FROM DIYLS TO YLIDES TO MY IDYLL

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by
GEORG WITTIG
Heidelberg, Federal Republic of Germany

Translation from the German text

Chemical research and mountaineering have much in common. If the goal or the summit is to be reached, both initiative and determination as well as perseverance are required. But after the hard work it is a great joy to be at the goal or the peak with its splendid panorama. However, especially in chemical research - as far as new territory is concerned - the results may sometimes be quite different: they may be disappointing or delightful. Looking back at my work in scientific research, I will confine this talk to the positive results (1).

Some 50 years ago I was fascinated by an idea which I investigated experimentally. The question was how ring strain acts on a ring if an accumulation of phenyl groups at two neighboring carbon atoms weakens the C-C linkage and predisposes to the formation of a diradical (for brevity called diyl) (Fig. 1). Among the many experimental results (2) I choose the synthesis of the hydrocarbons 1 and 4 (3), which we thought capable of diyl formation. Starting materials were appropriate dicarboxylic esters, which we transformed into the corresponding glycols. While these were obtained under the influence of phenylmagnesium halide only in modest yield, phenyllithium proved to be superior and was readily accessible by the method of K. Ziegler, using bromobenzene and lithium. The glycolates resulting from the reaction with potassium phenylisopropylide formed - on heating with methyl iodide - the corresponding dimethyl ethers, which supplied the equivalent hydrocarbons 1 and 4 by alkali metal splitting and demetalation with tetramethylethylene dibromide.

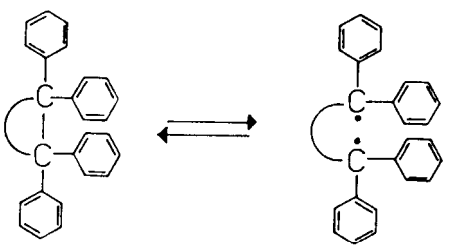


Fig. 1. Formation of a diradical (2).

The resulting tetraphenylbenzocyclobutane (1), however, rearranged to triphenyldihydroanthracene (3) (Fig. 2). In contrast,

tetraphenyldihydrophenanthrene (4), which was prepared analogously, proved to be a stable hydrocarbon, even when substituents R were introduced that forced the biphenyl system to twist. While 4 did not decompose at 340°C and was stable in solution against oxygen, its aryl-weakened C-C bond could be observed since it split with potassium into the ring-opened dipotassium derivate. The results of these investigations on formation of radicals and ring strain seem to indicate that ring closure is more likely to contribute to stabilization of the ethane bond.

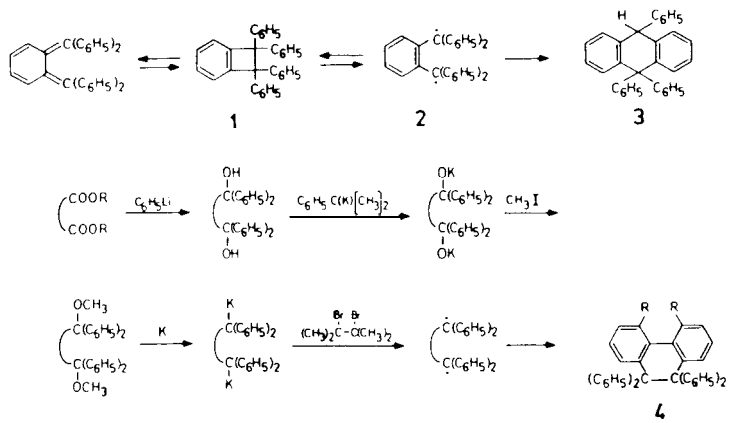


Fig. 2. Some reactions observed in the synthesis of 1 and 4 (3).

This stabilizing influence is documented impressively by the behavior of tris(biphenylene)ethane (7), which was also synthesized (4) (Fig. 3). The carbinol6, which was formed by the reaction of the ketone 5 with *o*-lithiobiphenyl, transformed into the desired hydrocarbon 7 by an acid-catalyzed twofold Wagner-Meerwein rearrangement.

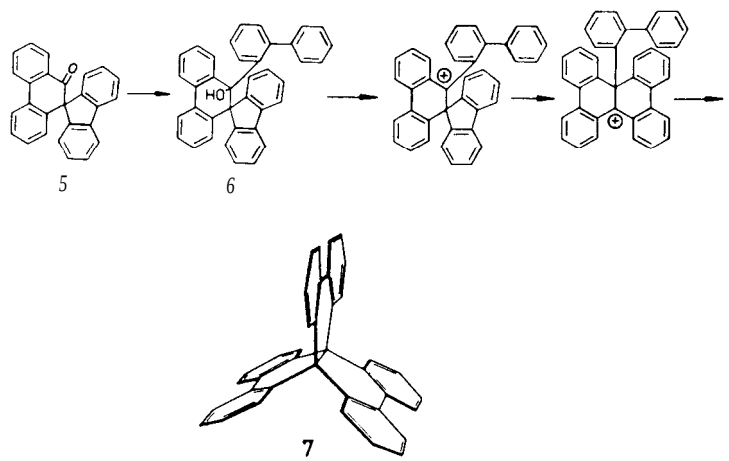


Fig. 3. Formation of tris(biphenylene)ethane (4).

This first aromatic propellane, which melted at 475°C without decomposition and whose structure agreed with the nuclear magnetic resonance spectrum, proved to be insensitive to ethane linkage-breaking sodium-potassium alloy. Evidently the close aryl packing prevents penetration of the metal into the interior of the molecule.

Since the tendency to form diradicals was not evident with the hydrocarbons mentioned, we intended to replace the phenyl groups by anisyls. Therefore, suitable dicarboxylic esters should be brought into reaction with *p*-lithioanisole (5). But, as we obtained unexpected smears, the functionally simple benzophenone was used to treat the mixture that resulted from the reaction of *p*-bromoanisolewith lithium. Instead of the expected *p*-anisyldiphenylcarbinol, the bromine-containing compound 9 was isolated, whose structure could be proved by conversion into the well-characterized derivative by zinc dust distillation. Accordingly, *p*-lithioanisole, which was originally formed, metalates the *p*-bromoanisole that is still present into compound 8 which then reacts with benzophenone to form the isolated compound 9 (Fig. 4).

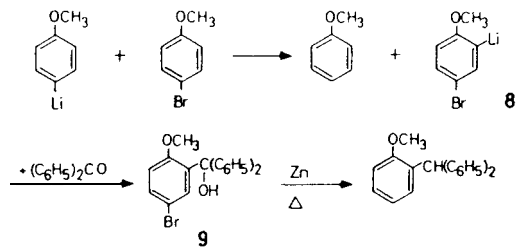


Fig. 4. Formation and characterization of compound 9 (5).

When it was noted that phenyllithium too can modify pbromoanisole to form 9, we decided to look closer at the lability of the aromatic proton as a function of the substituent. In the course of these studies we arrived at the surprising result that aryl iodide, bromide, and even chloride can exchange with the electropositive metal of phenyllithium (6). Later we called this principle ofreaction *umpolung*, or reversal of polarity (7) (Fig. 5). Simultaneously and independently, H. Gilman found the same behavior when treating aryl halides with butyllithium.

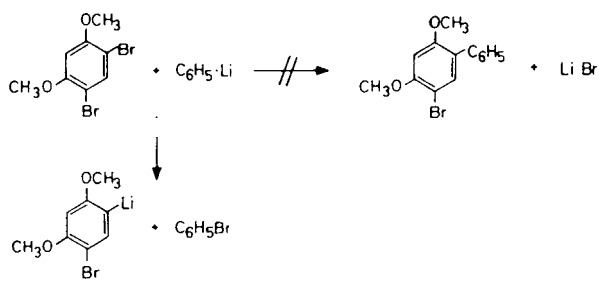


Fig. 5. Reversal of polarity (umpolung) (6).

Among the halogens of the various aromatic systems, fluorine proved to be not exchangeable with lithium (8). Here we found an unexpected reaction path. First we observed that in the formation of biphenyl by the reaction of monohalobenzene with phenyllithium, fluorobenzene acted rapidly, forming approximately 75 percent biphenyl, while the other halobenzenes produced only 5 to 7 percent. We interpreted this result as indicating that biphenyl formation was preceded by metalation of the halobenzene, which was stimulated by the inductive effect of the strongly electronegative fluorine. This explanation was supported by the finding that not biphenyl but *o*-lithiobiphenyl had been produced. In 1942 we further assumed that an elimination of metal and halogen results that leads to the occurrence of dehydrobenzene (9), and this is what changes phenyllithium into the *o*-lithiobiphenyl found experimentally (Fig. 6). Independent of our work, a proof for the intermediate occurrence of dehydrobenzene was given by Roberts *et al.* (10), who reacted [1-^{14}C] chlorobenzene with potassium amide in liquid ammonia and isolated the two expected anilines with approximately 50 percent yield (Fig. 7).

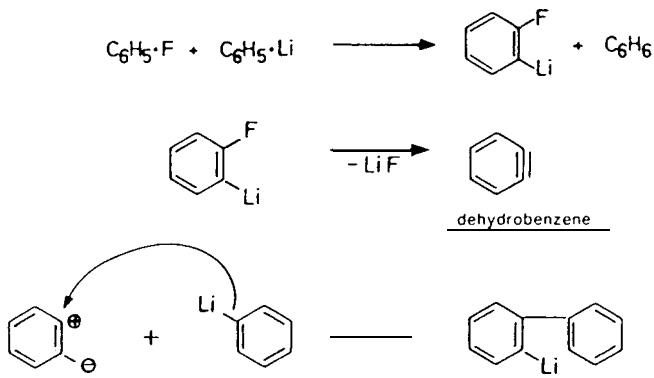


Fig. 6. Mechanism of formation of *o*-lithiobiphenyl (8, 9)

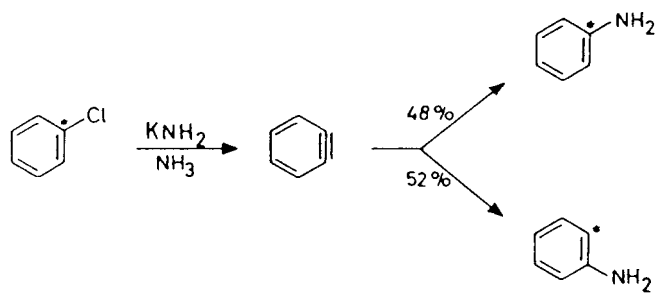
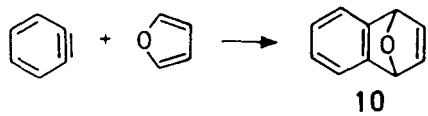


Fig. 7. Proof of the intermediate occurrence of dehydrobenzene in the reaction of ^{14}C-labeled chlorobenzene with potassium amide in liquid ammonia ***(10, 24).***

Later we could prove the existence of the dehydrobenzene by expecting that it would react as dienophile (11). For the diene and solvent we chose furan, which, being an ether, should favor organometallic exchange while simultaneously serving as a trapping agent. In an exciting experiment we had *o*-fluorobromobenzene react with lithium amalgam in furan and isolated with good yield the endo-oxide 10, which had been formed by a Diels-Alder addition (Fig. 8).



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Fig. 8. Proof of the existence of dehydrobenzene through the formation of 10 (11),

We found the lifetime of dehydrobenzene in the gas phase *(12)* by the thermal decomposition of bis (*o*-iodophenyl) mercury as well as phthaloyl peroxide to biphenylene at 600°C in an argon atmosphere at reduced pressure. When furan was injected behind the decomposition zone naphthol was evolved as a by-product from the dihydronaphthalene endoxide that occurred first. Under the conditions used, the lifetime of dehydrobenzene was determined to be 20 milliseconds. See Fig. 9.

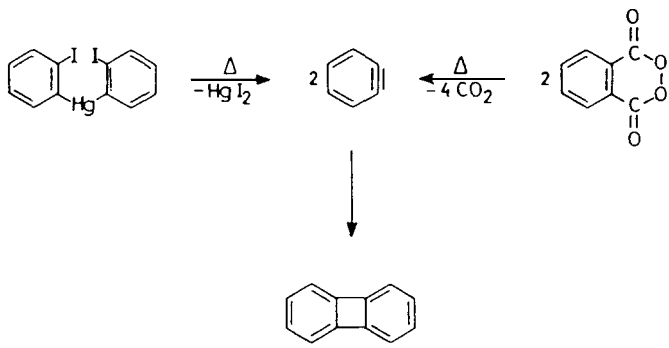


Fig. 9. Thermal decomposition reactions used to determine the lifetime of dehydrobenzene in the gas phase (12).

Phenyllithium, which had opened so many areas by acting as a sort of dowsing rod, was applied many times in the course of our research. Now our attention was drawn to the proton-labile substrates, to the aliphatic as well as the aromatic ones.

The process of proton-metal cation exchange appeared to us to be of fundamental importance, since the electron density at the carbon atom is enhanced after metalation. Thus the question arose of how carbanions, with their negative charge, would behave compared to carbonium ions, with their positively charged carbon atoms.

At the time we were not sure whether hydrogen bound to carbon would be proton-labile in quaternary ammonium salts. We came to this conclusion with an absurd experiment to prepare pentamethylnitrogen from tetramethylammonium salts by using the reaction of tetramethylammonium halide with methyllithium (13).

It was confirmed experimentally that the octet principle is strictly valid for the elements of the first eight-element period. The object of synthesizing compounds with a pentacoordinate central atom was reached only when we studied the higher elements of the fifth main group - that is, phosphorus, arsenic, antimony, and bismuth. It was easy to synthesize their pentaphenyl derivatives (14) and, in the case of antimony, also pentamethylantimony, which (as a nonpolar compound) is a liquid with a boiling point of 126°C (15).

Tetramethylammonium chloride reacting with methyl- or phenyllithium loses one proton and forms a product that we called trimethylammonium methylide (II) (Fig. 10). We gave the name *N*-ylides to this new class of substances since the bonding of the carbon to the neighboring nitrogen is homopolar (yl) and ionic (ide) at the same time. Trimethylammonium fluorenylide (12) could be isolated salt-free, thus its ylide structure is unambiguous (16). Subsequently, ylides as well as cryptoylides were studied more thoroughly (17).

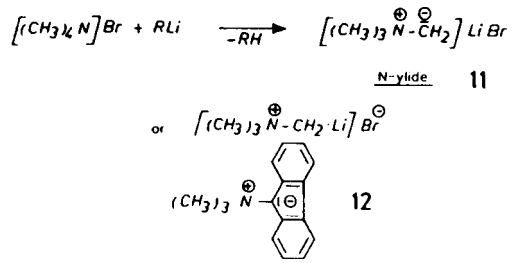


Fig. 10. Formation of Nylides (13).

When we extended this concept to the phosphonium salts, we found that they could be converted into the corresponding *P*-ylides even more readily than the analogous ammonium salts when treated with organolithium compounds (Fig. 11). The reason for the greater proton mobility is that phosphorus, unlike nitrogen, can expand its outer electron shell to a decet. This allows an energy-lowering resonance stability between the ylide and ylene forms.

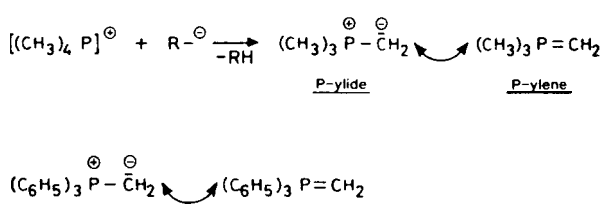


Fig. 11. Formation of *P*-ylides (17).

In the case of the *N*-ylide the semipolar nature of the N-C bond is demonstrated by its ability to add to benzophenone, forming the well-defined betaine (18) (Fig. 12). Now, if the same reaction was performed with triphenylphosphinemethylene, the expected betaine adductwas not obtained but, astonishingly, triphenylphosphine oxide and l,l-diphenylethylene (19). Evidently the initially produced betaine 13 - due to the ability of the central atom to expand its electron shell -formed the four-membered ring 14, which then decayed into two fragments as final products (20) and could not be isolated by itself (Fig. 13).

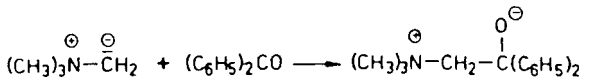




Fig. 12. Reactions with benzophenone (*18–20*).

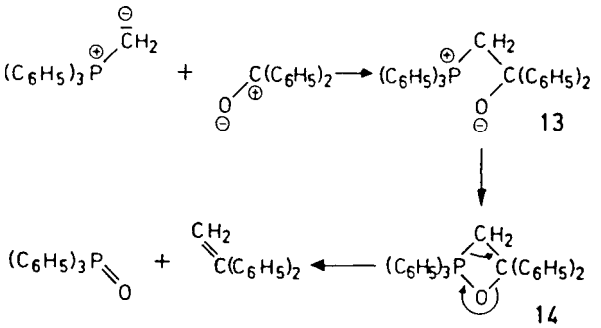


Fig. 13. Steps in the reaction of triphenylphosphinemethylene with benzophenone (25)

That the first step of the reaction is betaine formation was shown with the reaction of triphenylphosphinemethylene and benzaldehyde. In this case the betaine could be isolated as an intermediate product, and it decayed to triphenylphosphine oxide and styrene only on heating (20). This type of reaction (21) seemed to be of fundamental importance for preparative chemistry, and it also found industrial application (22). By these means it was possible to prepare vitamin A and β-carotene, among others. In the present context I restrict the discussion to the synthesis ofvitamin A, which is produced industrially at BASF under the direction of Pommer (22). The phosphonium salt 16, obtainable from vinyl-β-ionol 15, triphenylphosphine, and acid, changes with HX splitting into the corresponding phosphinemethylene derivative, which reacts with γ-formyl-crotylacetate 17 to produce vitamin A in the form of its acetate 18 (Fig. 14).

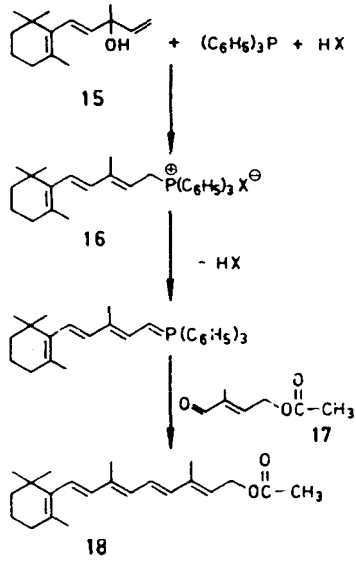


Fig. 14. Formation of vitamin A acetate (22).

With the addition of phenylsodium to triphenylboron, it could be demonstrated that boron can also act as tetracoordinate central atom (Fig. 15). Today this complex serves as an analytic reagent for the determination of potassium, rubidium, and cesium ions as well as for the quantitative determination and separation of ammonium and alkaloid salts.

$$(C_6H_5)_3B + C_6H_5Na \rightleftharpoons [(C_6H_5)_4B]Na$$

Fig. 15. Addition of phenylsodium to triphenylboron (*26*)

We called the complex salts with negatively charged central atom “ate” complexes for understandable reasons (23). They can be compared with the “onium” complexes, which were already known, as shown in Fig. 16. Because

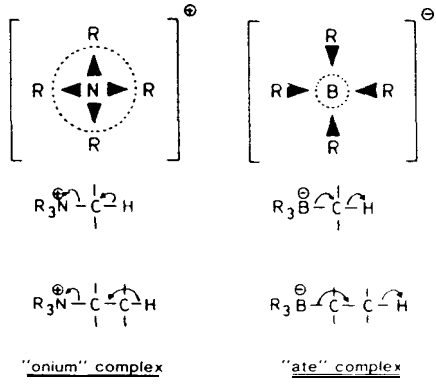


Fig. 16. Comparison of “onium” and “ate” complexes (23).

of the inductive effect of the central atom in onium complexes, all ligands R are cationically labilized and the hydrogen atoms at the neighboring carbon atoms are proton-mobile; however, in ate complexes all ligands at the central atom are anionically labilized and the hydrogen atoms at the neighboring carbon atoms are hydride-labile. This rule explains numerous reactions. I do not have time here to discuss its importance as a heuristic principle.

Thus I come to the end of my lecture. The excursion from diyls to ylides now ends at my idyll. With this I mean the conclusion of my research work as an emeritus, which allowed me to continue my work as a chemist free from the obligations of a teacher, and finally to devote myself completely to my interest in fine arts. I want to close my talk by offering cordial thanks to my collaborators. Without them my work could not have been accomplished.

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