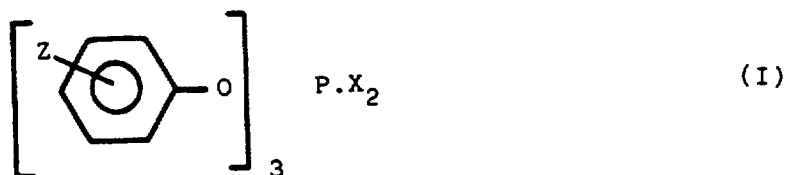


Description

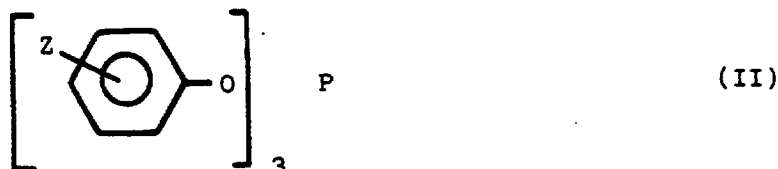
An intensive research effort in the field of cephalosporin antibiotics has produced a number of clinically significant cephalosporin compounds. One of the more recent developments in this area has been the discovery of cephem compounds directly substituted with halogen at the C-3 position. A number of 3-halo-3-cephems have been described by Chauvette in U.S. Patent Nos. 3,925,372, 4,064,343 and 3,962,227. These potent antibiotic compounds are prepared by halogenation of the corresponding 3-hydroxy-3-cephems. The halogenation of 3-hydroxy-3-cephems to provide 3-chloro and 3-bromo-3-cephems has typically been carried out by reacting the 3-hydroxy-3-cephem compounds with brominating or chlorinating agents including phosgene, oxalyl chloride, thionyl chloride, thionyl bromide and phosphorus halides such as phosphorus trichloride and phosphorus tribromide, usually in the presence of dimethylformamide.

This invention is directed to a novel class of halogenating agents which are useful in preparing 3-halo-3-cephems and in a wider context.

More particularly this invention covers the use of a compound of the general formula



which is the kinetically controlled product of the reaction of equivalent amounts of a triaryl phosphite of the formula

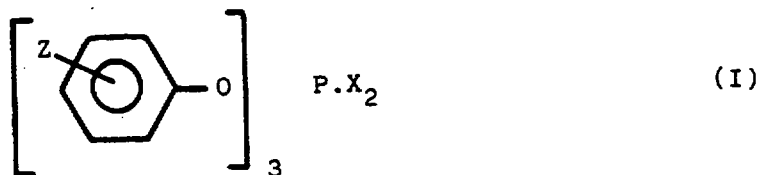


and chlorine or bromine in a substantially anhydrous inert organic solvent where in the above formulas Z is hydrogen, halo, $\text{C}_1\text{--C}_4$ alkyl or $\text{C}_1\text{--C}_4$ alkoxy and X is Cl or Br, as an agent for halogenating an enol or amido group.

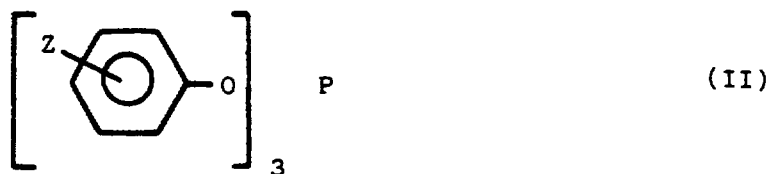
A number of halogenating agents derived from halogens and phosphorus or phosphorus containing compounds have been described. Known chlorinating and brominating compounds of this type include phosphorus trichloride, phosphorus tribromide, phosphoryl chloride, phosphoryl bromide, phosphorus pentachloride, phosphorus pentabromide, triphenyl phosphite dichloride, triphenyl phosphite dibromide, triphenylphosphine dichloride, triphenylphosphine dibromide, catechyl phosphorus tribromide.

Of those prior art compounds, those most closely related to the present compounds are the triphenyl phosphite dihalides which have an empirical formula identical to that of the present compounds. See, for example, D. G. Coe, S. R. Landauer, and H. N. Rydon, *J. Chem. Soc.*, 2021 (1954), H. N. Rydon and B. L. Tonge, *J. Chem. Soc.*, 3043—3056 (1956), Anschütz, *Annalen der Chemie* 353, 112—113 (1889) and Autenrieth, *Berichte der deutschen chemischen Gesellschaft*, 41, 155—157 (1908). The present triaryl phosphite-halogen compounds are derived generally from the reaction of a triaryl phosphite and chlorine or bromine. Physical and chemical data has unequivocally demonstrated the existence of two discrete molecular forms: a kinetic form, described herein and a thermodynamically stable form. The halogenating compounds of the present invention have been shown to exhibit marked differences in both physical characteristics and in chemical reactivity when compared with the thermodynamically stable triaryl phosphite dihalides. Most significantly the triaryl phosphite-halogen compounds of the present invention have been found to be far superior as halogenating agents. They can be employed advantageously in the preparation of known 3-halo-3-cephem antibiotic compounds and, more generally, for halogenating an eno or amido group.

The invention also comprises halogenating compounds having the general formula



which are the kinetically controlled products of the reaction of equivalent amounts of a triaryl phosphite of the formula



and chlorine or bromine in a substantially anhydrous inert organic solvent wherein the above formulas Z is hydrogen, halo, C₁—C₄ alkyl or C₁—C₄ alkoxy, and x is Cl or Br; provided that when X₂ is Cl₂, Z is not hydrogen, m-CH₃ or p-CH₃, and when X₂ is Br₂, Z is not hydrogen.

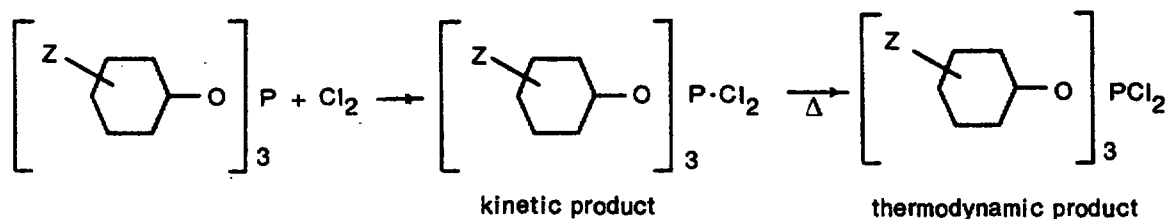
The term "halo" in the definition of Z includes chloro, bromo or iodo. "C₁—C₄ Alkyl" includes methyl, ethyl, isopropyl, n-propyl, n-butyl, sec-butyl, tert-butyl and isobutyl. Representative "C₁—C₄ alkoxy" groups are methoxy, ethoxy, isopropoxy, t-butoxy, n-butoxy.

The dot (●) in the general formula of the present compounds is used simply to designate that equivalent amounts of halogen and phosphite reagent are combined chemically and in a way that can be distinguished from that in the prior art compounds which typically have been drawn without the dot [e.g. $(\text{PhO})_3\text{PCl}_2$]. The exact molecular form of the triaryl phosphite-halogen kinetic complexes described herein has not been established definitively; however physical-chemical data do indicate that the kinetic product is one wherein the phosphorus center acquires some cationic character. Herein the terms "kinetic compound", "kinetic complex", "triaryl phosphite-halogen complex (compound)", "kinetically controlled halogenating compound", and "kinetically controlled product (compound)" are used synonymously and likewise are to be distinguished from thermodynamically stable triaryl phosphite dihalides.

The term kinetically controlled product is a term of art which, when used in reference to reactions yielding two (or more) products, refers to the product formed faster, regardless of its thermodynamic stability. If such a reaction is stopped well before the products achieve thermodynamic equilibrium, the reaction is said to be kinetically controlled since more of the faster-formed product will be present. In some cases, depending on the rate of formation of the kinetic product and the rate of thermodynamic equilibrium, the kinetically controlled product of a chemical reaction can be prepared and utilized before any significant amount of the product isomerizes to the thermodynamically stable product. It has been discovered that such is the case with the reaction of selected triaryl phosphites and chlorine or bromine in inert organic solvents. Thus, certain triaryl phosphites have been found to react with chlorine or bromine to provide a kinetically controlled product which although thermodynamically unstable, can be generated and utilized advantageously in subsequent reactions. To maximize the production and stability of the kinetically controlled product, reaction conditions are selected so as to minimize the potential for thermodynamic equilibrium of the initial product of the reaction. Most simply conditions for kinetic control are achieved both by lowering the reaction temperature and the temperature of the kinetic product after it is formed, and by minimizing the time allowed for thermodynamic equilibrium, such as by utilizing the kinetic product in a subsequent reaction immediately after it has been prepared.

If a compound of the present invention, prepared from the kinetically controlled reaction of a triaryl phosphite and chlorine or bromine in a substantially anhydrous inert organic solvent, is allowed to stand in solution, it converts to the corresponding thermodynamically stable prior art form at varying rates depending on, among other things, the nature of the triaryl phosphite, the halogen, the solvent and the solution temperature. Thus the reaction of a selected triaryl phosphite and chlorine, for example, in an inert organic solvent can, under selected conditions, be depicted as follows:

Reaction Sequence 1



Experimental data has also shown that the presence of an acid (HX) or an excess of triaryl phosphite will enhance the rate of conversion of the kinetic to the thermodynamic product.

Using ^{31}P nuclear magnetic resonance spectroscopy the half-life of the kinetically controlled product from the reaction of triphenyl phosphite and chlorine in methylene chloride at room temperature was determined to be about 8 hours. A half-life of about 39 hours was observed for the triphenyl phosphite-

bromide kinetic complex under the same conditions. As mentioned above the observed half-life (rate of conversion) for any given kinetic complex described herein can be affected by the solvent and by the presence of a hydrogen halide acid (HX) or excess triaryl phosphite. Thus for example, a shorter half life will be observed where the solvent for the preparation of kinetic complex has not been rigorously dried; the hydrogen halide acid produced from reaction of the kinetic complex with the moisture present in the solvent will enhance the rate of conversion to the stable form. Table I presents a summary of several properties of the kinetically controlled product and the thermodynamically controlled product of the reaction of triphenyl phosphite and chlorine.

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TABLE I
(See Reaction Sequence I Above)

Kinetic product	Thermodynamic product
1. ^{31}P nmr (CH_2Cl_2) -3.7 ppm*	1. ^{31}P nmr (CH_2Cl_2) $+22.7$ ppm*
2. $t_{1/2} \approx 8$ hours at room temperature in methylene chloride	2. Stable at room temperature
3. ir (CH_2Cl_2) 1120—1190 (vs), 1070 (vs), 1035 (s), 1010 (vs), 990 (vs), 640 (m), 625 (m), 580 (w), 510 (s), 465 (w). **	3. ir (CH_2Cl_2) 1130—1210 (vs), 1065 (vs), 1035 (s), 1010 (vs), 980 (vs), 625 (vw), 590 (m), 505 (s) 460 (s). **
4. Hydrolyzes to give HCl and $(\text{PhO})_3\text{PO}$	4. Hydrolyzes to give <i>inter alia</i> HCl, PhOH (phenol) and $(\text{PhO})_2\text{PCl}$
5. Reacts with n-BuOH to give HCl, n-BuCl and PhO_3P	5. Reacts with n-BuOH to give HCl, PhOH (phenol), n-BuCl and $(\text{PhO})_3\text{PO}$, POCl_3 wherein a,b,c, = 0, 1, 2 or 3 and $a + b + c = 3$

*Relative to ^{31}P of H_3PO_4 ; (+) indicates upfield shift; (—) indicates downfield shift.

**vs = very strong; s = strong; m = medium; w = weak.

The ^{31}P nmr signal for the thermodynamically controlled product was identical to that for the triphenyl phosphite dichloride prepared in accordance with the procedures described in the prior art references referred to hereinabove. (2)

Table II summarizes the ^{31}P nmr data for several triaryl phosphite dihalides.

TABLE II

Compound	^{31}P nmr-kinetic* (ppm)	half life	^{31}P nmr thermodynamic (ppm)
triphenyl phosphite-chlorine complex	-3.7	~8 hours	22.7
tri(4-methoxyphenyl) phosphite-chlorine complex	-2.2	>40 hours	—
tri(4-chlorophenyl) phosphite-chlorine complex	-6.8	<1 hour	23.5
triphenyl phosphite-bromine complex	-3.7	39 hours	22.4

*Relative to ^{31}P of H_3PO_4 in CH_2Cl_2

In order to potentiate the formation of the kinetically controlled product the reactants are combined in a substantially anhydrous inert organic solvent at a temperature below about 30°C . Although the present kinetically controlled products are formed at higher temperatures, such conditions favor more the formation of thermodynamically controlled products. Preferably the halogenating compounds of the present invention are prepared at temperatures at or below about 0° . Minimum reaction temperatures are, of course, determined by the freezing point of the solvent employed for the preparation. Most preferred reaction temperatures are in the range of about -70 to about 0°C .

To minimize opportunity for equilibration to the less reactive thermodynamic product, the halogenating reagents of the present invention are preferably prepared immediately before they are utilized. Typically the halogenating agent is prepared in the solvent selected for the subsequent halogenation process; the substrate is then simply added to the mixture after the triaryl phosphite-halogen complex of the present invention has been formed.

Thus the invention also comprises a halogenation process which comprises (a) preparing a kinetically controlled product of formula (I), as defined in claim 1, by reacting a triaryl phosphite of formula (II), as defined in claim 1, and chlorine or bromine in a substantially anhydrous inert organic solvent at a temperature of -70°C to 0°C , and (b) immediately utilizing the solution of kinetically controlled product to halogenate a substrate having an enol or amido group, at a temperature within the said temperature range.

It has been found that the triaryl phosphite itself reacts to some extent with its kinetic reaction product with chlorine or bromine effectively increasing the rate of conversion to the corresponding thermodynamic product. It is preferred, therefore, but not required, that an excess of halogen be maintained in the reaction mixture during the formation of the present halogenating compounds. This can be achieved practically by adding the triaryl phosphite to a solution of an equivalent amount of the halogen or by adding the halogen and the triaryl phosphite simultaneously to a quantity of an inert organic solvent at the desired temperature. The co-addition of reagents is conducted at such a rate that the color of the halogen persists in the reaction mixture until the last drop of triaryl phosphite discharges the color. Alternatively, excess halogen can be discharged using known halogen scavengers such as acetylenes, or olefins including alkenes, dienes, cycloalkenes, or bicycloalkenes. A preferred scavenger is a C_2 to C_6 alkene, for example, ethylene, propylene, butylene or amylene.

Attempts to isolate the present halogenating agents simply by evaporation *in vacuo* of reaction solvent provides a colorless solid which, after being redissolved in CH_2Cl_2 , is shown by ^{31}P nmr to be a mixture of the kinetically and thermodynamically controlled products and the corresponding triaryl phosphate; the product hydrolyzes to the triaryl phosphate spontaneously when exposed to air in the laboratory.

The kinetically controlled products of the present invention can be stabilized in solution by the addition of about 10 to about 100 mole percent of a tertiary amine base having a pK_b value of about 6 to about 10. If, for example, 50 mole percent of pyridine is added to a solution of the kinetically controlled product of the reaction of triphenyl phosphite and chlorine in methylene chloride, only trace amounts of the thermodynamic equilibrium product can be detected by ^{31}P nmr, even after prolonged periods at room temperature. The tertiary amine base can be added to a solution of the freshly prepared chlorinating compound or optionally it can be employed in the reaction mixture of the triaryl phosphite and halogen to produce a stabilized solution of the kinetically controlled product of the present invention. Of course,

(14)

employing such means for stabilizing the present kinetic products allows for the use of higher temperatures for the preparation and storage of the present products.

Suitable triaryl phosphites for the preparation of the present halogenating compound include triphenyl phosphite, tri(*p*-methoxyphenyl)phosphite, tri(*o*-chlorophenyl)phosphite, tri(*p*-chlorophenyl)phosphite, tri(*p*-tolyl)phosphite, tri(*o*-tolyl)phosphite, tri(*m*-bromophenyl)phosphite, tri(*p*-iodophenyl)phosphite, tri(*p*-*n*-propylphenyl)phosphite, tri(*p*-*t*-butylphenyl)phosphite, tri(*m*-tolyl)phosphite, tri(*p*-isopropoxyphenyl)phosphite and the like. Triphenyl phosphite is preferred primarily because it is commercially available.

Any of a wide variety of inert organic solvents may be employed as the medium for the preparation of the halogenating compounds of the present invention. By "inert organic solvent" is meant an organic solvent which, under the reaction conditions of the preparation and processes of the present invention, does not enter into any appreciable reaction with either the reactants or the products. Since the present halogenating compounds are susceptible to reaction with protic compounds such compounds, including water, alcohols, amines, thiols, organic acids and other such protic compounds should be excluded from the reaction medium.

A substantially anhydrous aprotic organic solvent is preferred. The term "substantially anhydrous", as used in the present description, means that although anhydrous organic solvents are generally preferred, trace amounts of water, such as that often found in commercially available solvents, can be tolerated. Although the kinetic products described herein will react with any water present in the solvent medium, additional amounts of reagents can easily be added to compensate for the loss. It is preferred that conventional laboratory techniques be employed to dry the solvents employed and to exclude moisture from the reaction mixtures.

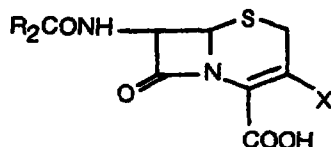
Suitable solvents include hydrocarbons, both aliphatic and aromatic, including pentane, hexane, heptane, octane, cyclohexane, cyclopentane, benzene, toluene, *o*-, *m*- or *p*-xylene, mesitylene and the like; ethers, cyclic and acyclic such as diethyl ether, butyl ethyl ether, tetrahydrofuran, dioxane, 1,2-dimethoxyethane and the like; carboxylic acid esters such as ethyl acetate, methylformate, methyl acetate, amyl acetate, *n*-butyl acetate, *sec*-butyl acetate, methyl propionate, methyl butyrate and the like; nitriles such as acetonitrile, propionitrile, butyronitrile and the like; halogenated hydrocarbons, both aromatic and aliphatic, such as chloroform, methylene chloride, carbon tetrachloride, 1,2-dichloroethane (ethylene dichloride), 1,1,2-trichloroethane, 1,1-dibromo-2-chloroethane, 2-chloropropane, 1-chlorobutane, chlorobenzene, fluorobenzene, *o*-, *m*-, or *p*-chlorotoluene, *o*-, *m*-, or *p*-bromotoluene, dichlorobenzene and the like; and nitro compounds such as nitromethane, nitroethane, 1- or 2-nitropropane, nitrobenzene and the like.

The particular inert organic solvent employed as a medium for the preparation of the present triaryl phosphite-chlorine complex or as a medium for its use in halogenation processes is not critical, however, such solvent properties as polarity (and therefore substrate solubility) and melting point, and the ease of isolation of the final products may be considered in selecting a most suitable solvent.

Preferred solvents for the preparation of the present compounds are hydrocarbons, especially aromatic hydrocarbons, and halogenated hydrocarbon solvents.

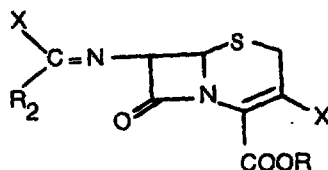
The triaryl phosphite-halogen complexes of the present invention are potent halogenating agents. Like the thermodynamically stable triaryl phosphite dihalide compounds, the present kinetic complexes react with aliphatic alcohols to provide the corresponding alkyl halides (with different by-products). Unlike the thermodynamically stable triaryl phosphite dichlorides, however, the present compounds *efficiently* halogenate under mild conditions both enolic groups to form the corresponding vinyl halides and, in the presence of base, amido functions to form the corresponding imino halides.

More particularly the present halogenating complexes can be used in preparing known 3-halo-cephem antibiotics of the formula



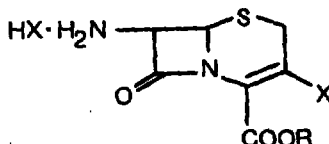
wherein X is chloro or bromo and R_2CO is an acyl group derived from a carboxylic acid, from the corresponding 3-hydroxy cephem compounds. The reaction is conducted in an inert organic solvent and is typically carried out at a temperature below about 30°C, preferably at or below 0°C, using about a 10 percent molar excess of both a halogenating compound of the present invention and a tertiary amine base, preferably pyridine. To prevent undesirable side reactions, the C-4 carboxylic acid function of the 3-hydroxy cephem starting materials is protected with one of the conventional carboxylic acid protecting groups. The course of the halogenation can be followed by thin-layer chromatography. The product 3-halocephem compounds can be isolated and purified using conventional laboratory techniques including chromatography, crystallization and recrystallization, filtration and trituration. Removal of the C-4 carboxylic acid protecting group and protecting groups, if any, on the C-7 acylamino group provides biologically active 3-halocephem compounds.

Alternatively, 7-acylamino-3-hydroxy-3-cephems react with about 2 equivalents of a halogenating compound of the present invention in an inert organic solvent in the presence of a tertiary amine base to provide the corresponding 3-halo-3-cephem imino halides of the formula



VI

wherein X, R and R₂ are as defined above. The imino halides when treated with a 3—10 fold excess of an alcohol or diol provides 7-amino-3-halo-3-cephem compounds of the formula



VII

which can be acylated and subsequently deesterified by conventional procedures to provide known 3-halo-3-cephem compounds.

It should be noted that the imino halides of other cephalosporins and penicillins can be prepared from the corresponding 7(or 6)-acylamino derivatives using the present halogenating compounds in the presence of base.

The following examples are provided to further illustrate the preparation and use of the kinetically controlled products. It is not intended that this invention be limited in scope by reason of any of these examples.

Example 1

Triphenyl phosphite-bromine kinetic complex.

To a solution of 1.6 gm of bromine in 30 ml of methylene chloride was added a solution of 3.1 gm of triphenyl phosphite in 5 ml of methylene chloride. After warming the product solution to room temperature, it was studied by ³¹P nuclear magnetic resonance (nmr). The ³¹P nmr spectrum initially indicated 1 major component having a signal at -3.7 ppm relative to the phosphoric acid ³¹P resonance signal. This signal decreased in intensity with time as a signal at 22.4 ppm increase in intensity. From the ³¹P nmr data the half-life for the initial product was determined to be about 39 hours.

Example 2

Triphenyl phosphite-chlorine kinetic complex

Chlorine was added to a solution of 20.0 gm of triphenyl phosphite in 100 ml of methylene chloride at -15 to -20°C until a faint chlorine color persisted in the mixture. After warming the product solution to room temperature it was studied by ³¹P nmr. The ³¹P nmr spectrum of the product solution initially indicated 1 component having a signal at -3.7 ppm relative to the phosphoric acid ³¹P nmr resonance signal. That signal decreased in intensity with time as a new signal at 22.7 ppm increased in intensity. From the ³¹P nmr data, the half-life for the initial product was determined to be about 8 hours.

Example 3

4-Nitrobenzyl 7-phenylacetamido-3-chloro-3-cephem-4-carboxylate.

Chlorine was bubbled through a solution of 2.89 ml (11 mmole) of triphenyl phosphite in 50 ml of methylene chloride at -15°C until the yellow color indicative of excess chlorine persisted. The color was then discharged by the addition of 2 drops of triphenyl phosphite. To the resulting solution of the triphenyl phosphite-chlorine reagent was added 4.54 gm (10 mmol) of 4'-nitrobenzyl 7-phenylacetamido-3-hydroxy-3-cephem-4-carboxylate and, dropwise over a 40 minute period, a solution of 0.89 ml (11 mmol) of pyridine in 8 ml of methylene chloride. During the pyridine solution addition the temperature of the reaction mixture was maintained at -15 to -10°C. The reaction mixture was then stirred at -15 to -10°C for an additional 60 minutes after which time the reaction mixture was removed from the cooling bath. Then 1 ml of conc. HCl was added to the mixture to effect hydrolysis of the small amount of imino chloride which had been formed. After stirring the reaction mixture for 30 minutes at room temperature, the mixture was diluted with 100 ml of 3A ethanol, stirred 15 minutes, and then filtered to provide 2.67 grams (54.7%) of the title product as white crystals: m.p. 214°C (decomp.). A second crop of the title product was obtained by concentrating the filtrate under a reduced pressure to a volume of about 50 ml. An additional 1.52 grams (31.1%) of the title product was isolated. Total yield — 85.8%.

nmr (DMSO d-6) δ 3.62 (s, 2), 3.94 (ABq, 2, $J=18\text{Hz}$), 5.3 (d, 1, $J=5\text{Hz}$), 5.52 (s, 2), 5.82 (q, 1, $J=5$ and 8Hz) and 7.2—8.4 (ArH).

Anal calcd for $\text{C}_{22}\text{H}_{18}\text{N}_3\text{O}_6\text{SCl}$: C, 54.16; H, 3.72; N, 8.61; Cl, 7.27; S, 6.57.
Found: C, 53.91; H, 3.92; N, 8.44; Cl, 7.27; S, 6.55.

Example 4

4'-Nitrobenzyl 7-phenoxyacetamido-3-chloro-3-cephem-4-carboxylate.

Following the procedure of Example 3 the triphenyl phosphite-chlorine reagent was prepared from 6.31 ml of triphenylphosphite and chlorine in 45 ml of methylene chloride at -15°C . To this solution at -15 to -10°C 5.24 gm (10 mmol) of 4'-nitrobenzyl 7-phenoxyacetamido-3-hydroxy-3-cephem-4-carboxylate was added and washed into the reaction mixture with 5 ml of methylene chloride. Then 1.01 ml (12.5 mmol) of pyridine in 8 ml of methylene chloride was added dropwise to the solution over a 30 minute period. After stirring the reaction mixture for 2 hours at -10°C 1 ml of conc. HCl was added. After stirring an additional 30 minutes the reaction mixture was washed with three 100 ml- portions of water, dried over magnesium sulfate, and evaporated *in vacuo* to an oil which was subsequently crystallized from 100 ml of 2B ethanol to provide 4.19 gm (83.2%) of the title product: m.p. $142.5^\circ\text{—}146^\circ\text{C}$.

nmr (CDCl_3) δ 3.7 (ABq, 2, $J=18\text{Hz}$), 4.60 (s, 2), 5.12 (d, 1, $J=5\text{Hz}$), 5.4 (s, 2), 5.93 (q, 1, $J=5$ and 9Hz), and 6.8—8.4 (ArH).

Anal calcd for $\text{C}_{22}\text{H}_{18}\text{N}_3\text{O}_7\text{SCl}$: C, 52.44; H, 3.60; N, 8.34; S, 6.36; Cl, 7.04.
Found: C, 52.67; H, 3.73; N, 8.12; S, 6.15; Cl, 6.95.

Example 5

4'-Nitrobenzyl 7-phenoxyacetamido-3-chloro-3-cephem-4-carboxylate using tri-o-tolyl phosphite dichloride

Chlorine gas was bubbled into a solution of 3.91 gm (10 mmol) of tri-o-tolyl phosphite in 45 ml of methylene chloride at -10°C until a yellow color persisted. The color was discharged by the addition of approximately 0.5 mmol of the phosphite. To the resulting solution at -10°C was added 5.4 gm (10 mmol) of 4'-nitrobenzyl 7-phenoxyacetamido-3-hydroxy-3-cephem-4-carboxylate which was washed into the solution with 5 ml of methylene chloride. Then 1.01 ml (12.5 mmol) of pyridine were added. After allowing the reaction mixture to stir for 90 minutes at -10° 1 ml of conc. HCl was added to the reaction mixture. After stirring for an additional 30 minutes the reaction mixture was washed successively with two 25 ml portions of water and 25 ml of dilute sodium chloride solution, dried over sodium sulfate, and evaporated *in vacuo* to an oil which crystallized from 50 ml of 2B ethanol to provide 3.35 gm (66.5%) of the title product. An nmr spectrum of the product was identical to that of the product obtained in Example 4.

Example 6

4'-Nitrobenzyl 7-phenoxyacetamido-3-bromo-3-cephem-4-carboxylate. Triphenyl phosphite-bromine complex.

To a solution of 2.30 ml (4.5 mmol) of bromine in 90 ml of methylene chloride at -70°C was added 12.22 ml (46.6 mmol) of triphenyl phosphite to discharge the bromine color. To this solution was added 10.6 gm (20 mmol) of 4'-nitrobenzyl 7-phenoxyacetamido 3-hydroxy-3-cephem-4-carboxylate which was washed into the reaction mixture with 10 ml of methylene chloride. The mixture was warmed to -35 to -30°C , and a solution of 3.64 ml (45 mmol) of pyridine in 16 ml of methylene chloride was added dropwise over 35 minutes. After 4 hours 50 ml of ice-water was added to the reaction mixture. The resulting solution was stirred for $\frac{1}{2}$ hour. Three layers were noted. The methylene chloride layer, the middle layer, was washed with 50 ml of water and brine and then dried with anhydrous Na_2SO_4 . The solvent was evaporated *in vacuo* to a weight of 29.7 grams. The addition of 150 ml of methanol induced crystallization of the titled product (3.78 g): m.p. $138\text{—}139^\circ\text{C}$.

nmr (DMSO d-6) δ 4.0 (ABq, $\text{C}_2\text{—H}$), 4.65 (s, 2, side chain CH_2), 5.28 (d, 1, $J=5\text{Hz}$), 5.47 (s, 2, ester CH_2), 5.8 (q, 1, $J=5\text{Hz}$ and 8Hz) and 6.9 8.4 (ArH).

Example 7

4'-Nitrobenzyl 7-amino-3-methyl-3-cephem-4-carboxylate, hydrochloride.

(A) From 4'-Nitrobenzyl 7-phenoxyacetamido-3-methyl-3-cephem-4-carboxylate.

A solution of the triphenyl phosphite-chlorine reagent was prepared by bubbling chlorine through a solution of 2.89 ml (11 mmol) of triphenyl phosphite in 50 ml of methylene chloride at -15°C . To this solution was added 5.02 gm (10 mmol) of 4'-nitrobenzyl 7-phenoxyacetamido-3-methyl-3-cephem-4-carboxylate and 0.85 ml (11.5 mmol) of pyridine. The reaction mixture was stirred for 1 hour at -15 to -10°C after which time was added 6.0 ml (64.8 mmole) of isobutanol. The cooling bath was removed, and the reaction mixture was allowed to warm to room temperature over a 2 hour period. The titled nucleus hydrochloride ester, which began to crystallize in about 15 minutes, was filtered, washed with methylene chloride, and dried. A total of 3.55 grams (92%) of the titled product was obtained as white crystals: m.p. 189°C (decomp.).

(B) From 4'-Nitrobenzyl 7-heptanoylamido-3-methyl-3-cephem-4-carboxylate.

The experimental procedure described in Paragraph A above was repeated in detail using 4.61 gm (10

mmol) of 4'-nitrobenzyl 7-heptanoylamido-3-methyl-3-cephem-4-carboxylate as the substrate. A total of 6.32 gm (93.8%) of the nucleus ester hydrochloride as snow white crystals was isolated: m.p. 188.5°C (decomp.).

(C) From 4'-Nitrobenzyl 7-phenoxyacetamido-3-methyl-3-cephem-4-carboxylate in tetrahydrofuran.
A solution of the triphenyl phosphite-chlorine reagent was prepared by bubbling chlorine into a solution of 11 mmol of triphenyl phosphite in tetrahydrofuran (THF) at -10°C. To the solution was added 4.84 gm (10 mmol) of 4'-nitrobenzyl 7-phenoxyacetamido-3-methyl-3-cephem-4-carboxylate. Subsequently 0.95 ml (11 mmol) of pyridine was added to the reaction mixture. The reaction was then allowed to stir at -10°C for 1 hour after which time it was allowed to warm to room temperature and stir for another 2 hours. Then 6.0 ml (65 mmol) of isobutanol was added. After 2 hours the reaction mixture was filtered. The crystalline nucleus hydrochloride ester thereby obtained was washed with THF and dried affording 3.03 gm (78.5%): m.p. 151—153°C (decomp.).

(D) From 4'-Nitrobenzyl 7-phenoxyacetamido-3-methyl-3-cephem-4-carboxylate in acetonitrile.
A solution of the triphenyl phosphite-chlorine reagent was prepared by bubbling chlorine into a solution of about 11 mmol of triphenyl phosphite in 45 ml of acetonitrile at -10°C. To this solution were added 4.84 gm (10 mmol) of 4'-nitrobenzyl 7-phenoxyacetamido-3-methyl-3-cephem-4-carboxylate and subsequently 0.95 ml (11 mmol) of pyridine at -10°C. After the reaction mixture was allowed to stir for 2 hours at -10°C the ice bath was removed. After an additional 2 hours, 6.0 ml (65 mmol) of isobutanol was added to the reaction mixture. With seeding the product crystallized, and after stirring for 1 hour, it was filtered, washed with acetonitrile, and dried. Total yield 2.55 gm (66.1%): m.p. 184°C (decomp.).

(E) From 4'-Nitrobenzyl 7-phenoxyacetamido-3-methyl-3-cephem-4-carboxylate in ethyl acetate.
The same procedure was followed as described in Paragraph D above except that ethyl acetate was used as a solvent for the triphenyl phosphite-chlorine kinetic product formation and for the cleavage process. Total yield 2.48 grams (64.2%): m.p. 177—179°C (decomp.).

(F) From 4'-Nitrobenzyl 7-phenoxyacetamido-3-methyl-3-cephem-4-carboxylate using tri-o-tolyl phosphite-chlorine.

A solution of tri-o-tolyl phosphite-chlorine reagent was prepared as follows: 3.91 gm (11 mmol) of tri-o-tolyl phosphite was added to 45 ml of methylene chloride and cooled to -10°C under a nitrogen atmosphere. Chlorine gas was bubbled into the solution until the yellow color persisted. Then about 0.5 mmol of tri-o-tolyl phosphite was added to discharge the yellow color. To the solution was added 4.84 gm (10 mmol) of 4'-nitrobenzyl 7-phenoxyacetamido-3-methyl-3-cephem-4-carboxylate and 1.01 ml (12.5 mmol) of pyridine. The reaction mixture was removed from the cooling bath and stirred for 90 minutes after which time 5.1 ml (55 mmol) of isobutanol was added. The product began to crystallize about 5 minutes after gaseous HCl was bubbled into the reaction mixture. After 90 minutes the reaction mixture was filtered. The product was washed with 25 ml of methylene chloride and dried at reduced pressure. Total yield — 3.46 grams (89.6%): m.p. 184°C (decomp.).

(G) From 4'-nitrobenzyl 7-phenoxyacetamido-3-methyl-3-cephem-4-carboxylate using tri(p-methoxyphenyl)phosphite-chlorine complex.

A solution of tri(p-methoxyphenyl)phosphite-chlorine complex was prepared as follows: A solution of 4.6 grams (11.5 mmol) of tri(p-methoxyphenyl)phosphite in about 5 ml of methylene chloride was added dropwise to 45 ml of methylene chloride at -10 to -20°C with simultaneous addition of chlorine to a colorless end-point. After the addition of all of the phosphite reagent, additional chlorine was added to give a faint yellow color; the color of excess chlorine rapidly dissipated without adding more phosphite. To the resulting solution was added 4.84 gm (10 mmol) of 4'-nitrobenzyl 7-phenoxyacetamido-3-methyl-3-cephem-4-carboxylate which was washed into the reaction mixture with 5 ml of methylene chloride. Subsequently a solution of 1.01 ml of pyridine (12.5 mmol) in 4 ml of methylene chloride was added dropwise to the reaction mixture over a 15 minute period. After stirring the reaction mixture for 15 minutes at -10°, 5.1 ml of isobutanol (55 mmol) was added to the reaction mixture. HCl gas was bubbled into the reaction mixture, and shortly thereafter the cooling bath was removed. After 2 hours at room temperature the reaction mixture was filtered to provide 0.89 grams (23%) of the nucleus hydrochloride ester: m.p. 173—174°C.

Example 3

2',2',2'-Trichloroethyl 7-amino-3-methyl-3-cephem-4-carboxylate, hydrochloride, in benzene.

(A) Chlorine gas and 3.16 ml (12 mmol) of triphenylphosphite were added simultaneously to 45 ml of benzene at 10 to 15°C. A slight yellow color was maintained in the reaction mixture until the last drop of phosphite added cleared the solution. To this solution was added 4.64 gm (10 mmol) of 2',2',2'-trichloroethyl 7-phenylacetamido-3-methyl-3-cephem-4-carboxylate. After stirring the reaction mixture for 5 minutes at 10 to 15°C a solution of 1.1 ml (12.5 mmol) of pyridine in 8 ml of benzene was added over 15 minutes. After stirring the reaction mixture for a total of 45 minutes, 5.1 ml (55 mmol) of isobutanol were added and HCl was bubbled into the reaction mixture for about 90 seconds. The titled product crystallized while the reaction mixture was stirred at room temperature for a period of 2 hours. Filtration provided 3.5 gm (91.6%) of titled nucleus ester hydrochloride: m.p. 179°C (decomp.).

nmr (DMSO d-6) δ 2.27 (s, 3), 3.6 (ABq, 2 J=16Hz), 5.00 (s, 2), and 5.12 (q, 2, J=4Hz, β -lactam H).
(B) The same procedure was followed as described in Example 8 Paragraph A immediately

hereinabove except that all preparations were conducted at room temperature (20—25°C) instead of 10—15°C. A total 3.26 gm (85.4%) of the titled nucleus ester hydrochloride was isolated: m.p. -179°C (decomp.).

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Example 9

4'-Nitrobenzyl 7-amino-3-methyl-3-cephem-4-carboxylate hydrochloride using tri(p-chlorophenyl)phosphite-chlorine kinetic complex.

To 5.17 g (12.5 mmol) of tri(p-chlorophenyl)phosphite and 0.27 ml (3.28 mmol) of pyridine in 25 ml of methylene chloride at -70°C was added chlorine gas. Amylene (0.40 ml) was added to discharge excess chlorine. To the resulting solution were added 4'-nitrobenzyl 7-phenoxyacetamido-3-methyl-3-cephem-4-carboxylate (2.42 gm, 5 mmol) and pyridine (0.79 ml, 9.22 mmol) in 4 ml of methylene chloride dropwise over 11 minutes. After 3 hours the cooling bath was removed and 6.94 ml of isobutanol was added. After the reaction mixture had warmed to about -10°C, HCl gas was bubbled into the mixture for about 1 minute. After 15 minutes the reaction mixture was filtered to give 1.86 gm (96%) of the titled product as a white solid, m.p. 184—185°C (decomp.).

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Example 10

4'-Nitrobenzyl 7-amino-3-chloro-3-cephem-4-carboxylate hydrochloride using tri(p-chlorophenyl)phosphite-chlorine kinetic complex.

To 10.34 gm of tri(p-chlorophenyl)phosphite and 0.53 ml (6.5 mmol) of pyridine in 50 ml of methylene chloride at -70° was added chlorine in 15 ml of methylene chloride. Amylene (0.52 ml) was added to discharge excess chlorine. To the resulting solution of the tri(p-chlorophenyl)phosphite-chlorine complex was added 4'-nitrobenzyl 7-phenoxyacetamido-3-hydroxy-3-cephem-4-carboxylate (5.28 gm) using 10 ml of methylene chloride to wash the substrate into the reaction mixture. Then 1.57 ml (19.5 mmol) of pyridine in 9 ml of methylene chloride was added dropwise over 33 minutes. After 2 hours the reaction mixture was allowed to warm to 2°C. Isobutanol (6.94 ml) was added, and HCl gas was bubbled through the mixture for 2 minutes. The mixture was evaporated in vacuo to a syrup to which was added 50 ml of ethyl acetate. The gum was triturated with about 100 ml of methanol. A white solid, tri(p-chlorophenyl)phosphate, was filtered. The filtrate was evaporated *in vacuo* to dryness. To the residue was added 15 ml of 1:1-toluene/ethyl acetate and just enough methanol to dissolve the gummy residue. Upon standing for about 5 minutes, 0.97 gm of the titled product crystallized as a white solid. m.p. 184—186°C (decomp.).

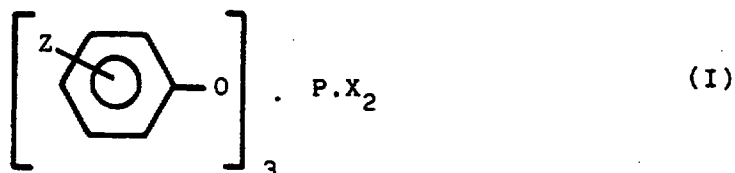
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Claims

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1. The use of a compound of the general formula

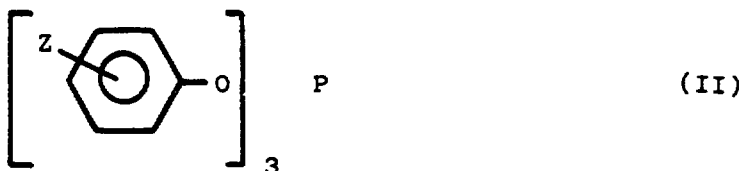
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which is the kinetically controlled product of the reaction of equivalent amounts of a triaryl phosphite of the formula

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and chlorine or bromine in a substantially anhydrous inert organic solvent where in the above formulas Z is hydrogen, halo, C₁—C₄ alkyl or C₁—C₄ alkoxy and X is Cl or Br, as an agent for halogenating an enol or amido group.

60

2. The use of a compound of formula (I) as defined in claim 1 in which Z is hydrogen, methyl or methoxy, as an agent for halogenating an enol or amido group.

3. The use of a compound of formula (I) as defined in claim 1 in which Z is hydrogen and X is Cl, as an agent for halogenating an enol or amido group.

4. The use of a compound of formula (I) as defined in claim 1 in which Z is hydrogen and X is Br, as an agent for halogenating an enol or amido group.

65

5. A halogenating compound of the general formula

hereinabove except that all preparations were conducted at room temperature (20—25°C) instead of 10—15°C. A total 3.26 gm (85.4%) of the titled nucleus ester hydrochloride was isolated: m.p. -179°C (decomp.).

5

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15

Example 10

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To 10.34 gm of tri(p-chlorophenyl)phosphite and 0.53 ml (6.5 mmol) of pyridine in 50 ml of methylene chloride at -70° was added chlorine in 15 ml of methylene chloride. Amylene (0.52 ml) was added to discharge excess chlorine. To the resulting solution of the tri(p-chlorophenyl)phosphite-chlorine complex was added 4'-nitrobenzyl 7-phenoxyacetamido-3-hydroxy-3-cephem-4-carboxylate (5.28 gm) using 10 ml of methylene chloride to wash the substrate into the reaction mixture. Then 1.57 ml (19.5 mmol) of pyridine in 9 ml of methylene chloride was added dropwise over 33 minutes. After 2 hours the reaction mixture was allowed to warm to 2°C. Isobutanol (6.94 ml) was added, and HCl gas was bubbled through the mixture for 2 minutes. The mixture was evaporated in vacuo to a syrup to which was added 50 ml of ethyl acetate. The gum was triturated with about 100 ml of methanol. A white solid, tri(p-chlorophenyl)phosphate, was filtered. The filtrate was evaporated *in vacuo* to dryness. To the residue was added 15 ml of 1:1-toluene/ethyl acetate and just enough methanol to dissolve the gummy residue. Upon standing for about 5 minutes, 0.97 gm of the titled product crystallized as a white solid. m.p. 184—186°C (decomp.).

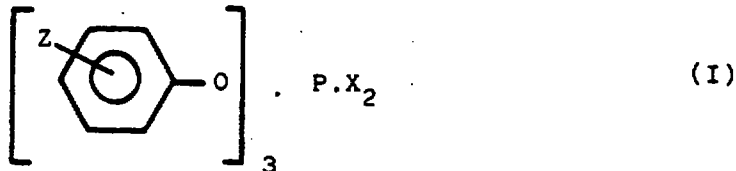
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Claims

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1. The use of a compound of the general formula

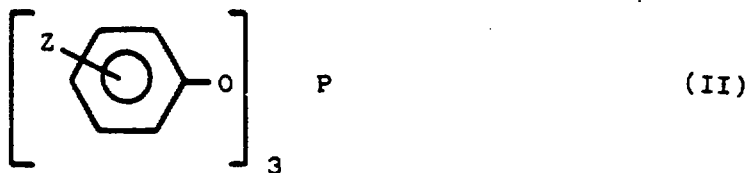
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which is the kinetically controlled product of the reaction of equivalent amounts of a triaryl phosphite of the formula

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and chlorine or bromine in a substantially anhydrous inert organic solvent where in the above formulas Z is hydrogen, halo, C₁—C₄ alkyl or C₁—C₄ alkoxy and X is Cl or Br, as an agent for halogenating an enol or amido group.

60

2. The use of a compound of formula (I) as defined in claim 1 in which Z is hydrogen, methyl or methoxy, as an agent for halogenating an enol or amido group.

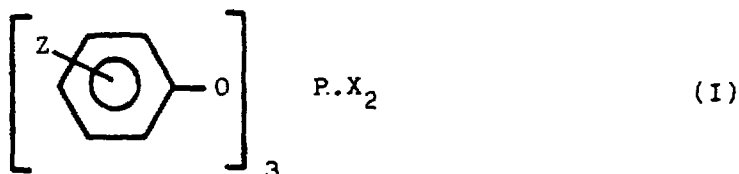
3. The use of a compound of formula (I) as defined in claim 1 in which Z is hydrogen and X is Cl, as an agent for halogenating an enol or amido group.

4. The use of a compound of formula (I) as defined in claim 1 in which Z is hydrogen and X is Br, as an agent for halogenating an enol or amido group.

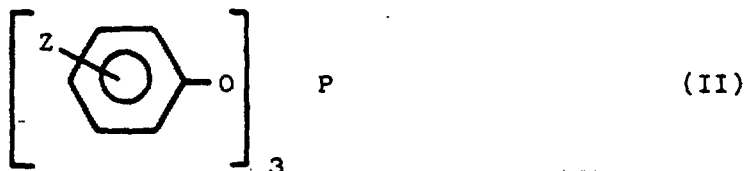
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5. A halogenating compound of the general formula





which is the kinetically controlled product of the reaction of equivalent amounts of a triaryl phosphite of the formula



20 and chlorine or bromine in a substantially anhydrous inert solvent where in the above formulas Z is hydrogen, halo, $\text{C}_1\text{--C}_4$ alkyl or $\text{C}_1\text{--C}_4$ alkoxy, and X is Cl or Br; provided that when X_2 is Cl_2 , Z is not hydrogen, $m\text{-CH}_3$ or $p\text{-CH}_3$, and when X_2 is Br_2 , Z is not hydrogen.

25 6. A halogenation process which comprises (a) preparing a kinetically controlled product of formula (I), as defined in claim 1, by reacting a triaryl phosphite of formula (II), as defined in claim 1, and chlorine or bromine in a substantially anhydrous inert organic solvent at a temperature of -70°C to 0°C , and (b) immediately utilising the solution of kinetically controlled product to halogenate a substrate having an enol or amido group, at a temperature within the said temperature range.

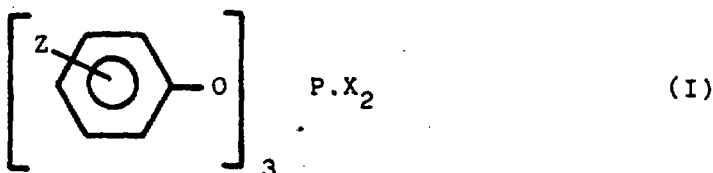
7. A process according to claim 6 in which the substrate is a 7-acylamino cephalosporin.

8. A process according to claim 6 in which the substrate is a 6-acylamino penicillin.

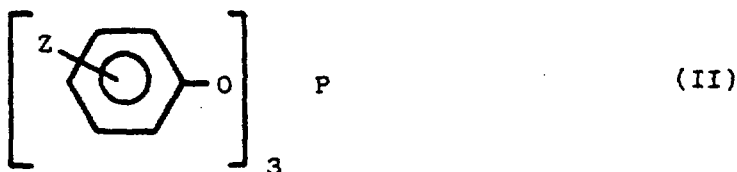
30 9. A process according to claim 6 in which the substrate is a 3-hydroxy-3-cephem.

Patentansprüche

35 1. Verwendung einer Verbindung der allgemeinen Formel



45 welche das kinetisch gesteuerte Produkt der Reaktion äquivalenter Mengen von einem Triarylphosphit der Formel



55 und von Chlor oder Brom in einem praktisch wasserfreien inerten organischen Lösungsmittel ist, worin in obigen Formeln Z Wasserstoff, Halogen, $\text{C}_1\text{--bis C}_4\text{-Alkyl}$ oder $\text{C}_1\text{--bis C}_4\text{-Alkoxy}$ ist und X für Cl oder Br steht, als Mittel zur Halogenierung einer Enolgruppe oder Amidogruppe.

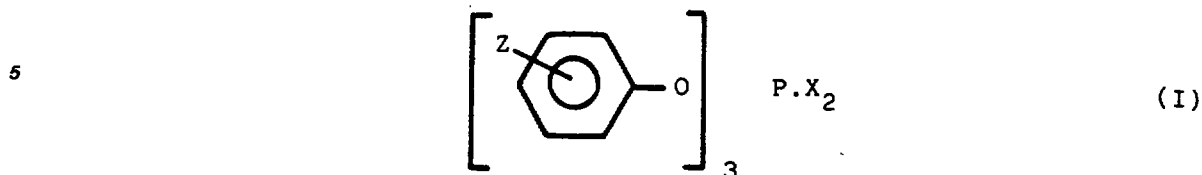
2. Verwendung einer Verbindung der Formel (I) gemäß Anspruch 1, dadurch gekennzeichnet, daß Z Wasserstoff, Methyl oder Methoxy ist, als Mittel zur Halogenierung einer Enolgruppe oder Amidogruppe.

3. Verwendung einer Verbindung der Formel (I) gemäß Anspruch 1, dadurch gekennzeichnet, daß Z Wasserstoff ist und X für Cl steht, als Mittel zur Halogenierung einer Enolgruppe oder Amidogruppe.

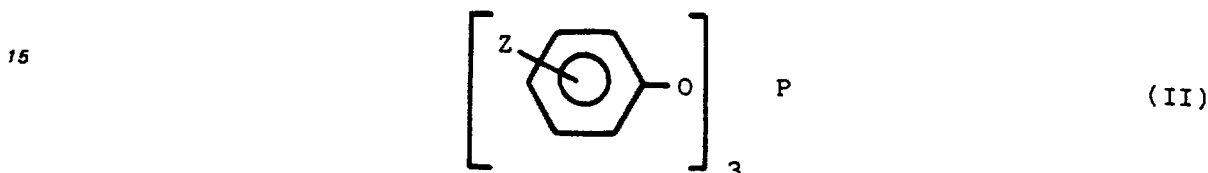
4. Verwendung einer Verbindung der Formel (I) gemäß Anspruch 1, dadurch gekennzeichnet, daß Z Wasserstoff ist und X für Br steht, als Mittel zur Halogenierung einer Enolgruppe oder Amidogruppe.



5. Halogenierungsmittel der allgemeinen Formel



10 dadurch gekennzeichnet, daß es sich hierbei um das kinetisch gesteuerte Produkt der Reaktion äquivalenter Mengen von einem Triarylphosphit der Formel



20 und von Chlor oder Brom in einem praktisch wasserfreien inerten organischen Lösungsmittel handelt, worin in obigen Formeln Z Wasserstoff, Halogen, C₁- bis C₄-Alkyl oder C₁- bis C₄-Alkoxy ist und X für Cl oder Br steht, mit der Maßgabe, daß Z nicht Wasserstoff, m-CH₃ oder p-CH₃ ist, falls X₂ für Cl₂ steht, und Z nicht Wasserstoff ist, falls X₂ für Br₂ steht.

25 6. Verfahren zur Halogenierung, dadurch gekennzeichnet, daß man (a) ein kinetisch gesteuertes Produkt der Formel (I) gemäß Anspruch 1 herstellt, indem man ein Triarylphosphit der Formel (II) gemäß Anspruch 1 und Chlor oder Brom in einem praktisch wasserfreien inerten organischen Lösungsmittel bei einer Temperatur von -70°C bis 0°C umsetzt, und (b) die erhaltene Lösung des kinetisch gesteuerten Produkts sofort zur Halogenierung eines Substrats, das eine Enolgruppe oder Amidogruppe aufweist, bei einer innerhalb dieses Temperaturbereichs liegenden Temperatur verwendet.

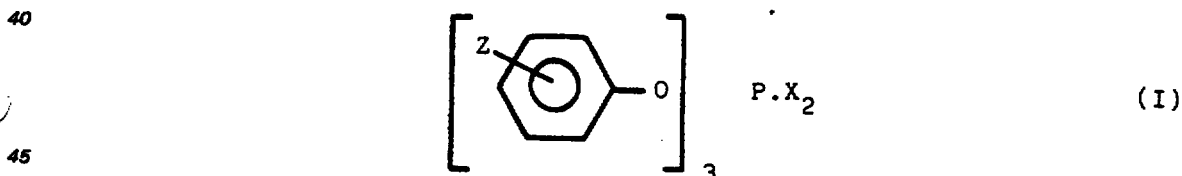
30 7. Verfahren nach Anspruch 6, dadurch gekennzeichnet, daß das Substrat ein 7-Acylaminocephalosporin ist.

8. Verfahren nach Anspruch 6, dadurch gekennzeichnet, daß das Substrat ein 6-Acylaminopenicillin ist.

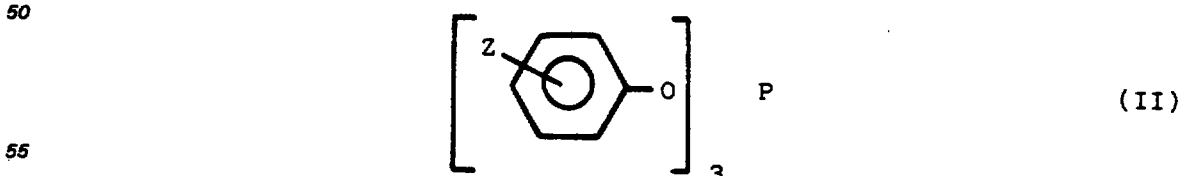
9. Verfahren nach Anspruch 6, dadurch gekennzeichnet, daß das Substrat ein 3-Hydroxy-3-cephem ist.

35 **Revendications**

1. Utilisation d'un composé de formule générale:



45 qui est le produit cinétiquement contrôlé de la réaction de quantités équivalentes d'un phosphite de triaryle de formule:



55 et de chlore ou de brome dans un solvant organique inerte pratiquement anhydre, formules dans lesquelles Z représente un atome d'hydrogène, un atome d'halogène, un groupe alkyle en C₁-C₄ ou un groupe alcoxy en C₁-C₄ et X représente Cl ou Br, comme agent pour l'halogénéation d'un groupe émol ou amido.

60 2. Utilisation d'un composé de formule (I) comme défini dans la revendication 1, dans laquelle Z représente l'atome d'hydrogène, le groupe méthyle ou le groupe méthoxy, comme agent pour l'halogénéation d'un groupe émol ou amido.

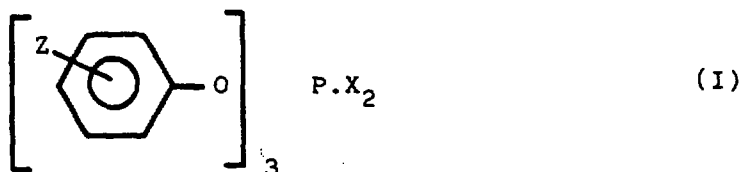
65 3. Utilisation d'un composé de formule (I) comme défini dans la revendication 1, dans laquelle Z



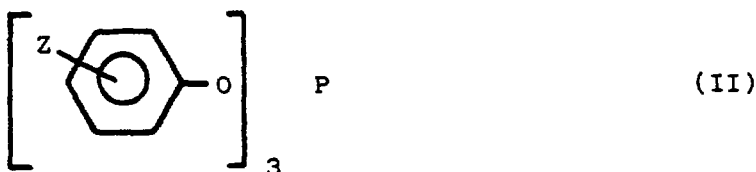
représente l'atome d'hydrogène et X représente Cl, comme agent pour l'halogénéation d'un groupe énoï ou amido.

4. Utilisation d'un composé de formule (I) comme défini dans la revendication 1, dans laquelle Z représente l'atome d'hydrogène et X représente Br, comme agent pour l'halogénéation d'un groupe énoï ou amido.

5. Composé d'halogénéation répondant à la formule générale:



qui est le produit cinétiquement contrôlé de la réaction de quantités équivalentes d'un phosphite de triaryle de formule:



et du chlore ou du brome dans un solvant organique inerte pratiquement anhydre, formules dans lesquelles Z représente un atome d'hydrogène, un atome d'halogène, un groupe alkyle en C_1-C_4 ou un groupe alcoxy en C_1-C_4 , et X représente Cl ou Br; avec cette réserve que, lorsque X_2 représente Cl_2 , Z n'est pas un atome d'hydrogène, m- CH_3 ou p- CH_3 et, lorsque X_2 est Br_2 , Z n'est pas un atome d'hydrogène.

6. Procédé d'halogénéation, caractérisé en ce qu'il comprend les étapes qui consistent à (a) préparer un produit cinétiquement contrôlé de formule (I) comme défini dans la revendication 1, en faisant réagir un phosphite de triaryle de formule (II) comme défini dans la revendication 1, ainsi que du chlore ou du brome dans un solvant organique inerte pratiquement anhydre à une température de -70°C à 0°C , et (b) utiliser immédiatement la solution du produit cinétiquement contrôlé pour halogéner un substrat comportant un groupe énoï ou amido, à une température se situant dans l'intervalle précité.

7. Procédé selon la revendication 6, caractérisé en ce que le substrat est une 7-acylamino-céphalosporine.

8. Procédé selon la revendication 6, caractérisé en ce que le substrat est une 6-acylaminopénicilline.

9. Procédé selon la revendication 6, caractérisé en ce que le substrat est une 3-hydroxy-3-céphém.

