

THE SYNTHESIS OF HIGHLY RADIOACTIVE ISOPROPYL METHYLPHOSPHONOFUORIDATE (SARIN) CONTAINING P³² AS TRACER ELEMENT¹

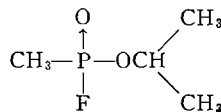
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ABSTRACT

Procedures are described for the safe processing of multicurie quantities of irradiated red phosphorus into isopropyl methylphosphonofluoridate (sarin) having a specific activity of 250 to 300 millicuries per gram. The use of costly remote-handling equipment is avoided by suitable choice of synthetic route and apparatus design.

INTRODUCTION

Several years ago, a requirement arose for radioactively tagged (P³²) isopropyl methylphosphonofluoridate (sarin) I, in order to study the biological effects and mode



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of action of the so-called "nerve gases". The degree of dilution likely to be encountered in such biological studies indicated that quantities of the order of 50 grams with a specific activity of 250-300 mc/g would be required. Safe handling of multicurie sources of radiation is ordinarily achieved by placing operators behind shields and manipulating apparatus with various remote-handling devices. Such devices are complex and costly. Since the hazard depends not only upon the intensity of radiation but the duration of exposure to it, it was visualized that the greater speed of direct handling might give less actual radiation dosage than the much longer exposures to lower levels of radiation attendant on the usual remote-handling operations. The greater surety against accidents provided by direct handling was a further consideration in the synthesis of a highly toxic compound.

Accordingly a careful study of synthetic methods was carried out with a view to elimination of operations requiring long periods of attention. A time study was made of the known alternative routes of synthesis to assess the approximate radiation hazard associated with each procedure. These routes are illustrated diagrammatically in Fig. 1. The results clearly indicated that the route involving the direct conversion of phosphorus trichloride via the APC complex to methylphosphonic dichloride, followed by fluorination to methylphosphonic difluoride and preparation of sarin from the equimolecular mixture of dichloride and difluoride, was the safest practical method to use. The very high yield and purity of the agent produced by this method was a further advantage.

Investigations of this chosen route led to modifications in the chemistry and in the synthetic apparatus used which further simplified the reactions and reduced the hazards considerably. Principally, improvement was obtained in the preparation of methylphosphonic dichloride by an anhydrous procedure (1), which eliminated a filtration, and

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EXPERIMENTAL

Purification of Red Phosphorus

The phosphorus to be irradiated is purified in our laboratory by treatment of reagent grade material with concentrated hydrochloric acid at reflux temperature for approximately 1 hour, followed by washing with copious quantities of boiling distilled water. Repeated water washing, and decanting from the phosphorus to remove most of the "fines", give a product which is more easily handled since the inclusion of the very fine phosphorus particles sometimes results in a sintered irradiated sample. Finally the phosphorus is filtered, washed with alcohol, ether, and dried in a vacuum desiccator.

When the irradiation was carried out at Idaho Falls, Idaho, the purified red phosphorus was charged into clean, pure (Sl grade) aluminum capsules, 15 g of phosphorus per capsule, and sealed in an atmosphere of dry helium. Atomic Energy of Canada at Chalk River do their own packing, and bulk lots of purified phosphorus were sent to them in polyethylene bottles.

Transfer of Irradiated Phosphorus to the Phosphorus Trichloride Apparatus

The transfer of the irradiated phosphorus to the tared PCl_3 reaction flask is accomplished by normal "hot" radiological dry box technique under an atmosphere of dry nitrogen.

Preparation of Phosphorus Trichloride

Phosphorus trichloride is synthesized in the apparatus illustrated in Fig. 3.

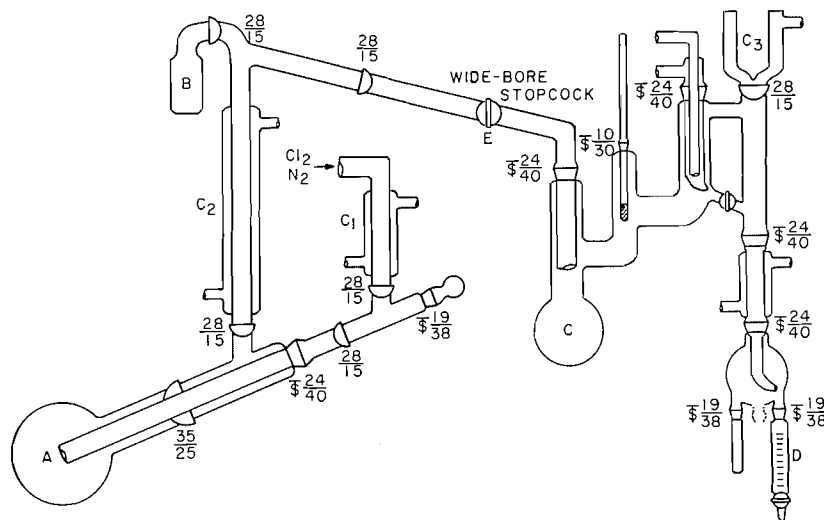


FIG. 3. PCl_3 apparatus.

Approximately 40 grams of dry boiling chips are placed in the reaction flask A, which is then evacuated and heated to dispel as much air as possible from the boiling chips. Dry nitrogen is let into the evacuated flask and the process of heating, evacuation, and admission of dry nitrogen is repeated so as to ensure that all oxygen (which would cause oxidation of the trichloride to oxychloride) is removed. The flask is then stoppered, weighed, and placed in the dry box ready for receipt of the irradiated phosphorus.

The stoppered flask is removed from the dry box after the addition of the irradiated

phosphorus, is weighed to determine weight of phosphorus (approximately 30 grams), and coupled up to the apparatus as shown in Fig. 3.

A slow stream of dry nitrogen is passed into the apparatus through the gas inlet tube to sweep out residual traces of oxygen, and the reaction flask is heated to 110°–120° C. At this stage the slow stream of nitrogen is replaced by a metered stream (6 to 7 liters per hour) of dry chlorine gas and at the same time a jet of cool air is directed on the upper, unheated surface of the reaction flask. Reaction occurs and the phosphorus pentachloride sublimes to the cool upper surface of the flask as it is formed. After 3/4 hour, when a fairly thick crust of phosphorus pentachloride has sublimed to the cool upper surface, chlorination is stopped and a very slow stream of nitrogen (sufficient to maintain a positive pressure only) is substituted for the chlorine. The reaction flask is then rotated through 180° on its ball joint so that the phosphorus pentachloride is covered with unreacted red phosphorus. Heating, without chlorination, is continued for about 15 minutes, by which time the phosphorus pentachloride is largely reduced by the unreacted red phosphorus to phosphorus trichloride. Chlorination is recommenced and the whole procedure repeated until a 20% excess of chlorine has been introduced. Heating is continued for 1 hour or until the residual phosphorus has disappeared.

This stage is fairly easy to observe and is facilitated by the use of boiling chips. Initially glass chips were used to keep the phosphorus mobile, but it was found that they become stained a dark brown by the intense radiation which tends to obscure the end point. The white boiling chips are hardly affected by the radiation and so provide a background against which the unreacted phosphorus is readily discerned.

The mixture in the flask now consists of phosphorus trichloride and phosphorus pentachloride. The mixture is allowed to cool to room temperature. Pure granular antimony (100 g) is then added to the mixture by tipping the antimony container B, which is built onto the apparatus. Powdered antimony reacts very vigorously with phosphorus pentachloride but results in a somewhat inferior product due to the surface film of antimony oxide normally present on the surface of the antimony, giving phosphorus oxychloride as a by-product. Granular antimony reacts more slowly, and a larger excess is required: the product, however, is purer. It is found that -20+80 mesh antimony is most suited to the reaction as a compromise between speed and purity.

Flask C is surrounded by a dry ice - acetone mixture and the nitrogen stream increased to approximately 2 liters per hour to help sweep out the trace amounts of phosphorus pentachloride sublimed into the gas inlet tube and also to prevent phosphorus trichloride distilling too far up the inlet tube in the subsequent operations.

The reaction mixture is then slowly heated. At approximately 75° C a strongly exothermic reaction sets in and phosphorus pentachloride is reduced to phosphorus trichloride by the antimony, antimony trichloride being formed at the same time. When the initial reaction has moderated, it is normal to obtain a yellowish-brown solid precipitate in the reaction mix. Reaction is regarded as complete when the liquid layer in the reaction flask is homogeneous and it has been found that this can only be attained quickly by strongly heating the reaction mixture. The heating mantle temperature is thus slowly raised to 280°–300° C and the elevated temperature is maintained until the liquid layer becomes homogeneous. During this period of heating, the rapidly refluxing phosphorus trichloride washes the last traces of sublimed phosphorus pentachloride into the reaction flask for reduction to trichloride. At the same time some 7–9% of the trichloride, entrained by the slow stream of nitrogen, condenses out in C₃ and is collected in the receiver.

Should there still be yellow solid material in the reaction mix after heating to

280°–300° C for 1 hour, the mixture may be cooled and a further quantity of the antimony added. The initial amount added, however, is a large excess and the further addition of antimony has been required only in those cases where the phosphorus was overchlorinated to give a large quantity of the pentachloride.

When the liquid layer becomes homogeneous the heating mantle temperature is reduced to 230° C, the water removed from the condenser C₂, and the product of phosphorus trichloride distilled in a slow stream of dry nitrogen while maintaining the charge of dry ice – acetone around receiver C. Distillation is continued until white fumes of antimony trichloride are observed in the reaction flask A.

Stopcock E is closed and the crude PCl₃ redistilled from a few grams of antimony to reduce any PCl₅ which might have been sublimed from the reaction flask during the reaction. The receiver is calibrated volumetrically so that the weight of product synthesized may be calculated directly without recourse to weighing and handling the "hot" product.

Yields of pure phosphorus trichloride, based on the phosphorus used, have varied from 92–99%.

Preparation of the Aluminum Chloride:Phosphorus Trichloride:Methyl Chloride (APC) Complex

The apparatus devised for this synthesis is illustrated in Fig. 4. The radioactive phos-

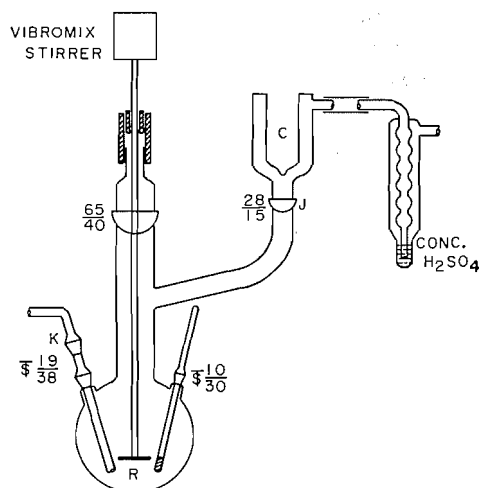


FIG. 4. APC complex apparatus.

phorus trichloride is run into the reaction flask R, which contains 1.5 molar proportions of very finely powdered anhydrous aluminum chloride. The very thick mixture is heated to 70°–75° C and agitated with a "vibrator"-type stirrer of fixed period but variable amplitude. The condenser C is charged with a dry ice – acetone mixture and a slow stream (1 to 1½ liters per hour) of dry methyl chloride is passed into the mixture as close to the point of stirring as possible. In the early stages reaction is slow, but after approximately 1 hour the mixture becomes fluid and the rate of absorption of methyl chloride increases markedly. When the mixture becomes fluid the efficiency of stirring is increased and the rate of addition of methyl chloride stepped up. On an approximate molar scale, absorption of methyl chloride is fairly rapid for approximately 2½ to 3 hours, when the mixture

becomes more viscous and crystals begin to separate on the walls of the flask. At this stage the rate of addition of methyl chloride is reduced to a very slow stream (approximately 1/2 to 1 liter per hour) while heating and stirring are continued. After a further 2 hours the mixture is a semisolid mush of crystals and the reaction is virtually complete. Methyl chloride addition is stopped and heating and stirring are continued for a further hour to ensure completion of the reaction. Heating and stirring are then stopped, the dry ice - acetone is removed from the condenser, and the excess methyl chloride is allowed to boil off. Throughout the whole of the reaction the rate of methyl chloride addition must be carefully controlled so that too great a reflux return to R is not obtained, as otherwise the reaction mixture is cooled below the temperature at which the formation of complex proceeds rapidly. During the period of rapid absorption, the maximum rate of addition of methyl chloride is always used commensurate with maintaining the reaction temperature of 70°-75° C.

Preparation of Methylphosphonic Dichloride from the APC Complex

The apparatus used in the radioactive synthesis is illustrated in Fig. 5.

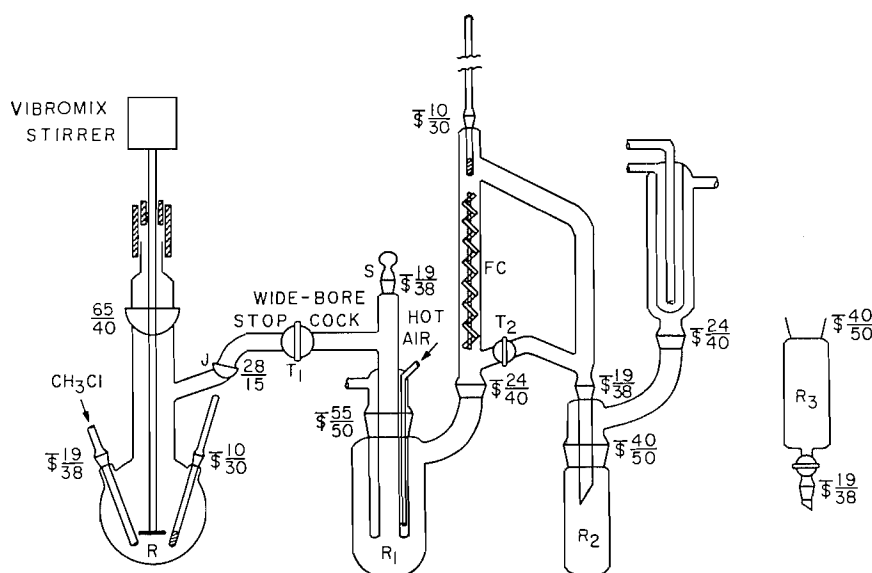


FIG. 5. Methylphosphonodichloridate apparatus.

The reaction flask in which the APC complex is prepared is also used for the breakdown of the complex and as the distillation flask for the recovery of the crude methylphosphonic dichloride. On completing the preparation of the APC complex the ball joint J (Fig. 4) is opened and 3 moles/mole complex of dry diethyl phthalate is added to the complex. The joint J is remade and stirring is begun to dissolve the complex as far as possible in the diethyl phthalate. Solution is accompanied by a pronounced rise in temperature and external water cooling should be used to prevent "hot spots" in the early stages until the solid breaks up. At this point a stream (10-12 liters/hour) of dry sulphur dioxide is passed through the stirred mixture via the inlet tube used for methyl chloride. An exothermic reaction occurs and the temperature of the reaction mixture normally rises to a maximum of approximately 50° C, and after approximately 2 hours begins to fall.

Sulphur dioxide is passed into the stirred mixture for a further 30 minutes and the mixture is then allowed to stand for a further 1 hour to ensure completion of reaction. During the passage of the sulphur dioxide the small amount of undissolved but dispersed complex rapidly dissolves and a very fine precipitate of the diethyl phthalate : aluminum chloride complex appears.

On completion of the reaction, the joint J is opened, and the whole reaction flask and contents are transferred to the distillation unit shown in Fig. 5 and joined up via the ball joint J (Fig. 5), the reaction flask then becoming the distillation flask R of Fig. 5. The inlet joint K at the upper end of the gas inlet tube is disconnected and replaced with a capillary air bleed coupled to an air-drying train. The reaction mixture is then thoroughly degassed under water pump vacuum.

The receivers R_1 and R_2 are immersed in dry ice - acetone cooling mixture and the apparatus evacuated by a high-capacity high-vacuum pump to approximately 0.1-0.5 mm Hg. The distillation flask is then heated to 85° to 90° C, when the residual thionyl chloride and methylphosphonic dichloride distill from the diethyl phthalate into receiver R_1 . During the radioactive synthesis 6 hours is allowed, after which time the distillation is considered to be complete. This crude distillation is carried out with the tap T_2 in the open position to avoid a pressure drop which might be caused by the fractionating column FC and to ensure as high a pumping speed as possible at the distillation flask. The taps T_1 and T_2 are then closed, heating is discontinued, the dry ice - acetone cooling mixtures are removed, and dry air is let into the main receiver part of the apparatus.

The receiver R_1 is then heated by a heating mantle and the thionyl chloride is fractionally distilled from the recovered mixture at atmospheric pressure via the column FC. Heating is continued until the temperature at the top of the column is approximately 150°-155° C, which indicated that methylphosphonic dichloride is about to distill. Heating is then stopped and the apparatus allowed to cool to room temperature. The stopper S is replaced by a fine capillary bleed and the receiver R_2 is removed and replaced by the receiver R_3 for methylphosphonic dichloride. The apparatus is evacuated to approximately 60 mm Hg using a water pump and R_1 is again heated to recover pure methylphosphonic dichloride by fractional distillation.

During the evacuation of the apparatus to 60 mm Hg the last traces of thionyl chloride are removed from the upper part of the column and condenser surfaces. At 60 mm Hg the methylphosphonic dichloride distills at 84°-85° C and is distilled at a sufficiently rapid rate to prevent crystallization in the cool parts of the receiver. The product receiver is weighed before and after to determine the yield.

Yields of 88-89%, based on the phosphorus trichloride, are obtained.

Preparation of Radioactive Sarin

The apparatus used in the synthesis is illustrated in Fig. 6.

The dropping funnel which forms the receiver R_3 for the collection of methylphosphonic dichloride in the previous synthesis is transferred to one neck of the three-necked reaction flask and its molten contents are run in. The funnel is washed through into the flask with 100 ml of dry methylene chloride, and the mixture, stirred by means of a magnetic stirrer, is brought to reflux. During this stage of the reaction, water is led through the jacket of the beryl-saddle-packed fractionating column F, so that it acts as a reflux condenser.

A mole/mole solution of anhydrous hydrofluoric acid in anhydrous isopropanol is then prepared. A 5% excess over the theoretical weight of this solution required to react with the methylphosphonic dichloride previously synthesized is introduced into the copper

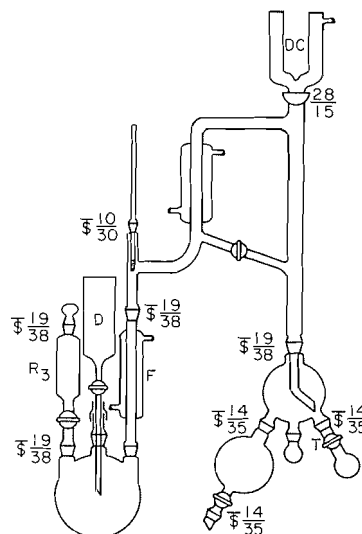


FIG. 6. Sarin apparatus.

dropping funnel D and from there run dropwise into the methylphosphonic dichloride solution at such a rate as to maintain gentle reflux without application of external heat. When addition is complete, the mixture is refluxed for 15 minutes, the water is drained from around the column F, and methylene chloride is distilled off for 15 minutes at atmospheric pressure, by which time evolution of HCl is virtually complete. The remaining methylene chloride is taken off and degassing is completed under water pump vacuum.

At this stage 10 ml of diethylaniline is added, the copper dropping funnel is replaced by a capillary bleed, and fractionation is begun at a pressure of about 10 millimeters. The condenser DC is charged with dry ice - acetone to prevent the loss of sarin which has been found to occur when distilling at this pressure. The forerun is collected in a receiver which may be shut off from the system by means of a tap T when collection is complete, thus preventing its contents from distilling back into the main fraction as distillation proceeds. This measure has been found to increase the purity of the sarin produced from 96-97% up to 99% or better. The main fraction is collected in a dropping-funnel-type receiver to facilitate subsequent dispensing of the product.

Using this method, yields of between 82 and 87% of sarin are obtained. The purity of this material has been found to be consistently better than 99%.

DISCUSSION

Safety

P^{32} is a pure β emitter and these particles are readily stopped by light weight lucite sheets. The bremsstrahlung X rays from such a source as we were handling, however, require thick, heavy metal sheets for complete protection. No laboratory with remote-handling equipment was available at Suffield but after careful consideration of the problem it was decided that the synthetic program could be undertaken using the facilities of our tracer laboratory. The laboratory consists of a main laboratory with seven in-line fumehoods each 5 ft wide and 2 ft 6 in. deep, and auxiliary observation, storage, and changing rooms. The fumehoods are of modern streamline design with all

service outlets inside and to the front whereas all service controls are outside. The hoods can be used singly or jointly as the size of apparatus dictates.

The bases of the fumehoods are of concrete cast in the form of a shallow sink and are lead lined; they are sufficiently robust to allow the heavy screening of local hot spots, such as reaction flasks, with lead bricks or thick sheet lead. The heavy screening of the whole apparatus was found to be impracticable and, in fact, undesirable during general distillation procedures. For general screening work, mobile screens of 1/2-in. thick Lucite (polymethyl methacrylate) faced each side with 1/16-in. steel were found to be ideal. These screens are 15 in. wide and extend the full height of the fumehood face. They run on ball races on permanent tracks along the front of the hoods, and are quickly and very easily moved to the desired screening position. Windows cut in the steel allow observations at the required height and the width of the screen allows an operator to work with his body shielded while using both hands for required manipulations in the fumehood. The steel-lined Lucite screens completely stop all β rays and reduce the bremsstrahlung X rays to approximately 15% of the unscreened value. The main face window of each hood is a vertically rising sheet of 1/2-in. Lucite and is coupled to a damper in the ventilation duct of the hood so that the draft is increased or decreased as the main window is raised or lowered respectively. With the main window completely closed each hood is positively ventilated at a low speed.

The bank of fumehoods is ventilated by a communal system powered by an 8000 cu. ft/min (at 1½ in. static water pressure) exhaust fan. This flow is ample to allow work to proceed safely at three or four fumehoods simultaneously. Inlet air is filtered, thermostatically heated, and enters via the auxiliary rooms into the main laboratory and so to the fumehoods. This system ensures that at all times the operators work in a positive flow of clean air from the clean to the dirty parts of the laboratory.

The concept of dividing the laboratory into "clean" and "dirty" areas was vigorously enforced and easily removed coveralls and boots were worn, as were respirators at all times of transfers in order to eliminate ingestion hazards.

Monitoring of the personnel engaged in the syntheses has been carried out in three ways:

- (i) by plotting the low energy X-ray dosage fields and observing the time spent by each operator at any position,
- (ii) by wearing $\beta\gamma$ film badges, and
- (iii) by wearing pocket dosimeters.

Probably the most important point pertaining to safety is the particular care which must be paid to the design of apparatus and choice of reaction conditions which enable the syntheses to be carried out with a minimum of handling and infrequent observation.

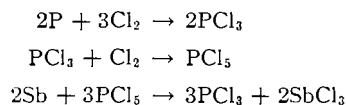
The five-stage synthesis is carried out in 5 days—a total of approximately 60 working hours—by three of the personnel. By dividing the hazardous tasks between the three (monitoring was continuously carried out to facilitate this), each worker receives less than 300 μ r per person, the radiation dosage recommended at that time as the limit for those working continuously with radioactive materials. Since a decay period of at least 3 months is allowed to elapse between syntheses, our experience to date has indicated that complex organic syntheses involving high level sources can be carried out safely without remote handling provided adequate attention is paid to process flow and apparatus design.

Purification of Red Phosphorus

Our first irradiation of commercial red phosphorus graphically illustrated the need for

a preliminary purification of this material. Trace quantities of sodium ion must be eliminated in order to prevent the inclusion of a high-intensity γ source in the starting material.

Preparation of Phosphorus Trichloride



The method (2) of chlorinating red phosphorus to phosphorus trichloride on a large scale, although a straightforward reaction, suffers the disadvantage that an excess of phosphorus must be used to prevent the appearance of the pentachloride in the product. Saunders and Worthy (3) have developed a method for the complete conversion of small (1 g) amounts of phosphorus to the trichloride. Such a method proved impractical on the scale required at Suffield since it required careful standardization of procedures and constant supervision. To avoid waste of the active phosphorus the method of chlorination was modified and advantage was taken of the reducing properties of pure antimony to convert phosphorus pentachloride to the trichloride. The purity of the phosphorus trichloride, checked by infrared spectroscopy, is excellent. The absorption spectrum (Fig. 7) shows a very small percentage of P=O, much less than by reagent grade commercial product triply distilled in dry nitrogen.

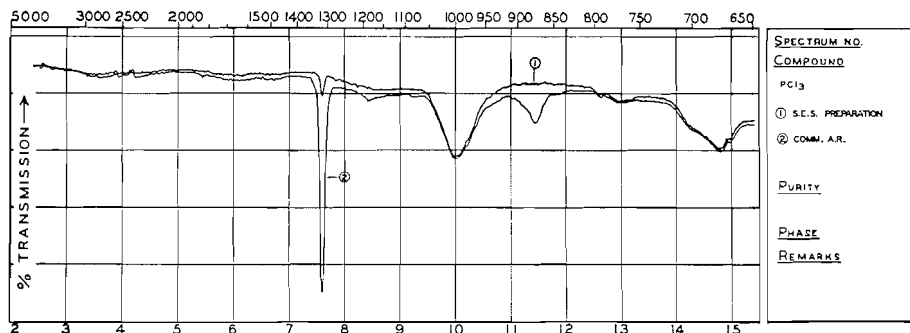


FIG. 7. Spectrum of PCl_3 . (1) Synthetic product; (2) commercial product, AR grade.

Preparation of the Aluminum Chloride:Phosphorus Trichloride:Methyl Chloride (APC) Complex

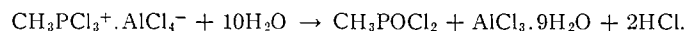
The formation of the 1:1:1 molar aluminum chloride:phosphorus trichloride:methyl chloride (APC) complex proceeds very smoothly in pressure-type apparatus to give yields which are virtually quantitative. When the method is applied to the synthesis of radioactive APC complex, however, it has one marked disadvantage in that the solid has to be transferred from the pressure-type reaction apparatus to the reactor in which the subsequent breakdown of the complex is to be carried out. This introduces a severe radiological hazard since, of necessity, it results in external contamination of the apparatus with consequent risk of ingestion in subsequent operations. The use of the high-boiling electron-donating solvent (used in the breakdown of the APC complex) to dissolve the complex from the pressure reactor reduced, but did not eliminate, this hazard.

Fortunately, it was discovered that the formation of the APC complex at atmospheric pressure proceeds very smoothly at the temperature of refluxing phosphorus trichloride,

and yields are very good provided that loss of the trichloride by the purging action of the methyl chloride passing through the reaction mixture is prevented, and that the reactants are vigorously agitated. The 1:1:1 molar complex can not be made satisfactorily by this method due to the high melting point of this complex, and accordingly an excess of aluminum chloride is used to give a mixture of the 1:1:1 and 2:1:1 aluminum chloride:phosphorus trichloride:methyl chloride complexes, which remain sufficiently fluid for adequate mixing at a temperature of 70°–75° C until absorption of methyl chloride is complete.

Preparation of Methylphosphonic Dichloride

The successful preparation of alkylphosphonic dichlorides was first reported by Kinnear *et al.* (4) and by Clay (5). Their method involved the hydrolysis of a refrigerated solution of the complex in methylene chloride by means of water according to the following reaction:

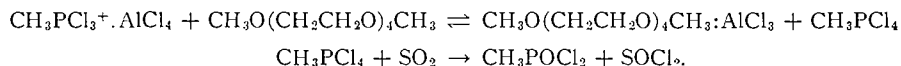


The temperature limits for the hydrolysis (–20° C to –30° C) are critical, and it is essential to filter off immediately the precipitate of the non-anhydrate from this very cold mixture on completion of the reaction. In the laboratory, the high cooling rate could be maintained only by the continuous addition of dry ice. Constant supervision was also required to determine the end point of the hydrolysis.

The breakdown of the complex by this method would prove to be a most difficult and radiologically dangerous part of the synthesis.

An investigation of the breakdown process was made, therefore, and resulted in a novel method, which eliminated almost entirely the excessive hazards intrinsic in the old water hydrolysis reaction scheme. The details of this process, which is completely anhydrous in its function, are reported elsewhere (1). For clarity, however, the following brief account is made.

It was found initially that a high-boiling polyether, dimethoxytetraglycol, not only exhibits excellent solvent properties but also, by complexing with the aluminum chloride itself, frees the phosphorus-containing moiety of the APC complex. The methylphosphonic tetrachloride so liberated reacts smoothly with sulphur dioxide to give thionyl chloride and methylphosphonic dichloride.



The original discovery of the role of dimethoxytetraglycol has been extended to diethyl phthalate, a more stable electron donor.

The methylphosphonic dichloride is readily recovered in excellent yields (80–85% of pure redistilled product) by vacuum distillation.

It can be seen, by comparison with the original aqueous procedure, that the new method has eliminated most of the hazardous procedures; all contaminated residues are left in the flask, no filtration is required, no refrigeration is required, no contaminated volatile gases are evolved, and observation and control are easily effected from a distance.

Preparation of Radioactive Sarin

The two-stage synthesis (reactions 3 and 4) of sarin from methylphosphonic dichloride is relatively simple to carry out and gives good yields of very pure product. The main disadvantage is the radiological hazard which results from the numerous handling

procedures involved in preparing the equimolar di-di (methylphosphonic dichloride and methylphosphonic difluoride) mixture required for the esterification stage.

The mechanism of the di-di reaction (6) clearly indicated that it should be possible to produce sarin from methylphosphonic dichloride by direct esterification and fluorination in one stage provided that the half esterification of the dichloride is carried out in the presence of free hydrofluoric acid. The reaction was investigated using non-radioactive dichloride and was found to proceed smoothly in methylene chloride as a diluent using reaction conditions very similar to those employed in the normal di-di reaction. Distillation of the product from diethylaniline removes last traces of free acid, and the trace amount that codistills with the pure sarin stabilizes the final product. Yields of pure sarin obtained by this method are virtually the same as those by the normal di-di reaction, viz. 82–87%.

The synthesis of sarin by this one-stage process from the dichloride has the following advantages:

(a) The elimination of one stage decreases the time of synthesis and the radiological exposure of the operators.

(b) The handling procedures required in making the equimolar di-di mixture are eliminated.

(c) The over-all yield of sarin from dichloride is increased since the fluorination stage, which gave a 90–92% yield of difluoride, is eliminated as are small losses which were inevitable in making up the accurate equimolar di-di mixture.

The purity of the sarin prepared by the one-stage process, like that of the normal di-di reaction, is better than 99% (7) with careful fractionation.

ACKNOWLEDGMENTS

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