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REVIEW

FLUORINE CHEMISTRY - FORTY YEARS ON

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The last forty years starting with the Manhatten project has seen a remarkable growth in fluorine chemistry both academically and industrially. Looking forward over the same time span one cannot see limitations to this growth imposed by any scarcity of raw materials, provided that the products of the industry are not wasted in frivolous applications, and fluorine chemists remain as innovative. In the developed world the chemical industry as a whole has become ex-growth, if not in partial decline, and with the location of new plants close to the source of supply as in the Middle-East area it is evident that the European industry, at least, will not be competitive in much of the bulk chemical production. Instead, for survival, effort will have to be concentrated on speciality chemicals with a high added value requiring a major input from basic research to suggest possible chemicals and processes, and constant upgrading of products by application chemists in conjunction with end-users.

It seems to the writer that fluoro-chemicals are, and can continue to be, the speciality chemicals par excellence. Their uniqueness is based on the interactions of a few simply stated properties:

1 The strength of bonds formed with fluorine leading to chemical and physical stability.

2 The chemical qualities of these bonds, such as polarity, induced by the electronigative character of fluorine.

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3 The strong repulsive fields around fluorine leading to low interfacial tensions and surface energies.

4 The ability of fluorine to mimic and replace hydrogen or hydroxyl because of geometric or electronic similarities.

5 The low refractivity of fluorine originally exploited in lens design and now in opto-electronic technology.

6 The stabilization of high oxidation and spin states, a relatively unexploited area.

During the development of uranium isotope separations the main emphasis was on perfluorination of material to achieve maximum resistance to corrosive fluorides and this type of approach persisted. The reagents used were more powerful than specific and incompletely fluorinated materials were only isolated with difficulty as by-products. This work however revealed the 'Alice-in-Wonderland' situation with the rules of organic (C-H) chemistry inverted, for example, electrophilic substitution being replaced by nucleophilic substitution.

The next more systematic approach was to introduce fluorinated groups such as perfluoro-alkyl and aryl which again required special techniques because of fluorine's electronegativity. In the future one can foresee that the main effort will be on the introduction of the minimal fluorine to produce the maximum effect which is economically correct as well as aesthetically pleasing to the chemist. The effect of introducing a single fluorine into some structures is quite remarkable as was illustrated in the descriptively named lethal synthesis when replacement of acetyl by a mono-fluoro acetyl group allows entry into the Kreb's cycle and then blockage of the cycle by inhibition of a specific enzyme. The effectiveness of a number of drugs incorporating single fluorines or CF_3 groups also illustrates the specific nature of fluorine-substrate interactions.

The introduction of single fluorines at correct sites and with correct stereochemistry requires specific reagents or reagent systems. The latter should be emphasized since the reagent cannot usually be divorced from the medium in which it is used. Hence a major effort will be required to extend our understanding of reaction mechanisms. In fact the mechanisms of many of the most popular reagents are far from clear. Thus the classic Swarts' type of reagent probably belongs to the Friedel-Craft family but the complexity of the Sb-Cl-F system both in the solid state and presumably in solution will make any elucidation of mechanism difficult. Simon's electrochemical fluorination also remains somewhat of a mystery in spite of the numerous mechanisms proposed. Possibly a combination of the newer physico-chemical surface techniques and a quasi-chemical approach by systematically altering the electrode composition in bulk and on the surface may solve the problem. It may well be that a range of mechanisms is available dependent on substrate. Certainly the geometric factors at the atomic level have to be considered. Thus it is not generally appreciated why antimony pentafluoride is such a powerful Lewis acid. It has an octahedral chain structure and to maintain stoichiometry must have a fluoride ion vacancy at the end of the chain. It also follows that it is zwitter-ionic in nature and this could contribute to the high viscosity $(F_4\overset{+}{Sb}\ [F/_2SbF_4F/_2]_n\overset{-}{Sb}F_6)$.

We need to generate a battery of similar reagents preferably assembled in situ from readily available components so that one can match the requirements of the reaction with the 'strength' of reagent. Iso-electronic series - the term being used in its broadest sense - may provide protypes for such families. The reagent core based on a single atom or group of atoms can be periodically varied by descending a group or traversing a period. The peripheral part of the reagent or ligand can be varied in basicity in a similar manner (cf. the moderating effect of

NMe_2 groups or reactivity of SF_4). The ligand geometry can also be varied to restrict approach to a substrate and modify reactivity. The relation of reactivity to reagent structure must be systematically investigated if really specific reagents are to evolve.

Another approach to minimal fluorination is spatial restriction. If surface properties are sought then the bulk of the material can remain unfluorinated and carry a fluorinated surface film. Diffusion controlled fluorination of plastics with fluorine at low temperatures has been studied. Perhaps we can transfer ideas of slow-release reagents already used in pharmaceutics and even in soil treatment to localize and control fluorination.

It is interesting to speculate on a few possible fields of enquiry. Surfactants have hydrophilic and hydrophobic groups at opposite ends of linear arrays. Many possibilities arise if these are cyclised in two or three dimensions. At one extreme the hydrophobic groups could be arranged externally thus allowing aqueous chemistry within the cavity. Conversely with the hydrophobic groups internal, organic reactions could be envisaged in an aqueous environment. Between the two extremes effective phase transfer reagents are possible. In fact one can visualize enlarged reagents containing areas or volumes within the reagent geometrically and electronically matched to the requirements of a reaction. One looks forward to a fluorinated cyclic chemistry analogous to the existing enclosure or clathrate type of chemistry typified by crown, cryptate, cyclodextrin,zeolite and layer structures.

Liquid crystals, like lasers, originally phenomena without apparent use, have become ideal display materials when electronically orientated and packed. A systematic study on the effect of fluorinating these molecules and increasing intermolecular repulsions could give results of academic as well as industrial significance.

Solid state applications of fluorinated compounds have not been extensively explored probably because the high ionicity is less conducive to defect structures than with oxide systems. Also these materials have limited hydrolytic resistance even the ionic compounds being subject to pyrohydrolysis by ambient moisture and high temperature. However in encapsulated systems operating at medium temperatures it seems that fluoride coatings could be useful, for example as insulants. One beneficial application has been the lanthanum trifluoride crystal electrode in which the inherent fluoride ion mobility is enhanced by Eu^{2+} doping. This has placed fluoride analysis almost on par with that of the other halogens. It may be possible to lower detection limits by using mixed oxy-fluoro solid state systems of lower solubility. Oxy-fluoro systems are involved in some of the alumina or chromia catalysed fluorinations. Hydroxyl surface sites on many materials can be replaced by the iso-electronic fluorine with modification of properties which could find applications in chromatographic separations.

More use could be made of the less reactive but readily available fluorides. For example much silicon tetrafluoride is wasted in fertilizer production, and chloro-fluorocarbons for aerosol sprays. These can be reacted at high temperatures or in plasmas as evidenced by the chemistry of difluorosilane, and ion-etching using fluorocarbons for the production of intergrated circuits. However one feels there must be ways of inducing chemical reactivity by more conventional methods possibly by operating in suitable solvent systems.

Certainly there is no lack of scope for new fluorine chemistry and one can only hope that industry and academia can forge mutually beneficial contacts for its implementation and utilization.