Vinylpyrazine (10.6 g., 0.1 mole in 25 ml. of anhydrous ether) was added and the mixture was stirred for an additional 30 min. Then, ammonium chloride (5.5 g.) and about 100 ml. of ether were added and the liquid ammonia was allowed to evaporate. The residue was poured onto ice and the phases were separated. The aqueous phase was extracted twice with ether and twice with chloroform. The combined organic phases were dried over sodium sulfate, the solvents were removed at atmospheric pressure, and the residue was distilled to give phenyl 3-pyrazyl-1-propyl ketone [2.0 g., 8.9%, b.p. 158–162° at 1.0 mm., m.p. 60–60.8° from petroleum ether (b.p. 60–70°) (*Anal.* Calcd. for $C_{14}H_{14}N_2O$: C, 74.31; H, 6.24. Found: C, 74.26; H, 6.33.); 2,4-dinitrophenylhydrazone, m.p. 173.8–174.6° from 95% ethanol (*Anal.* Calcd. for $C_{20}H_{18}N_6O_4$: C, 59.12; H, 4.46. Found: C, 59.36; H, 4.23.)]. The distillation residue was extracted with boiling petroleum ether to give the bis Michael adduct, 1,5-dipyrazyl-3-benzoylpentane [1.6 g., 9.7%, m.p. 69–69.8° from petroleum ether (*Anal.* Calcd. for $C_{20}H_{20}N_4O$: C, 72.26; H, 6.06. Found: C, 72.57; H, 5.92.)].

Pyrazylethylation of Ethyl Phenylacetate.—A mixture of ethyl phenylacetate (16.4 g., 0.1 mole), vinylpyrazine (10.6 g., 0.1 mole), and sodium (0.1 g.) was refluxed for 90 min., cooled to room temperature, and then processed as described in the first experiment above except that chloroform was used in place of ether to give ethyl 2-phenyl-4-pyrazylbutanoate [14.7 g., 54.5%, b.p. 171–172° at 1.15 mm. (*Anal.* Calcd. for $C_{16}H_{18}N_2O_2$: C, 71.09; H, 6.71. Found: C, 71.30; H, 6.57.); styphnate, m.p. 114–115° from 95% ethanol (*Anal.* Calcd. for $C_{22}H_{21}N_5O_{10}$: C, 51.28; H, 4.11. Found: C, 51.46; H, 4.25.)]. Hydrolysis of a sample of the product with 20% sodium hydroxide gave 2-phenyl-4-pyrazylbutanoic acid, m.p. 105.8–106.6° (from water) (*Anal.* Calcd. for $C_{14}H_{14}N_2O_2$: C, 69.40; H, 5.82. Found: C, 69.44; H, 5.64.).

Pyrazylethylation of Phenylacetonitrile.—A mixture of phenylacetonitrile (23.4 g., 0.2 mole), vinylpyrazine (10.6 g., 0.1 mole), and sodium (0.1 g.) was stirred and heated at 120–130° for 20 min., allowed to cool to room temperature, and processed as described in the preceding experiment to give 2-phenyl-4-pyrazylbutanenitrile: 13.3 g., 59.8%, b.p. 150–151° at 0.12 mm. (*Anal.* Calcd. for $C_{14}H_{13}N_3$: C, 75.31; H, 5.87. Found: C, 75.40; H, 5.71.). A sample of this nitrile was hydrolyzed with 10% hydrochloric acid to give 2-phenyl-4-pyrazylbutanoic acid, m.p. 105.5–106.5° alone and when mixed with the acid obtained in the preceding experiment.

Pyrazylethylation of Acetamide.—A mixture of acetamide (11.8 g., 0.2 mole), vinylpyrazine (10.6 g., 0.1 mole), and sodium (0.1 g.) was allowed to react under the conditions described in the preceding experiment to give N-(2-pyrazylethyl)acetamide: 7.1 g., 43.0%, b.p. 150–154° (0.54 mm.) (*Anal.* Calcd. for $C_8H_{11}N_3O$: C, 58.16; H, 6.71. Found: C, 58.22; H, 6.66.). A mixture of the product (6.0 g., 0.037 mole) and 70 ml. of 20% sodium hydroxide solution was refluxed for 1 hr., cooled to room temperature, and extracted with several portions of chloroform. After removing the solvent at atmospheric pressure, the residue was distilled to give 2-aminoethylpyrazine [2.7 g., 60.5%, b.p. 102–103° at 9.0 mm.[2]; phenylthiourea derivative, m.p. 82–83° (from benzene) alone and when mixed with an authentic sample].[2]

Synthesis of Trifluoromethyl Hypofluorite[1]

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Until the present time the reported syntheses of trifluoromethyl hypofluorite (CF_3OF) and other fluoroxy compounds were performed by the fluorination of oxygen-containing compounds with fluorine and/or silver difluoride.[2-8] The reaction of dioxygen difluoride (O_2F_2) with tetrafluoroethylene(C_2F_4) to produce CF_3OF has also been described.[9] The only previously reported formation of a hypofluorite from oxygen difluoride (OF_2) resulted from a reaction between OF_2 and sulfur trioxide (SO_3) which gave a compound containing a primary fluorine and an OF group (FSO_2-OOF).[10] Ruff and Menzel[11] reported that methane (CH_4) and OF_2 exploded when ignited by a spark, but they did not indicate the nature of the products.

Discussion

Equimolar mixtures of CHF_3 and OF_2 at pressures between 20 and 100 mm. do not react spontaneously at room temperature in the absence of light. Strong irradiation of these mixtures with a high-pressure quartz mercury vapor light results in a slow reaction in which hydrogen fluoride (HF), carbon tetrafluoride (CF_4), carbon dioxide (CO_2), carbonyl fluoride (COF_2), and silicon tetrafluoride (SiF_4) (from HF and glass) are formed. Products capable of oxidizing iodide to iodine were not observed in the light-induced reactions. A gas phase explosion occurs when an electric spark is used to initiate the reaction of an equimolar mixture of CHF_3 and OF_2 at pressures above 25 mm. At 25 mm. or less, the detonation does not propagate. At pressures of 100 mm. or more, the products are again only HF, CF_4, CO_2, COF_2, and SiF_4. At a pressure of 50 mm., a 15% yield of CF_3OF is observed in addition to the products previously mentioned. Compounds such as perfluoroethane (C_2F_6), perfluorodimethyl ether $(CF_3)_2O$, and perfluorodimethyl peroxide $(CF_3O)_2$ are not observed.

Mixtures of CH_4 and OF_2 from 1:4 to 1:10 were allowed to react at total pressures ranging from 6 to 60 mm. As with CHF_3–OF_2, a spontaneous reaction was not observed at room temperature. When the reaction mixtures were exposed to sparks, explosive reactions occurred. These explosive reactions occurred at pressures as low as 6 mm. with 1:4 CH_4:OF_2 mixtures. The lower pressure limit of this explosive reaction was not determined. The products obtained in this reaction were CF_3OF, CO_2, HF, SiF_4, and small amounts of COF_2. Trace amounts of CF_4 (<1%) were also present. Yields of up to 50% CF_3OF were obtained. This compound was present in all of the reactions with CH_4 and OF_2.

The reactions can be pictured schematically as shown. At this time, knowledge of there action

$$CHF_3 + OF_2 \longrightarrow CF_3OF + HF$$

$$CH_4 + 4\,OF_2 \longrightarrow CF_3OF + 4HF + {}^3/{}_2O_2$$

kinetics of these reactions is insufficient to determine if the reaction mechanism is a concerted single-step reaction or a multistep recombination of radicals produced

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[1] This work was supported by the Office of Naval Research under Contract Nonr 3597(00).

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in the explosive reaction. However, owing to the high temperature which must be present, a radical recombination is most likely.

The CF$_3$OF was identified by comparison of its spectroscopic and chromatographic properties with those of authentic CF$_3$OF. The infrared spectrum is in good agreement with that published previously,[3] as later corrected.[7] The F^{19} n.m.r. spectrum of the compound conforms very closely to the published n.m.r. spectrum of authentic CF$_3$OF.[7,12,13] The compound was also identified in a gas chromatogram using FC 75[14] as a liquid phase on a firebrick support. The column was cooled in Dry Ice–acetone. This column is capable of separating air, OF$_2$, CF$_4$, CHF$_3$, COF$_2$, and CF$_3$OF. The retention time of the product compound was the same as that of an authentic sample of CF$_3$OF.

Experimental Section

Reaction Vessel.—A 1-l. Pyrex bulb closed with a stopcock was employed as the reaction vessel. Two small holes (0.5 mm.) were made in the bulb at an angular separation of 180°. Pieces of no. 26 nichrome wire were passed through each hole until they almost touched in the center of the bulb (5 mm. separation). The wires were bent over and taped to the bulb at the exit points. Vacuum tight seals were made by dripping hot Apiezon W wax on the holes.

Pressure Measurements.—Since OF$_2$ and CF$_3$OF reacted rapidly with mercury, a nickel bellows pressure transducer (Giannini) was employed for pressure measurements.

Chromatographic Analysis.—A Loenco Model 15B gas chromatograph containing a hot-wire thermal conductivity detector was used for separation and analysis of the products. The chromatographic column employed was 0.25 in. × 6 ft. copper tube filled with 30% FC 75[14] on 60–80-mesh acid-washed firebrick. The column was cooled to $-78°$ in an external Dry Ice–acetone bath, and helium was used as the carrier gas. The column could separate mixtures into the following components: O$_2$ + N$_2$, OF$_2$, CF$_4$, SiF$_4$, CHF$_3$, CO$_2$ + COF$_2$, and CF$_3$OF. Oxidizing compounds (OF$_2$, CF$_3$OF) could be detected by placing a moist starch–iodide test paper at the chromatograph outflow.

Spectroscopic Analysis.—Infrared adsorption spectra were obtained with a Perkin-Elmer 421 spectrophotometer. A 10-cm. monel-body gas cell was employed with NaCl windows.

N.m.r. spectra were made on Varian Model HR60 spectrometer operating at 56.4 Mc. Fluorotrichloromethane was used as a solvent and internal standard.

Trifluoromethane Reaction.—The reaction bulb was filled with a 50-mm. pressure equimolar mixture of CHF$_3$ and OF$_2$. One wire of the bulb was grounded and the other was attached to a high voltage vacuum leak detector. When the high voltage was turned on momentarily (<0.5 sec.) an orange flash and an audible detonation occurred. The contents of the bulb were transferred into an evacuated 100-ml. bulb cooled in liquid N$_2$. It was necessary to repeat the transfer several times since a noncondensible gas was present (probably O$_2$). Chromatographic analysis and infrared analysis gave the following results. A 12% yield of CF$_3$OF was observed and CO$_2$ and COF$_2$ were also seen. The ratio of CO$_2$ and COF$_2$ was highly variable. This is apparently due to the fact that COF$_2$ reacts with glass to give CO$_2$ and SiF$_4$, or with the water released by the reaction of HF on glass. The yield of the CO$_2$–COF$_2$ was about 70% with the remaining 8% made up by CF$_4$. The identity of the CF$_3$OF was confirmed by infrared and n.m.r. spectra. An authentic sample of CF$_3$OF was passed through the gas chromatograph and had the same retention time as the product compound (2.5 min.).

Methane Reaction.—The reaction bulb was filled with 2.5-mm. of CH$_4$ and 15 mm. of OF$_2$. A spark was discharged through the mixture resulting in a white flash and a detonation. The reaction mixture was worked up and analyzed by the above procedures. A yield of about 50% CF$_3$OF, 48% CO$_2$, 1% COF$_2$, and less than 0.5% CF$_4$ was found. When this reaction was performed in a metal system, CO$_2$ was still a major product; thus it does not entirely originate from COF$_2$ and glass or water.

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[12] R. A. Ogg, Abstracts, 126th National Meeting of the American Chemical Society, New York, N. Y., Sept. 1954, p. 24M.

[13] G. H. Cady and C. I. Merrill, *J. Am. Chem. Soc.*, **84**, 2260 (1962).

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The Mitomycin Antibiotics. Synthetic Studies. VIII. Nitration and O-Benzyl Rearrangement in the 7-Oxypyrroloindole System[1]

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During the course of an attempted preparation of 6-demethyl-7-methoxymitosene by a route essentially parallel to that employed in the synthesis of 7-methoxymitosene,[2] we sought to cleave the benzyloxy group of 7-benzyloxy-2,3-dihydro-9-formyl-1H-pyrrolo-[1,2-*a*]indole (I).[3] Concern for possible reduction of the 9-formyl group during hydrogenolysis with palladium catalyst[4] led us first to try cleavage with aluminum chloride.[5] However, when I was submitted to the latter reagent, it was found that the desired 7-hydroxy compound II was only the minor component of the resulting mixture.[6] The major component (III) was also a 7-hydroxy-9-formylpyrroloindole, but it contained a benzyl group (n.m.r.: five protons at 7.28 p.p.m. and two protons at 4.08 p.p.m.). That this group had entered the 6-position was apparent from its subsequent transformations.[7,8] Oxidation of III with potassium nitrosodisulfonate[2,9] gave a purple *o*-quinone VI which had ultraviolet absorption almost identical

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[1] Paper VII: W. A. Remers, R. H. Roth, and M. J. Weiss, *J. Org. Chem.*, **30**, 2910 (1965).

[2] G. R. Allen, Jr., J. F. Poletto, and M. J. Weiss, *J. Am. Chem. Soc.*, **86**, 3877 (1964).

[3] W. A. Remers and M. J. Weiss, *J. Med. Chem.*, **8**, 700 (1965).

[4] See G. R. Allen, Jr., J. F. Poletto, and M. J. Weiss, *J. Am. Chem. Soc.*, **86**, 3878 (1964).

[5] This reagent successfully cleaved the 7-methoxy group of a related 9-formylpyrroloindole.[2]

[6] Separation of this mixture proved very difficult. Although a small portion of the major component (III) could be obtained pure by fractional crystallization from acetone, partition chromatography involving large eluent volumes was necessary to afford substantial amounts of both isomers.

[7] The n.m.r. spectrum of III supported this assignment, although superposition of phenyl-ring protons on one of the C-ring protons complicated the interpretation of this spectrum. A sharp singlet at 7.73 p.p.m. is assigned to the C-8 proton, since deshielding of this proton by the formyl group at C-9 should shift it downfield relative to the C-5 or C-6 proton [see W. A. Remers, *J. Am. Chem. Soc.*, **86**, 4610 (1964), footnote 9]. Since this peak appears unsplit by the other C-ring proton, the latter must be at the C-5 (*para*) position, rather than at the C-6 (*meta*) position.

[8] Zinc chloride catalyzed benzyl migration in benzyl phenyl ether (to give *p*-hydroxydiphenylmethane) was reported by J. van Alphen [*Rec. trav. chim.*, **46**, 799 (1927)]. In this paper a similar migration in diphenylmethyl phenyl ether was also noted. We wish to thank a referee for bringing this work to our attention.

[9] H. J. Teuber and G. Thaler, *Chem. Ber.*, **91**, 2253 (1958), and previous papers.