chosen which has the smaller locant in the first cited differing position'. This rule, though nowhere explicitly codified, is tacitly used by many chemists; by its application cuneane becomes *pentacyclo[3.3.0.$0^{2,4}$.$0^{3,7}$.$0^{6,8}$]octane* rather than *pentacyclo[3.3.0.$0^{2,8}$.$0^{3,7}$.$0^{4,6}$]octane*. The set of rules mentioned here and included in POLCYC seems to be complete in the sense that for any polycycle a name and a systematic numbering scheme can be unambiguously constructed.

The program POLCYC has exactly the same scope as *IUPAC* rule *A-32*, in that it is meant to name and number saturated carbopolycyclic parent systems; therefore, substituents (including so-called separable ring systems [5b]) should be removed. Since the program depends on at least three independent pathways between at least two bridgehead atoms, in accordance with *IUPAC* rule *A-32*, it cannot be expected to name monocyclic or free spiro compounds. Other (non-free) spiro compounds pose no problem. *The logic of the program does not pose any restrictions as to the number* (n) *and connectivity of the C-atoms, to the number of cycles* (c), *to the number of atoms located on secondary bridges or to the topology of the polycycle.*

Restrictions of two kinds do, however, exist. First, the built-in dictionary [12] limits the number of C-atoms and of cycles to 2–999. Further expansion, if desired, should be possible by some minor adjustments.

A second type of restrictions is caused by the hardware used: The number n dealt with is limited primarily by the computer's storage capacity, while its speed of operation sets a practical limit to the combination of a molecule's size and complexity. The authors ran the program in the interactive or the batch mode on a *IBM 3090* machine using a 3 M virtual storage capacity, in this case the limit for n was found beyond 128. Since the required storage increases with the third power of n, use of a 16 M storage capacity expands the range up to beyond 235.

The CPU time used for POLCYC treatment of a particular compound depends exponentially on both its size and complexity. Other factors like symmetry and the initial numbering are also of some importance. *Fig. 6* shows the dependence of CPU time on the molecule's size, n, for the more than 280 compounds of moderate to high complexity ($0.6 \geq c/n \geq 0.1$) named by POLCYC hitherto (c = number of cycles in the sense of rule *A-32.12*). Less complex compounds require considerably less time, compare *e.g.* the tetracyclic hexacontane **7** to the polycyclic hexacontanes **5**, **11**, **12** in *Table 1*. This dependence of time on complexity clearly reflects the rapidly growing number of possible pathways to be searched as c increases. It is seen from *Fig. 6* that the names and systematic numbering schemes of all compounds of the size normally occurring to a chemist (up to

ca. 40 C-atoms) are generated within a few seconds at most.

A copy of the program POLCYC is available upon request from the authors [13].

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[13] After completion of this work the authors were informed by Dipl.-Chem. P. Röse (Technische Universität München) that he had written a program for the same purpose in 1987, which is not yet published. In a few preliminary tests (*e.g.* **12**) both programs generated identical names.

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Drucklose Direktfluorierung: Eine einfache Methode zur präparativen Synthese von neuen Fluorierungsreagenzien

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Abstract. Large-scale synthesis of the new saccharin-derived *N*-fluorosultam **1** is described, starting from readily available saccharin **2**. A newly designed fluorination apparatus, which allows the preparation of 100-g quantities of **1** at atmospheric pressure, is discussed in detail.

1. Einleitung

Unter neuen Pharma- und Agro-Wirkstoffen findet man vermehrt solche, die an strategisch wichtigen Positionen ein oder mehrere F-Atome enthalten [1]. Somit gewinnen Reaktionen, mit welchen Fluor in ein multifunktionelles Molekül selektiv und in guten Ausbeuten eingeführt werden kann, immer mehr an Bedeutung [2]. Durch Direktfluorierung mit elementarem F_2 gelingt es bis heute nur in seltenen Fällen, Fluor selektiv in ein Substrat einzuführen [3]. Alternative Fluorierungsmittel werden gesucht, wobei anfänglich nur gefährlich zu handhabende Reagenzien wie Perchloryl-fluorid, OF_2, CF_3COOF, *etc.* als 'F^+'-Quellen bekannt waren. Heute sind neue stabile 'F^+'-Reagenzien wie XeF_2 [4], *N*-Fluoro-2(1*H*)-pyridinon [5], *N*-Fluoroquinuclidinium-fluorid [6], *N*-Fluorosulfonamide [7], *N*-Fluorosultame [8] oder *N*-Fluoropyridinium-triflate [9] bekannt und teilweise sogar schon käuflich erhältlich [4] [7]. Alle diese erwähnten Fluorierungsreagenzien vermögen prinzipiell Fluor auf Metallenolate [9] und metallierte aromatische oder aliphatische Substrate zu übertragen [9–11]. Bis heute gibt es allerdings noch kein universell einsetzbares 'F^+'-Reagenz, das die ganze Breite der Palette möglicher Substrate zu fluorieren vermöchte.

Wir berichten hier über die Synthese eines sehr effizienten und stabilen 'F^+'-Reagenzes **1** [8b], das sich besonders bei Umsetzungen mit Enolaten als Reagenz der Wahl bewährt hat [12] [13].

2. Synthese von *N*-Fluorosultam 1

Saccharin (**2**) kann, wie im *Schema 1* gezeigt, einfach im kg-Maßstab, *via* die 3-Chloro-Verbindung **3** in das schon lange bekannte 2,3-Dihydro-3,3-dimethylbenzothiazol-1,1-dioxid (**4**) nach einem modifizierten Literaturverfahren [14] überführt werden. In einer in *Fig. 1* und *2* skizzierten, allgemein für drucklose Fluorierungen im Labormaßstab verwendeten [8a] Anlage

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