CHEMISTRY OF FLUORINE

ON November 30 a symposium on fluorine chemistry was held by the Chemical Society at the Royal Institution, London. The choice of this subject is indicative of a rapid growth of interest in both inorganic and organic fluorine compounds. Twenty years ago, elementary fluorine was available in few laboratories and little work on its compounds was in progress. During the war years, however, progress was rapid, particularly in various laboratories in the United States, and the fields opened up then are being more fully explored now. The topics dealt with at the symposium, representing some of the research in progress in Great Britain, were diverse, and for this reason each is separately reviewed below.

Anode phenomena in the production of fluorine (A. J. Rudge). Hitherto, relatively little has been published on the anode phenomena occurring in the medium-temperature fluorine cell, which is the type now commonly used for the laboratory and technical production of the element. It has been found that when potassium fluoride-hydrogen fluoride mixtures containing at least 42 per cent of hydrogen fluoride are electrolysed with a carbon anode, the contact angle between anode and melt is 150–160°. Provided a critical current density is not exceeded, no bubbles of fluorine leave the anode surface. Instead, gas evolution occurs at the electrode/electrolyte/gas space interface. This, and the limited spread of the evolved hydrogen, has the important consequence that no diaphragm need be used in a carbon-anode fluorine cell. Anodic polarization, hitherto a common source of trouble during the generation of fluorine, is influenced by various factors such as the current density, electrolyte composition and its water content and the anode material. With suitable grades of amorphous carbon of high permeability, however, polarization difficulties may be eliminated up to current densities of 1 amp. per square inch, this satisfactory performance being maintained over the whole useful range of electrolyte composition and operating temperature.

Preparation and properties of chlorine trifluoride (R. le G. Burnett and A. A. Banks). Chlorine trifluoride, first prepared on a laboratory scale in 1930 by Ruff and Krug, can now be made and handled on a technical scale. The density, surface tension and parachor have been measured and their implications discussed. Several publications on the controlled reactions of chlorine trifluoride have already appeared in the literature, but it was not realized hitherto that fluorocarbons or even carbon tetrachloride could be used as reaction media. In these media hydrogen in organic compounds is substituted in roughly equal proportions by chlorine, and fluorine. Complete replacement of hydrogen is, however, difficult; to take an example, with hydrocarbons containing eight or more carbon atoms in the molecule, about 15 per cent of the hydrogen remains, even with a final reaction temperature of 150°.

Bromine trifluoride as an ionizing solvent (H. J. Emeléus, A. G. Sharpe, A. A. Woolf and V. Gutmann). Pure bromine trifluoride at 25° has a specific conductivity of 8×10^{-8} ohm⁻¹ cm.⁻¹, the corresponding values for chlorine trifluoride (at 0°) and iodine pentafluoride (at 25°) being $< 10^{-8}$ and $2-3 \times 10^{-6}$ ohm⁻¹ cm.⁻¹ respectively. Bromine trifluoride is believed to ionize to a small extent according to the

equation $2\text{BrF}_3 \rightleftharpoons \text{BrF}_2^+ + \text{BrF}_4^-$. Adopting the broad definition of acids and bases as compounds which, in a particular solvent, give rise respectively to the cation and anion of the solvent, acids and bases in bromine trifluoride should yield the above ions. The bases KBrF_4 , AgBrF_4 and $\text{Ba}(\text{BrF}_4)_2$ have, in fact, been prepared by dissolving the corresponding fluorides or other salts of these metals in bromine trifluoride and evaporating excess of the solvent. Similarly, several acids have been isolated ($(\text{BrF}_2)_2\text{SbF}_6$, $(\text{BrF}_2)_2\text{SnF}_6$, BrF_2AuF_4 , BrF_2NbF_6 , BrF_2TaF_6). It is also possible to carry out a conductimetric titration of an acid with a base in this solvent (for example, $\text{AgBrF}_4 + \text{BrF}_2\text{SbF}_6 = \text{AgSbF}_6 + 2\text{BrF}_3$). The gold acid BrF_2AuF_4 is of special interest because, when heated, it yields the hitherto unknown auric fluoride, AuF_3 .

Certain bases (for example, $\text{Ca}(\text{BrF}_4)_2$) are known to be unstable and to lose bromine trifluoride readily. Similarly, there are probably various unstable acids, the intermediate existence of which can be inferred only from the products of reactions. Potassium metaphosphate, for example, when treated with bromine trifluoride, forms potassium hexafluorophosphate, which is believed to result from a neutralization reaction between the base KBrF_4 and the acid BrF_2PF_6 . Hexafluoroarsenates are formed rather similarly, and by dissolving silver and bismuth pentafluoride in bromine trifluoride it is possible to prepare silver hexafluorobismuthate. The same principle, involving reactions of the unstable base NO_2BrF_4 (formed from NO_2 and BrF_3), may be used to explain the formation of a number of new derivatives of the NO_2 ion (NO_2BF_4 , $(\text{NO}_2)_2\text{SnF}_6$, NO_2PF_6 , NO_2AsF_6 , NO_2SbF_6 , NO_2AuF_4).

Dissociation energy of the fluorine molecule (M. G. Evans, E. Warhurst and E. Whittle). From a review of available data, it appears that a value of $D(\text{F}_2)$ of 33–43 kcal. mol.⁻¹, based on recent work by Schmitz and Schumacher and by Wahrhaftig, is more probable than the hitherto accepted value of 63.5 kcal. mol.⁻¹ obtained by von Wartenberg. With a value of the dissociation energy in the lower range, the value of the electron affinity of gaseous fluorine must be less than that of chlorine. The electron affinity of fluorine in solution remains, however, larger than that of chlorine, and the conclusions regarding the ionic character of covalent bonds involving fluorine remain unchanged.

During the discussion of this paper, R. F. Barrow presented evidence obtained by a spectroscopic study of caesium, rubidium and thallous fluorides, which leads to a value of $D(\text{F}_2)$ of 45–50 kcal. mol.⁻¹, that is again considerably lower than the present standard value.

Rates of reaction of sodium atoms with fluoromethanes (M. G. Evans, E. Warhurst and E. Whittle). The Polanyi sodium-flame technique applied to the series CH_3F , CH_2F_2 , CHF_3 and CF_4 leads to some interesting results. A maximum velocity constant is observed for CHF_3 , whereas in the corresponding chloro- and bromo-methane series there is a progressive increase from the mono- to the tetra-halide. The two opposing factors influencing the activation energy of these reactions were considered. The first, an increase in resonance energy of the Polanyi-Evans transition state in the series CH_3F to CF_4 , causes a steady increase in the rate. This, however, is opposed

by a progressive increase in the C—F bond energy, for which some experimental evidence is now available.

Organic fluorine compounds (M. Stacey). In a general survey of the present position of organic fluorine chemistry, the methods available for the introduction of fluorine into organic compounds were first surveyed. These include the use of reagents such as hydrogen fluoride, antimony trifluoride and other metallic fluorides for the replacement of chlorine, bromine or iodine by fluorine in halohydrocarbons, and the use of fluorides which require elemental fluorine for their preparation. The method of fluorination involving fluorine itself in the presence of a gold- or silver-plated copper catalyst was then considered, and the advantages of the reactive metallic fluorides, such as argentic fluoride or cobalt trifluoride, as agents for the vapour-phase fluorination of organic compounds, were mentioned. It appears probable that this method can be applied under certain conditions to produce fully fluorinated heterocyclic compounds.

A novel polymerization reaction involves the polymerization and simultaneous fluorination of fluoro-hydrocarbons by fluorine and leads to the formation of stable fluoro-oils. A further interesting development relates to the synthesis of perfluoro adipic acid by the oxidation with potassium permanganate of unsaturated products obtained by the low-temperature fluorination of benzene.

Chemistry of iodotrifluoromethane and iodopentafluoroethane (R. N. Haszeldine and Miss J. Banus). The C—I bond in iodotrifluoromethane breaks heterolytically under certain conditions to give reactions involving a 'positive' iodine atom. Thus with potassium hydroxide, fluoroform and not trifluoromethyl alcohol, together with potassium hypoiodite, is obtained. This reaction has been studied radiochemically in alcohol solution. The homolytic fission of the C—I bond in the fluoroiodides yields fluorocarbon radicals such as $\text{CF}_3\cdot$, and these radicals initiate the chain polymerization of olefines. With ethylene, polymers of the type $\text{CF}_3[\text{CH}_2\text{CH}_2]_n\text{I}$ ($n = 1-4$) have been synthesized; and from these, trifluoro-hydrocarbons of the general formula $\text{CF}_3(\text{CH}_2)_n\text{CH}_3$ are obtained; polymers of the type $\text{CF}_3[\text{CF}_2\text{CF}_2]_n\text{I}$ ($n = 1-15$) are likewise formed with tetrafluoroethylene. The fluoroiodides obtained from tetrafluoroethylene have also been converted into oils and greases comparable with fluorocarbons in their stability; furthermore, these long-chain fluoroiodides act as sources of long-chain fluorocarbon radicals.

The formation of organometallic compounds from CF_3I and $\text{C}_2\text{F}_5\text{I}$ has been achieved, and the compounds CF_3HgI (and derivatives), $\text{Hg}(\text{CF}_3)_2$, $\text{As}(\text{CF}_3)_3$, $\text{As}(\text{CF}_3)_2\text{I}$, $\text{S}(\text{CF}_3)_2$, $\text{P}(\text{CF}_3)_3$ and $\text{P}(\text{CF}_3)_2\text{I}$ were described. The properties and reactions of certain of these compounds were considered, and it was evident that they are useful intermediates for the synthesis of other compounds containing fluorocarbon groups. A further interesting reaction involving fluorocarbon radicals led to the synthesis of trifluoropropyne, a compound of great potential synthetic value.

Trifluoroacetic acid and its derivatives (J. C. Tatlow). The methods currently available for the synthesis of trifluoroacetic acid, and some of its reactions, were described. The anhydride of this acid has interesting properties. Hydroxyl groups may be trifluoroacetylated, and the unusual properties of sugar trifluoroacetates were revealed. They are unstable compared with normal acetates and are readily

hydrolysed by moisture; ethyl alcohol causes alcoholysis to the parent sugar. Since the trifluoroacetyl group is not removed during subsequent tosylation or acetylation reactions in pyridine solution, however, the trifluoroacetyl group may prove to be of use as a 'blocking' group in carbohydrate chemistry.

A mixture of acetic acid and trifluoroacetic anhydride gives sugar and alcohol acetates in good yield; even cellulose may be acetylated successfully by this method. It is of interest to note that amines form the trifluoroacetyl derivative, and not the acetyl derivative, when treated with a carboxylic acid and trifluoroacetic anhydride.

With nitric acid, trifluoroacetic anhydride forms an active nitrating mixture, and excellent yields of the nitro derivatives of nitrobenzene, benzonitrile and bromobenzene may be obtained; it appears likely that even aliphatic nitration may occur under mild conditions. The value of trifluoroacetic acid in synthetic organic fluorine chemistry is apparent.

H. J. EMELEUS

HORMONE ASSAYS

A SYMPOSIUM on "Hormone Assays" was held on October 20 in London, organised jointly by the Biological Methods Group of the Society of Public Analysts and Other Analytical Chemists and by the Society for Endocrinology. Seven papers were read, dealing with the assay of insulin, posterior pituitary, gonadotrophins, thyroid, oestrogens (in man), and with general principles of bioassay. The Biological Methods Group is to be congratulated on its enterprise. Previous symposia organised by the Group have dealt with penicillin assay, the assay of curare and curare-mimetic substances, the evaluation of selective weed-killers and other bioassay problems of general interest. These discussions are, as a rule, published in full in the *Analyst*. A shortened abstract of the present meeting will also be published in the *Journal of Endocrinology*.

Although certain hormones may be detected by colorimetric or other chemical reactions, in most cases these are not sensitive enough, and bioassay methods are required. Hormone assays are often conducted without proper regard for the principles of biological assay, and much of the discussion at the meeting was devoted to reconsidering these principles as they apply to hormone assays. In general, bioassays are of two kinds: those in which standard and unknown differ quantitatively, and those in which they differ qualitatively. Assays of the first kind have the same object as chemical determinations, and they are used only where no adequate chemical methods are available. The design of these assays has been greatly improved during the past few years, and they can now be rendered extremely accurate. Particularly satisfactory are those assays in which, as in the standardization of insulin, standard and unknown can be relied upon to be pure and have the same chemical composition. Assays of mixed and impure extracts, such as the assay of sex hormones or gonadotrophins in urine, are rather less satisfactory. In these cases more than one active principle is usually present, and there is the danger that the unknown solution may be assayed in terms of a standard of different composition. Prof. J. H. Gaddum discussed some of the difficulties arising in the interpretation of these assays.