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OPTICALLY ACTIVE COMPOUNDS: AN EXCEPTION TO THE USUAL DEFINITION OF ASYMMETRIC CARBON ATOM

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The discovery of the stereospecific polymerization processes gave rise to new problems in the field of organic stereochemistry.

As is known, the presence of a tridimensional order and, primarily, the fact that the polymeric chain assumes an ordered conformation make crystallinity possible in many polymers. In the vinyl polymers, and, in general, in all polymers in which stereoisomerism phenomena are possible around the tetrahedral carbon atoms, the conformational regularity of the chain depends on the presence of regular steric arrangements of the substituents in the different monomeric units, and therefore on the configurational relationships between the tertiary carbon atoms in the chain.

In many cases, the examination of the crystalline structure has permitted the determination of such relationships, and several groups of stereoregular polymers have been recognized so far, for instance, isotactic, syndiotactic, polytactic polymers, etc..

As a logical development of these discoveries, we tried to obtain optically active polymers, in which the optical activity was due to the presence of only one (or largely one) type of configuration in the asymmetric atoms in chain.

However, the simple isotactic polymers of vinyl monomers cannot be adapted to this purpose, because the carbon atoms of the single monomeric units, though actually asymmetric on polymerization, are essentially symmetric when considered in the whole polymer. An ideal isotactic polymer of infinite molecular weight does not show any asymmetry of the configurational type. In actual high molecular weight polymers, in which the terminal groups can be neglected, the two antipodes cannot be distinguished from each other, and therefore no optical activity can occur (1,2,3). This fact is confirmed by the results published by Murahashi, Nozakura and Takeuchi (4) and by Fray and Robinson (5) who obtained optically inactive products by polymerizing either styrene or propylene in the presence of asymmetric organometallic compounds.

Only particular types of monomers, though lacking centres of optical stereoisomerism, can yield polymers in which it is possible to distinguish two enantiomorphous chains, even when these are of infinite length. Among these monomers, mention must be made of 1 or 1,4 substituted butadienes and of homocyclic and heterocyclic olefins.

Several monomers of these types, such as the esters of the sorbic, β-styryl acrylic and β-vinyl acrylic acids, (6), benzofuran (7), 1-methyl-butadiene (8), were pplymerized in our Institute with the aid of optically active initiators of of symmetric catalysts used with optically active complexing agents. The polymers thus obtained showed an indubious and considerable optical activity.

Examination of the symmetry properties of some of the polymeric chains obtained show the existence of peculiarities that do not fit completely into the concepts and stereochemical definitions commonly used.

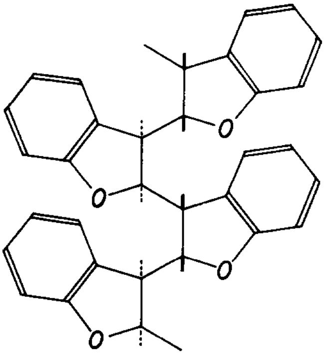
Polybenzofuran obtained by asymmetric synthesis using, as catalyst, $AlCl_3$ complexed with (+) or (-) β-phenyl alanine shows an optical activity of the same sign as that of the cocatalyst, with values even higher than 70°, determined in sodium light and benzene or dioxane solution (9).

As already discussed in previous papers (7,9) the polymer consists of a succession of cyclic monomeric units.

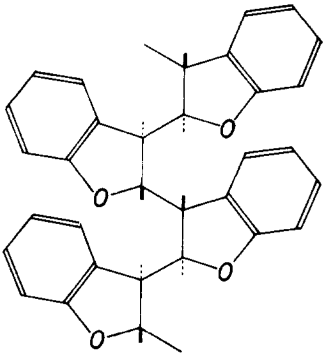
Schematic drawings of the erythro- and threo-di-isotactic structures are shown in I and II[*]: they are the simplest structures able to exist in enantiomorphous forms, and are among those most probably constituting at least the greater part of the polymer.

Polybenzofuran is not crystalline and therefore the type of structure could not be established. Other cyclic monomers (10) with internal double bonds yielded crystalline polymers of the erythro-di-isotactic type; this structure is more probable when the double bond is of the cis type, as indicated also by the polymerization of cis-β-chlorovinyl alkyl ethers (11).

Structures I and II show a configurational-type asymmetry, independently of the conformation assumed by the molecule.



I



II

A problem can arise concerning the type of asymmetry present: whether this is due to atropisomerism or to the presence of asymmetric carbon atoms. If simple models of monomeric units, such as 2,3-disubstituted cumarans (e.g. 2,3-dimethyl cumaran) are considered; the presence of real asymmetric carbon atoms, each with four different substituents, can be observed.

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[*] The formulas show only one of the enantiomers.

This notwithstanding, each atom of the polymeric chain is bound to two substituents which are identical "in themselves". For instance, the carbon atom, in the α position with respect to the oxygen, is bound to the oxygen atom, to a hydrogen atom and to two equivalent carbon atoms Cβ. (It is, or seems to be, an atom of the Ca, a, b, d type). Analogous remarks are valid for the carbon atom in the β position.

Therefore, as far as both these atoms are concerned, the classical definition of an asymmetric carbon atom (i.e. atom with four different substituents of the Ca, b, d, e type) cannot be considered to apply, nor can that of a pseudo-asymmetric atom (e.g.:Ca$^+$, a$^-$, b, d), because, in the studied structures, the equivalent atoms show the same configuration in the subsequent monomeric units.

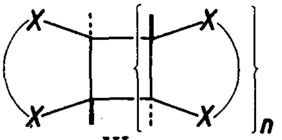
However, they are not equal to the atoms Ca, a, b, d of the type usually considered; in fact, unlike them, they show intrinsic asymmetry.

In the structures under examination the two atoms Cβ, which are identical if examined in themselves, are different if considered in their relationships with the Cα atom. In fact, one belongs to the same cycle as Cα (endo), whereas the other belongs to an external cycle (hexo). In this case, the symmetry properties do not depend on the type of substituent, but on how the substituent is bound to the atom considered.

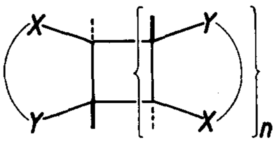
Therefore, the definition of asymmetric carbon atom should be modified, if the case examined is to be included (both Cα and Cβ have the properties of the asymmetric atoms). It must also take into account the type of bond existing between substituents and the atom considered (hexo or endo), when this represents the only difference between the two substituents.

The remarks now discussed do not only concern the case of polymeric systems, but also some types of cylic compounds, which are closely related to the previous ones, at least from the symmetry standpoint (a cyclo corresponds, from many points of view to a chain of infinite length).

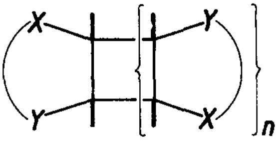
Compounds of the type indicated in III, IV and V (cyclobutanes, cyclohexanes, etc. condensed with other rings which do or do not contain hetero atoms) can be resolved into antipodes, even if they have, as stereoisomeric centres, only carbon atoms of the previously discussed type.



III



IV



V

The trans-anti-trans...structure shown in III has several symmetry elements, but it does not contain alternating axes: therefore it exists in two enantiomeric forms. Form III corresponds to the threo-di-isotactic structure of the polymeric chain.

The same remarks can be made for the compounds represented as IV and V. The latter, of the cis-sin-cis...type, corresponds to the erythro-di-isotactic form of the polymer.

Taking into account the tendency nowadays to consider asymmetry as a property of the whole molecule, the discussion given here is still of considerable interest. Among other things, this is necessary for determination of the absolute configuration of the asymmetric atoms in compounds of the type reported above. In relation to this, it can be observed that the rules, proposed by Cahn, Ingold and

Prelog (12) for a univocal definition of the configurational sign of the asymmetric carbon atoms, are insufficient to determine the priority of the two seemingly identical substituents in the sense mentioned above (eg $C\beta_n$ and $C\beta_{n-1}$).

As recently proposed in another paper (9), a new rule should be introduced and be formulated as follows: if in a polycyclic compound, two substituents belonging to different cycles are identical according to all previous rules, the substituent belonging to the same cycle as the atom considered, precedes the external substituent of the said cycle (endo precedes hexo).

Hoping to extend and to give a wider experimental basis to the above remarks, we have turnes our attention to the group of polycyclic compounds. Attempts at the synthesis and resolution into antipodes of some compounds corresponding to the formulas III, IV and V are now in progress in our laboratory.

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