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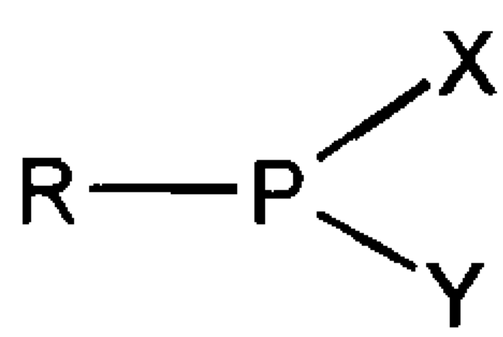
(54) Titre : PREPARATION IN SITU DE PHOSPHORAMIDITES DE NUCLEOSIDES ET LEUR UTILISATION POUR LA SYNTHESE D'OLIGONUCLEOTIDES

(54) Title: IN SITU PREPARATION OF NUCLEOSIDE PHOSPHORAMIDITES AND THEIR USE IN SYNTHESIS OF OLIGONUCLEOTIDES



(II)

(57) Abrégé/Abstract:
The invention provides novel bifunctional phosphitylating reagents and their application in in situ preparation of 5'-protected nucleoside phosphoramidites and synthesis of oligonucleotides. Bifunctional phosphitylating reagents according to the invention react quickly with nucleosides under weakly acidic conditions. In addition, the bifunctional phosphitylating reagents according to the invention generate chemoselectively the corresponding nucleoside phosphoramidites in situ, without need to purify the nucleoside phosphoramidites before using them in oligonucleotide synthesis. Finally, the bifunctional phosphitylating reagents according to the invention are relatively stable and easy to handle.

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(54) Title: *IN SITU* PREPARATION OF NUCLEOSIDE PHOSPHORAMIDITES AND THEIR USE IN SYNTHESIS OF OLIGONUCLEOTIDES

(57) Abstract

The invention provides novel bifunctional phosphitylating reagents and their application in *in situ* preparation of 5'-protected nucleoside phosphoramidites and synthesis of oligonucleotides. Bifunctional phosphitylating reagents according to the invention react quickly with nucleosides under weakly acidic conditions. In addition, the bifunctional phosphitylating reagents according to the invention generate chemoselectively the corresponding nucleoside phosphoramidites *in situ*, without need to purify the nucleoside phosphoramidites before using them in oligonucleotide synthesis. Finally, the bifunctional phosphitylating reagents according to the invention are relatively stable and easy to handle.

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IN SITU PREPARATION OF NUCLEOSIDE PHOSPHORAMIDITES AND THEIR USE IN SYNTHESIS OF OLIGONUCLEOTIDES

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates to the chemical synthesis of oligonucleotides and to chemical entities useful in such synthesis.

Summary of the Related Art

Oligonucleotides have become indispensable tools in modern molecular biology, being used in a wide variety of techniques, ranging from diagnostic probing methods to PCR to antisense inhibition of gene expression. This widespread use of oligonucleotides has led to an increasing demand for rapid, inexpensive and efficient methods for synthesizing oligonucleotides.

The synthesis of oligonucleotides for antisense and diagnostic applications can now be routinely accomplished. See *e.g.*, Methods in Molecular Biology, Vol 20: Protocols for Oligonucleotides and Analogs pp. 165-189 (S. Agrawal, Ed., Humana Press, 1993); Oligonucleotides and Analogues: A Practical Approach, pp. 87-108 (F. Eckstein, Ed., 1991). Agrawal and Iyer, Curr. Op. in Biotech. 6: 12 (1995); and Antisense Research and Applications (Crooke and Lebleu, Eds., CRC Press, Boca Raton, 1993). Early synthetic approaches included phosphodiester and phosphotriester chemistries. Khorana et al., J. Molec. Biol. 72: 209 (1972) discloses phosphodiester chemistry for oligonucleotide synthesis. Reese, Tetrahedron Lett. 34: 3143-3179 (1978), discloses phosphotriester chemistry for synthesis of oligonucleotides and polynucleotides. These early approaches have largely given

way to the more efficient phosphoramidite and H-phosphonate approaches to synthesis. Of these, the phosphoramidite approach has become the most popular for most applications. Beaucage and Caruthers, Tetrahedron Lett. 22: 1859-1862 (1981), discloses the use of deoxynucleoside phosphoramidites in polynucleotide synthesis. The phosphoramidite approach has been used to synthesize oligonucleotides having a variety of modified internucleoside linkages. Agrawal and Goodchild, Tetrahedron Lett. 28: 3539-3542 (1987), teaches synthesis of oligonucleotide methylphosphonates using phosphoramidite chemistry. Connolly et al., Biochemistry 23: 3443 (1984), discloses synthesis of oligonucleotide phosphorothioates using phosphoramidite chemistry. Jager el al., Biochemistry 27: 7237 (1988), discloses synthesis of oligonucleotide phosphoramidates using phosphoramidite chemistry. Solid phase synthesis of oligonucleotides by the phosphoramidite approach can be varied for different applications, but ordinarily involves the same generalized protocol. Briefly, this approach comprises anchoring the 3'-most nucleoside to a solid support functionalized with amino and/or hydroxyl moieties and subsequently adding the additional nucleosides in stepwise fashion. Desired internucleoside linkages are formed between the 3' phosphoramidite group of the incoming nucleoside and the 5' hydroxyl group of the 5'-most nucleoside of the nascent, support-bound oligonucleotide.

Refinement of methodologies is still required, however, particularly when making a transition to large-scale synthesis (10umol to 1 mmol and higher). See Padmapriya et al., Antisense Res. Dev. 4: 185 (1994). Several modifications of the standard phosphoramidite methods have already been reported to facilitate the synthesis and isolation of oligonucleotides. See *e.g.*, Padmapriya et al., *supra*; Ravikumar et al., Tetrahedron 50: 9255 (1994); Theisen et al., Nucleosides & Nucleotides 12: 43 (1994); and

Iyer et al., Nucleosides & Nucleotides 14: 1349 (1995) (Kuijpers et al., Nucl. Acids Res. 18: 5197 (1990); and Reddy et al., Tetrahedron Lett. 35: 4311 (1994).

A major limiting factor for cost efficient synthesis of oligonucleotides is the time and cost required to make and purify the monomeric nucleoside phosphoramidites. Bodepudi *et al.*, Chem. Res. Toxicol. 5: 608-617, discloses that the preparation of phosphoramidites from 2'-deoxy-7,8-dihydro-8-oxoguanosine and 2'-deoxy-7,8-dihydro-8-oxoadenosine according to the standard procedure results in extensive decomposition of the phosphoramidites during purification due to their instability and sensitivity to water. One potential approach to overcome these problems is to generate the phosphoramidite *in situ* as the oligonucleotide synthesis process is being carried out. Unfortunately, the numerous attempts at this approach have been disappointing. Moore and Beaucage, J. Org. Chem. 50: 2019-2025 (1985) teaches *in situ* preparation of phosphoramidites by reacting deoxyribonucleosides with bis-(pyrrolidino)methoxyphosphine activated by 4,5-dichloroimidazole in 1-methyl-2-pyrrolidinone. However, this method was limited by poor chemoselectivity, with about 8-10% (3'-3')-dinucleoside methyl phosphite triester being formed as a by-product. Barone *et al.*, Nucleic Acids Res. 12: 4051-4061 (1984) and Lee and Moon, Chem. Lett. 1229-1232 (1984) disclose better chemoselectivity in preparation of phosphoramidites *in situ*, by reacting deoxyribonucleosides with bis-(N,N,-dialkylamino)alkoxyphosphines and 1H-tetrazole or its N,N-diisopropylammonium salt. Unfortunately, the tetrazole-N,N-diisopropylammonium salt, either added or generated *in situ* may form precipitates inside the synthesizer. Helinski *et al.*, Tetrahedron Lett. 32: 4981-4984 (1991) and 34: 6451 - 6454 (1993) disclose selective activation of bifunctional phosphitylating reagents containing a p-nitrophenoxy group. However, this methodology is not adaptable to current phosphoramidite approaches because the p-nitrophenoxy group

has to be activated by using a strong base. Finally, Fourrey *et al.*, Tetrahedron Lett. 22: 729-732 (1981) and Cao *et al.*, Tetrahedron Lett. 24: 1019-1020 (1983) disclose, as reactive bifunctional phosphitylating agents, phosphorodichlorite and the corresponding ditetrazolite and ditriazolite. Unfortunately, the application of these agents to the synthesis of oligonucleotides is generally problematic, because of their extremely high reactivity and poor chemoselectivity.

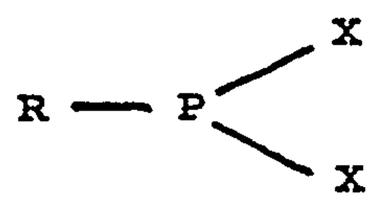
There have also been reports of using methylphosphordiamidites to produce nucleoside methylphosphonamidites for oligonucleotide synthesis. Engels *et al.*, Nucl. Acids Res. Symposium Series No. 24, pp. 83-86 (1991), discloses the use of methylphosphordiamidites to produce nucleoside methylphosphonamidite monomers for stereoselective synthesis of oligonucleoside methylphosphonates. However, the monomers were purified prior to their use in synthesis, rather than being prepared *in situ*, and sufficient chemoselectivity for the latter approach was not demonstrated.

There is, therefore, a need for new bifunctional phosphitylating reagents and their application in *in situ* preparation of 5'-protected nucleoside phosphoramidites and P-substituted phosphonamidites and subsequent synthesis of oligonucleotides without prior purification of the nucleoside phosphoramidites or P-substituted phosphonamidites. Ideally, such reagents should be selectively activated and react quickly with nucleosides, should generate chemoselectively the corresponding nucleoside phosphoramidites or P-substituted phosphonamidites *in situ*, and should be relatively stable and easy to handle.

BRIEF SUMMARY OF THE INVENTION

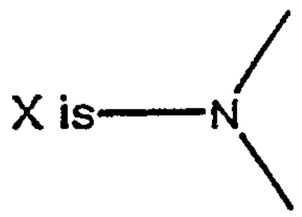
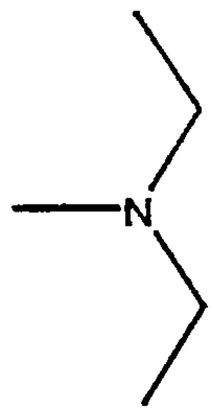
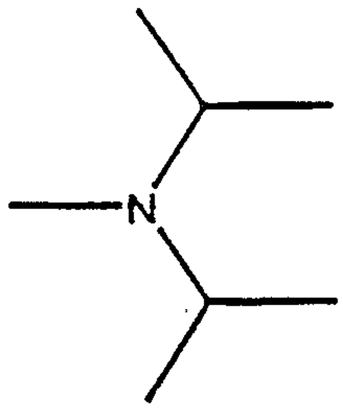
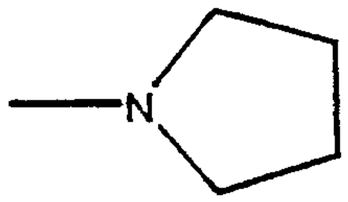
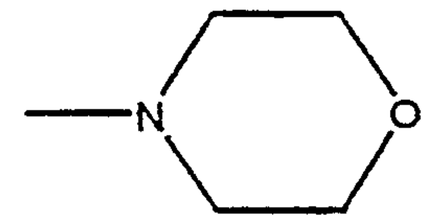
The invention provides novel bifunctional phosphitylating reagents and novel processes for *in situ* preparation of 5'-protected nucleoside phosphoramidites and P-substituted phosphonamidite monomers and synthesis of oligonucleotides. Bifunctional phosphitylating reagents according to the invention react quickly with nucleosides under weakly acidic conditions. In addition, the bifunctional phosphitylating reagents according to the invention generate chemoselectively the corresponding nucleoside phosphoramidite or P-substituted phosphonamidite monomers *in situ*, without the need to purify the nucleoside phosphoramidite or P-substituted phosphonamidite monomers before using them in oligonucleotide synthesis. Finally, the bifunctional phosphitylating reagents according to the invention are relatively stable and easy to handle.

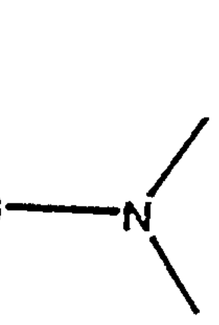
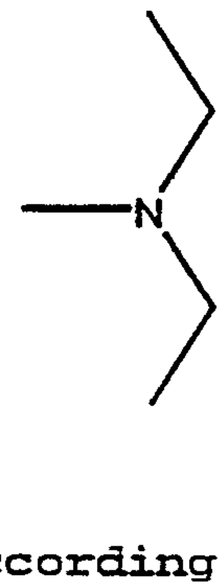
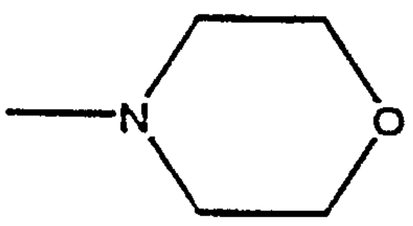
In a first aspect, the invention provides bifunctional phosphitylating reagents which are useful for *in situ* preparation of 5'-protected nucleoside alkyl, aryl, or aralkyl phosphonamidite monomers and synthesis of oligonucleotides. Bifunctional phosphitylating reagents according to this aspect of the invention have the general structure (**I**):



wherein R is an alkyl, aryl, or aralkyl group having from one to about 20 carbon atoms and being unsubstituted or up to fully substituted with halogen and or nitrogen

constituents, more preferably being a methyl group; and wherein

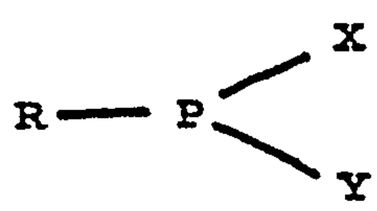
X is  ,  ,  ,  , or  ;

except that when R is methyl, X is  ,  , or  .

Bifunctional phosphitylating reagents according to this aspect of the invention react in the presence of a weak acid with 5'-protected nucleosides to chemoselectively produce 5'-protected nucleoside-3'-alkyl, aryl, or aralkyl phosphonamidite monomers.

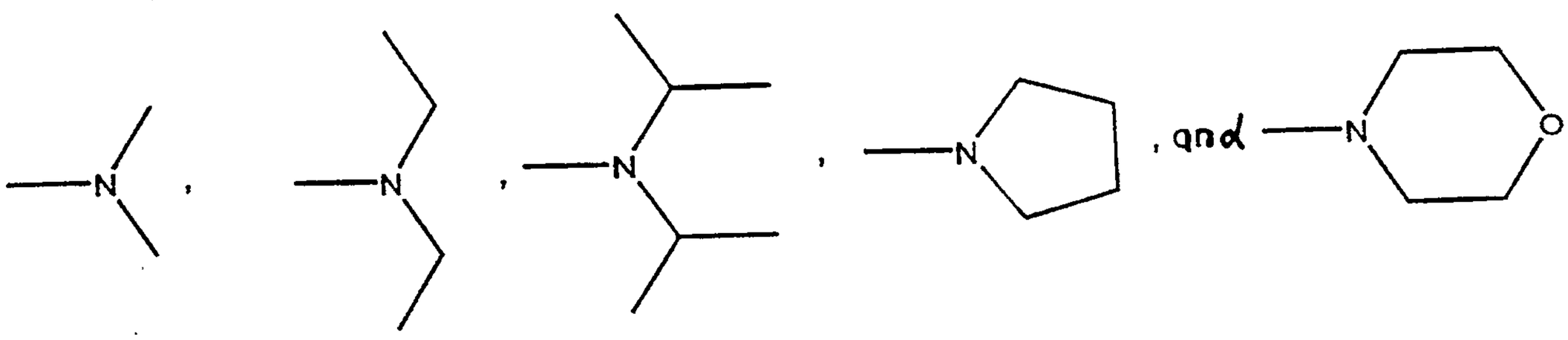
In a second aspect, the invention provides bifunctional phosphitylating reagents which are useful for *in situ* preparation of 5'-protected nucleoside phosphoramidite or P-substituted phosphonamidite monomers and synthesis of oligonucleotides. For purposes of the invention, a nucleoside P-substituted phosphonamidite is a nucleoside phosphonamidite in which a non-bridging oxygen atom of the corresponding phosphoramidite has been replaced with an organic substituting group. Preferred organic substituting groups have from one to about 20 carbon atoms and include alkyl, aryl, aralkyl, alkoxy, aroxy, aralkoxy, thioalkyl, thioaryl, or thioaralkyl groups, any of which may be unsubstituted or up to fully substituted with halogen and or nitrogen constituents. Particularly preferred organic substituting groups include CH_3O-, NCC_2H_4O-, CH_3-, NCC_2H_4S-,

or $PhCOSCH_2CH_2S$- groups, wherein Ph is phenyl or 2,4-dichlorophenyl. Bifunctional phosphitylating reagents according to this aspect of the invention have the general structure (II):



wherein R is an alkyl, aryl, aralkyl, alkoxy, aroxy, aralkoxy, thioalkyl, thioaryl, or thioaralkyl group having from one to about 20 carbon atoms and being unsubstituted or up to fully substituted with halogen and or nitrogen constituents, more preferably being CH_3O-, NCC_2H_4O-, CH_3-, NCC_2H_4S-, or $PhCOSCH_2CH_2S$-, wherein Ph is phenyl or 2,4-dichlorophenyl;

and wherein X and Y are different from each other and are independently selected from the group consisting of



Bifunctional phosphitylating reagents according to this aspect of the invention react in the presence of a weak acid with 5′-protected nucleosides to chemoselectively produce 5′-protected nucleoside phosphoramidite or P-substituted phosphonamidite monomers.

In a third aspect, the invention provides a process for generating 5'-protected nucleoside alkyl, aryl, or aralkyl phosphonamidite monomers without producing a precipitate and without requiring purification of the nucleoside P-substituted phosphonamidite monomers prior to their use in oligonucleotide synthesis, *i.e.*, having less than 3% contaminating nucleoside 3'-3' dimer. In the process according to this aspect of the invention, bifunctional phosphitylating reagents according to the first aspect of the invention are reacted with 5'-protected nucleosides in the presence of a weak acid to produce 5'-protected nucleoside alkyl, aryl, or aralkyl phosphonamidite monomers.

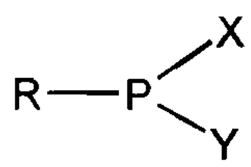
In a fourth aspect, the invention provides a process for generating 5'-protected nucleoside phosphoramidite or P-substituted phosphonamidite monomers without producing a precipitate and without requiring purification of the nucleoside phosphoramidite or P-substituted phosphonamidite monomers prior to their use in oligonucleotide synthesis. In the process according to this aspect of the invention, bifunctional phosphitylating reagents according to the second aspect of the invention are reacted with 5'-protected nucleosides in the presence of a weak acid to produce 5'-protected nucleoside phosphoramidite or P-substituted phosphonamidite monomers.

In a fifth aspect, the invention provides an improved process for synthesizing oligonucleotides. In the process according to this aspect of the invention, the improvement comprises the step of generating the nucleoside phosphoramidite or P-substituted phosphonamidite monomers *in situ*, rather than adding purified nucleoside phosphoramidite or P-substituted phosphonamidite monomers at the appropriate point in a conventional oligonucleotide synthesis procedure. The *in situ* generation preferably utilizes the

phosphitylating agents according to the first or second aspect of the invention.

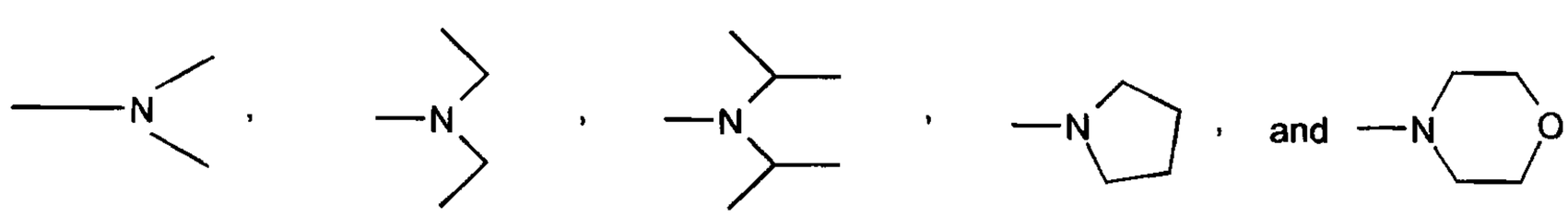
The reagents and processes according to the invention are useful for producing a wide variety of oligonucleotide or P-substituted oligonucleotide compounds, or radiolabeled oligonucleotide or P-substituted compounds, all of which are referred to herein generally as "oligonucleotides". The reagents and processes according to the invention can be used or practiced on a scale ranging from a small laboratory scale to a large commercial scale.

According to one aspect of the present invention, there is provided a bifunctional phosphitylating reagent having the general structure (II):



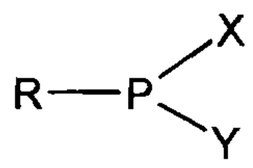
(II)

wherein R is an alkyl, aryl, aralkyl, alkoxy, aroxy, aralkoxy, thioalkyl, thioaryl, or thioaralkyl group having from one to 20 carbon atoms and being unsubstituted or up to fully substituted with halogen and/or nitrogen constituents; and wherein X and Y are different from each other and are selected from the group consisting of



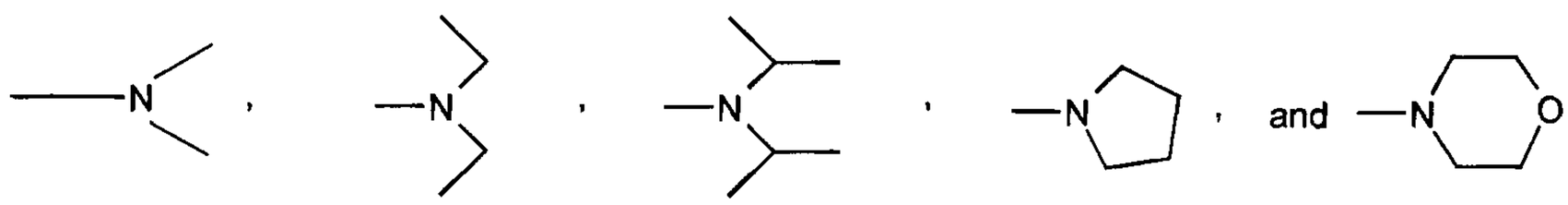
provided that when R is methoxy, X or Y is not diisopropylamino when the other is morpholino, and that when R is ethoxy, that X or Y is not diisopropylamino when the other is diethylamino.

According to another aspect of the present invention, there is provided a process for generating 5'-protected nucleoside phosphoramidites or P-substituted phosphonamidites, the process comprising reacting a bifunctional phosphitylating reagent having the general structure (II):



(II)

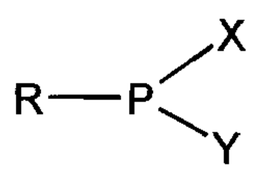
wherein R is an alkyl, aryl, aralkyl, alkoxy, aroxy, aralkoxy, thioalkyl, thioaryl, or thioaralkyl group having from one to 20 carbon atoms and being unsubstituted or up to fully substituted with halogen and/or nitrogen constituents; and wherein X and Y are different from each other and are selected from the group consisting of



provided that when R is methoxy, X or Y is not diisopropylamino when the other is morpholino and that when R is ethoxy, that X or Y is not diisopropylamino when the other is diethylamino; with a 5'-protected nucleoside in the presence of a weak acid to produce a 5'-protected nucleoside phosphoramidite or P-substituted phosphonamidite.

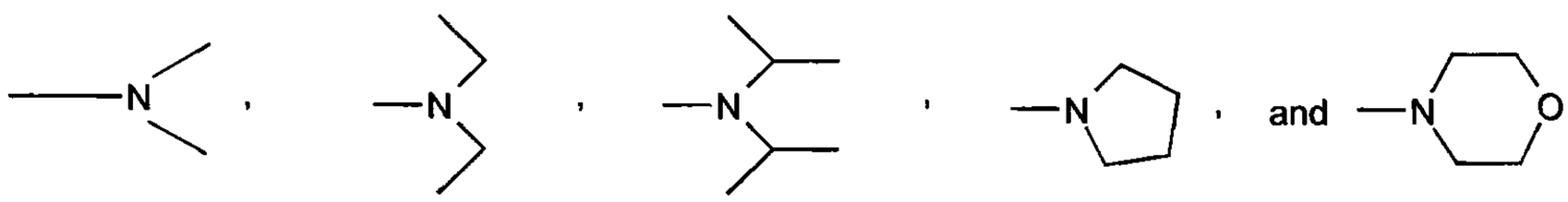
According to yet another aspect of the present invention, there is provided a process for synthesising an oligonucleoside containing one or more P-substituted internucleoside linkages which comprises generating a 5'-protected nucleoside phosphoramidite or nucleoside P-substituted phosphonamidite *in situ* by reacting a

bifunctional phosphitylating reagent having the general structure (II):



(II)

wherein R is an alkyl, aryl, aralkyl, alkoxy, aroxy, aralkoxy, thioalkyl, thioaryl, or thioaralkyl group having from one to 20 carbon atoms and being unsubstituted or up to fully substituted with halogen and/or nitrogen constituents; and wherein X and Y are different from each other and are selected from the group consisting of



with a 5'-protected nucleoside in the presence of a weak acid to produce a 5'-protected nucleoside phosphoramidite or 5'-protected nucleoside P-substituted phosphonamidite.

According to still another aspect of the present invention, there is provided a process for synthesising P-substituted oligonucleotides, comprising generating a 5'-protected nucleoside-P-substituted phosphonamidite *in situ* and coupling the P-substituted phosphonamidite of the 5'-protected nucleoside-P-substituted phosphonamidite with an unprotected 5' end of a nucleoside by a process as described herein, wherein R is an alkyl, aryl or aralkyl group having from one to 20 carbon atoms and being unsubstituted or up to fully substituted with halogen and/or nitrogen constituents.

According to a further aspect of the present invention, there is provided a process for synthesising P-substituted oligonucleotides, comprising generating a 5'-protected nucleoside-P-substituted phosphoramidite *in situ* and coupling the P-substituted phosphoramidite of the 5'-protected nucleoside-P-substituted phosphoramidite with an unprotected 5' end of a nucleoside by a process as described herein, wherein R is an alkoxy, aroxy, aralkoxy, thioalkyl, thioaryl, or thioaralkyl group having from one to 20 carbon atoms and being unsubstituted or up to fully substituted with halogen and/or nitrogen constituents.

According to yet a further aspect of the present invention, there is provided use of a bifunctional phosphitylating reagent as described herein for synthesis of an oligonucleotide.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows five particularly preferred embodiments of bifunctional phosphitylating reagents according to the first aspect of the invention.

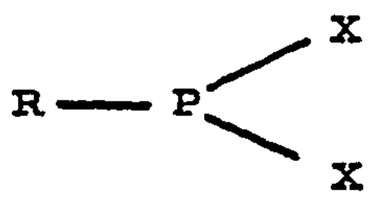
Figure 2 shows 13 particularly preferred embodiments of bifunctional phosphitylating reagents according to the second aspect of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

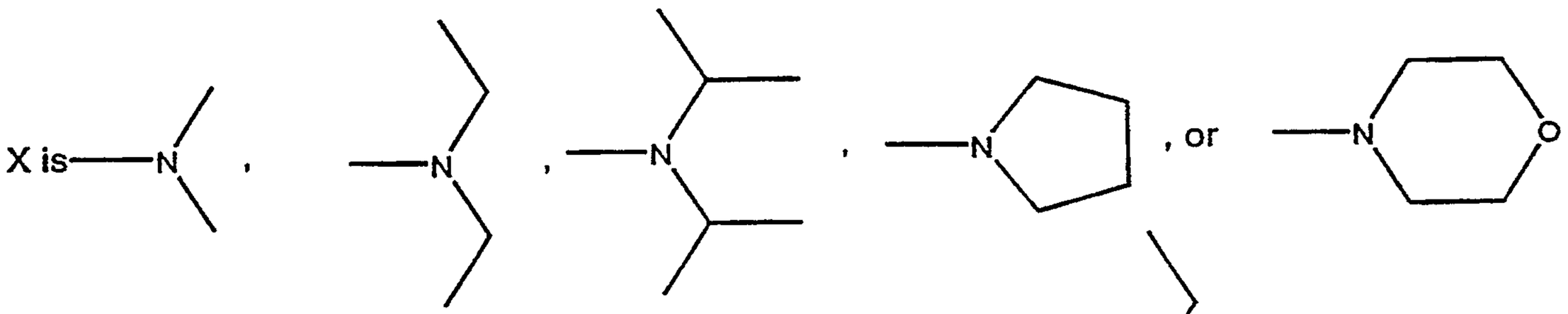
The invention relates to the chemical synthesis of oligonucleotides and to chemical entities useful in such synthesis.

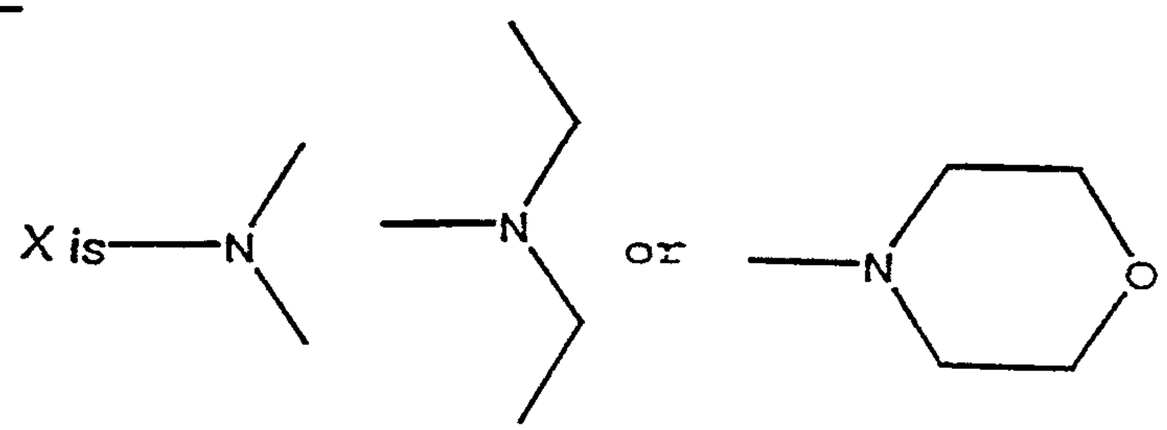
The invention provides novel bifunctional phosphitylating reagents and novel processes for *in situ* preparation of 5'-protected nucleoside phosphoramidite or P-substituted phosphonamidite monomers and synthesis of oligonucleotides. Bifunctional phosphitylating reagents according to the invention react quickly with nucleosides under weakly acidic conditions. In addition, the bifunctional phosphitylating reagents according to the invention generate chemoselectively the corresponding nucleoside P-substituted phosphonamidite monomers *in situ*, without the need to purify the nucleoside P-substituted phosphonamidite monomers before using them in oligonucleotide synthesis. Finally, the bifunctional phosphitylating reagents according to the invention are relatively stable and easy to handle.

In a first aspect, the invention provides bifunctional phosphitylating reagents which are useful for *in situ* preparation of 5'-protected nucleoside alkyl, aryl, or aralkyl phosphonamidite monomers and synthesis of oligonucleotides. Bifunctional phosphitylating reagents according to this aspect of the invention have the general structure (I):



wherein R is an alkyl, aryl, or aralkyl group having from one to about 20 carbon atoms and being unsubstituted or up to fully substituted with halogen and or nitrogen constituents, more preferably being a methyl group; and wherein

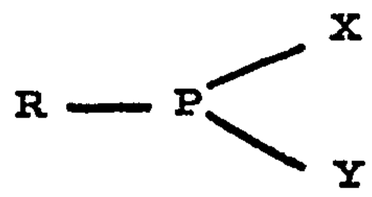


except that when R is methyl 

Bifunctional phosphitylating reagents according to this aspect of the invention can be synthesized using dichloromethylphosphine and the corresponding (dialkylamino)trimethylsilane or diisopropylamine. Bifunctional phosphitylating reagents according to this aspect of the invention react in the presence of a weak acid with 5'-protected nucleosides to chemoselectively produce 5'-protected nucleoside-3'-alkyl, aryl, or aralkyl phosphonamidite monomers. To avoid formation of a nucleoside 3'-3' dimer byproduct, the *in situ* activation using these reagents is preferably carried out using as a

weak acid 0.25-0.3 equivalents of tetrazole or 4,5-dichloroimidazole.

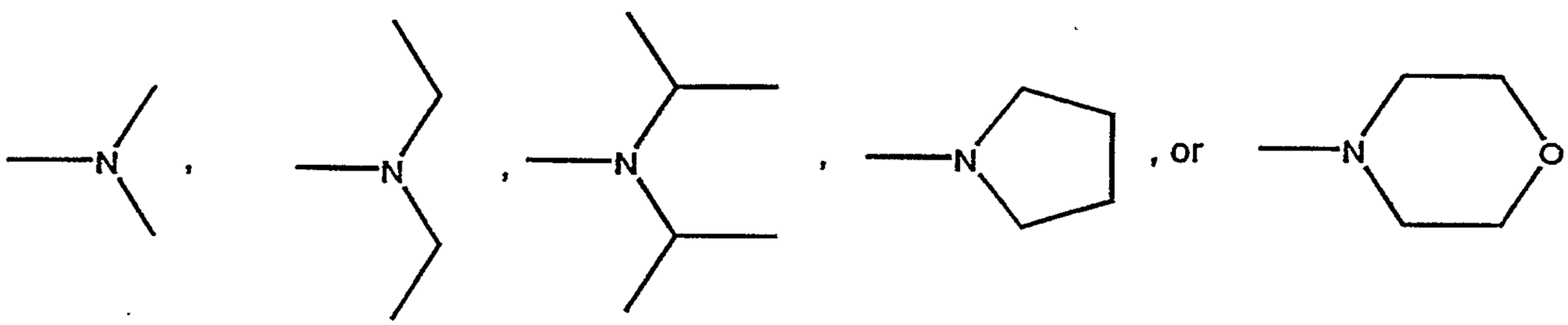
In a second aspect, the invention provides bifunctional phosphitylating reagents which are useful for *in situ* preparation of 5'-protected nucleoside phosphoramidite or P-substituted phosphonamidite monomers and synthesis of oligonucleotides. For purposes of the invention, a nucleoside P-substituted phosphonamidite is a nucleoside phosphonamidite in which a non-bridging oxygen atom of the corresponding phosphoramidite has been replaced with an organic substituting group. Preferred organic substituting groups have from one to about 20 carbon atoms and include alkyl, aryl, aralkyl, alkoxy, aroxy, aralkoxy, thioalkyl, thioaryl, or thioaralkyl groups, any of which may be unsubstituted or up to fully substituted with halogen and or nitrogen constituents. Particularly preferred organic substituting groups include CH_3O-, NCC_2H_4O-, CH_3-, NCC_2H_4S-, or $PhCOSCH_2CH_2S-$ groups, wherein Ph is phenyl or 2,4-dichlorophenyl. Bifunctional phosphitylating reagents according to this aspect of the invention have the general structure (**II**):



wherein R is an alkyl, aryl, aralkyl, alkoxy, aroxy, aralkoxy, thioalkyl, thioaryl, or thioaralkyl group having from one to about 20 carbon atoms and being unsubstituted or up to fully substituted with halogen and or nitrogen

constituents, more preferably being CH_3O-, NCC_2H_4O-, CH_3-, NCC_2H_4S-, or $PhCOSCH_2CH_2S$-, wherein Ph is phenyl or 2,4-dichlorophenyl;

and wherein X and Y are different from each other and are independently selected from the group consisting of



Bifunctional phosphitylating reagents according to this aspect of the invention can be synthesized as described in Examples 6-18, below, or by simple adaptation of these Examples. Bifunctional phosphitylating reagents according to this aspect of the invention react in the presence of a weak acid with 5'-protected nucleosides to chemoselectively produce 5'-protected nucleoside-P-substituted phosphonamidite monomers. To avoid formation of a nucleoside 3'-3' dimer byproduct, the *in situ* activation using these reagents is preferably carried out using as a weak acid 0.25-0.3 equivalents of tetrazole or 4,5-dichloroimidazole.

In a third aspect, the invention provides processes for generating 5'-protected nucleoside alkyl, aryl, or aralkyl phosphonamidites, without producing a precipitate and with sufficient chemoselectivity to eliminate the need for purification of the nucleoside alkyl, aryl, or aralkyl phosphonamidites so formed, *i.e.*, having less than 3% contaminating nucleoside 3'-3' dimer. In the process

according to this aspect of the invention, bifunctional phosphitylating reagents according to the first aspect of the invention are reacted with 5'-protected nucleosides in the presence of a weak acid to produce a 5'-protected nucleoside alkyl, aryl, or aralkyl phosphonamidite. Preferred 5'-protected nucleosides include adenosine, guanosine, cytosine, uridine, inosine and thymidine, as well as modified nucleosides (see *e.g.*, Sanghvi, in Antisense Research and Applications, pp. 273-288 (Crook and Lebleu, Eds.) CRC Press (1993) and the references cited therein). The 5' position of the nucleoside may be protected by any of the standard protecting groups (see *e.g.*, Sonveaux in Protocols for Oligonucleotide Conjugates, pp. 1-72 (S. Agrawal, Ed.), Humana Press (1994)) or with any protective group suitable for oligonucleotide synthesis. In certain preferred embodiments, the 5' position of the nucleoside is protected by a dimethoxytrityl (DMT) group.

The reaction between the bifunctional phosphitylation reagent and the 5'-protected nucleoside can be monitored by conventional ^{31}P NMR spectroscopy. The most preferred bifunctional phosphitylation reagents according to the invention will react to completion with the 5'-protected nucleoside within about 10 minutes.

In the process according to this aspect of the invention, to obtain chemoselectivity of the reaction for the desired 5'-protected nucleoside alkyl, aryl, or aralkyl phosphonamidite, the concentration and nature of the activator is controlled. Thus, the activation is preferably carried out using as a weak acid about 0.25-0.3 equivalents of tetrazole or 4,5-dichloroimidazole. In this context, "about" means approximately plus or minus 3%. These conditions lead to rapid synthesis of the desired 5'-protected nucleoside alkyl, aryl, or aralkyl phosphonamidite, with contamination by the nucleoside 3'-3' dimer at a level of only 3% or less.

In a fourth aspect, the invention provides processes for generating 5'-protected nucleoside phosphoramidites or P-substituted phosphonamidites, without producing a precipitate and with sufficient chemoselectivity to eliminate the need for purification of the nucleoside phosphoramidites or P-substituted phosphonamidites so formed. In the process according to this aspect of the invention, bifunctional phosphitylating reagents according to the second aspect of the invention are reacted with 5'-protected nucleosides in the presence of a weak acid to produce a 5'-protected nucleoside phosphoramidite or P-substituted phosphonamidite. Preferred 5'-protected nucleosides include adenosine, guanosine, cytosine, uridine, inosine and thymidine, as well as modified nucleosides (see *e.g.*, Sanghvi, in Antisense Research and Applications, pp. 273-288 (Crook and Lebleu, Eds.) CRC Press (1993) and the references cited therein). The 5' position of the nucleoside may be protected by any of the standard protecting groups (see *e.g.*, Sonveaux in Protocols for Oligonucleotide Conjugates, pp. 1-72 (S. Agrawal, Ed.), Humana Press (1994)) or with any protective group suitable for oligonucleotide synthesis. In certain preferred embodiments, the 5' position of the nucleoside is protected by a dimethoxytrityl (DMT) group.

The reaction between the bifunctional phosphitylation reagent and the 5'-protected nucleoside can be monitored by conventional ^{31}P NMR spectroscopy. The most preferred bifunctional phosphitylation reagents according to the invention will react to completion with the 5'-protected nucleoside within about 10 minutes.

In the process according to this aspect of the invention, to obtain chemoselectivity of the reaction for the desired 5'-protected nucleoside P-substituted phosphonamidite, the concentration and nature of the activator is controlled. Thus, the activation is preferably carried out using as a weak acid about 0.25-0.3 equivalents

of tetrazole or 4,5-dichloroimidazole. In this context, "about" means approximately plus or minus 3%. These conditions lead to rapid synthesis of the desired 5'-protected nucleoside P-substituted phosphonamidite, with contamination by the nucleoside 3'-3' dimer at a level of only 3% or less.

In a fifth aspect, the invention provides an improved process for synthesizing oligonucleotides. In the process according to this aspect of the invention, the improvement comprises the step of generating the nucleoside phosphoramidite or P-substituted phosphonamidite monomers *in situ*, rather than adding purified nucleoside phosphoramidite or P-substituted phosphonamidite monomers at the appropriate point in a conventional oligonucleotide synthesis procedure. The *in situ* generation preferably utilizes the phosphitylating agents according to the first or second aspect of the invention. Some of the oligonucleotides synthesized according to this aspect of the invention will be P-substituted oligonucleotides. For purposes of the invention, a P-substituted oligonucleotide is an oligonucleotide in which from one to about all of the internucleoside phosphorous atoms has one non-bridging oxygen atom from the corresponding phosphodiester substituted with an organic substituting group. Preferred organic substituting groups have from one to about 20 carbon atoms and include alkyl, aryl, aralkyl, alkoxy, aroxy, aralkoxy, thioalkyl, thioaryl, or thioaralkyl groups, any of which may be unsubstituted or up to fully substituted with halogen and or nitrogen constituents. Particularly preferred organic substituting groups include CH_3O-, NCC_2H_4O-, CH_3-, NCC_2H_4S-, or $PhCOSCH_2CH_2S$- groups, wherein Ph is phenyl or 2,4-dichlorophenyl. In another preferred embodiment, another non-bridging oxygen atom from the corresponding phosphodiester is replaced by a sulfur atom.

For purposes of the invention, the term *in situ* is intended to mean "without intervening purification". Thus, generating 5'-protected nucleoside P-substituted phosphonamidites *in situ* takes place whenever at least one of the 5'-protected nucleoside P-substituted phosphonamidites are generated and then used for oligonucleotide synthesis without intervening purification of the 5'-protected nucleoside P-substituted phosphonamidites. Thus, the improved process for synthesizing P-substituted oligonucleotides according to the invention comprises generating a 5'-protected nucleoside phosphoramidite or P-substituted phosphonamidite *in situ* and coupling the P-substituted phosphonamidite of the 5'-protected nucleoside-P- substituted phosphonamidite with an unprotected 5' end of a nucleoside, which is preferably covalently bound to a solid support and which may be the 5'-terminal nucleoside of a nascent oligonucleotide. The generation of the 5'-protected nucleoside phosphoramidites or P-substituted phosphonamidites and synthesis of oligonucleotides may take place in the same reaction vessel as the nucleoside coupling reactions, or it may take place in different reaction vessels. Moreover, the generation of 5'-protected nucleoside phosphoramidites or P-substituted phosphonamidites may take place either prior to, or contemporaneous with oligonucleotide synthesis.

In a particularly preferred embodiment of the process according to this aspect of the invention, the biphosphitylating agent used to produce the nucleoside phosphoramidites or P-substituted phosphonamidites *in situ* is selected from the biphosphitylating agents shown in Figure 1 or Figure 2. The preferred nucleoside P-substituted phosphonamidite is generated *in situ*, followed by coupling without intervening purification of the nucleoside P-substituted phosphonamidite.

The improvement according to this aspect of the invention can be incorporated into any standard

phosphoramidite synthesis protocol using any automated synthesizer. For example, for small scale oligonucleotide synthesis, a standard protocol for oligonucleotide synthesis on a 0.2 or 1.0 micromole scale using a Millipore™ 8909 Expedite™ automated synthesizer (Millipore, Bedford, MA) can be followed, except that at the points at which 5'-protected nucleoside phosphoramidites are normally added, instead, a 0.1 M solution of 5'-protected nucleoside P-substituted phosphonamidite is generated *in situ*, by adding to the reaction a bifunctional phosphitylating reagent according to the invention or Figure 1 and a 5'-protected nucleoside in the presence of one equivalent of a weak acid. This procedure produces oligonucleotides in an average stepwise yield of > 97%. For larger scale synthesis, similar modification of a large scale synthesis procedure can be carried out, by using a proportionately larger amount of bifunctional phosphitylating reagent and 5'-protected nucleoside.

The versatility of the improvement according to this aspect of the invention allows it to be used for the synthesis of a wide variety of different oligonucleotides. For purposes of the invention, the term "oligonucleotide" includes polymers of two or more deoxyribonucleotide or 2'-O-substituted ribonucleotide monomers, or any combination thereof. Such monomers may be coupled to each other by any of the numerous known internucleoside linkages. In certain preferred embodiments, these internucleoside linkages may be phosphodiester, phosphotriester, phosphorothioate, phosphorodithioate, methylphosphonate, or phosphoramidate linkages, or combinations thereof. The term oligonucleotide also encompasses such polymers having chemically modified or radioisotopically labeled bases or sugars and/ or having additional substituents, including without limitation lipophilic groups, intercalating agents, diamines and adamantane. For purposes of the invention the term "2'-O-substituted" means substitution of the 2' position of the

pentose moiety with an -O- alkyl group containing 1-6 saturated or unsaturated carbon atoms, or with an -O-aryl or allyl group having 2-6 carbon atoms, wherein such alkyl, aryl or allyl group may be unsubstituted or may be substituted, *e.g.*, with halo, hydroxy, trifluoromethyl, cyano, nitro, acyl, acyloxy, alkoxy, carboxyl, carbalkoxyl, or amino groups; or such 2′ substitution may be with a hydroxy group (to produce a ribonucleoside), an amino or a halo group, but not with a 2′-H group.

The following examples are intended to further illustrate certain preferred embodiments of the invention and are not intended to be limiting in nature. Except as otherwise indicated, in each of the following examples, reagents were sourced as follows. Anhydrous acetonitrile was purchased from J. T. Baker Inc. (Phillipsburg, NJ). dT-CPG, 5′-DMT-deoxyadenosine (Bz) cyanoethyl phosphoramidite, 5′-DMT-deoxycytidine (Bz) cyanoethyl phosphoramidite, 5′-DMT-deoxyguanosine (ibu) Cyanoethyl phosphoramidite, 5′-DMT-thymidine Cyanoethyl phosphoramidite, Cap A, Cap B, activator, oxidizing and deblock solutions were purchased from PerSeptive Biosystems™, (Framingham, MA). Ammonia solution in methanol (ca. 7N) was purchased from ACROS ORGANIC (Pittsburgh, PA). All other chemicals were purchased from Aldrich. ^{31}P NMR spectra (121.65 MHz) and ^{1}H NMR spectra (300 MHz) were recorded on a Varian UNITY 300 (the chemical shift was correlated to 85% H_3PO_4 and tetramethylsilane, respectively). Oligonucleotide synthesis was performed on a 8909 Expedite™ DNA synthesizer (Millipore). Compound numbers, shown in bold, refer to the compounds shown in Figures 1.

Example 1

Synthesis of Methyl-bis-pyrrolidinophosphine (1)

To a solution of methyldichlorophosphine (5.0 g, 42.8 mmol, 3.8 mL) in CH_2Cl_2 (70 mL) was added dropwise 1-(trimethylsilyl)pyrrolidine (15.3 mL, 12.6 g, 87.7 mmol) at 0°C. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give a colorless oil (6.28 g, 79%) as a product. ^{31}P NMR ($CDCl_3$) δ 64.1.

Example 2

Synthesis of Methyl-bis(N,N-dimethylamino)phosphine (2)

To a solution of methyldichlorophosphine (4.5 g, 38.5 mmol, 3.45 mL) in CH_2Cl_2 (70 mL) was added dropwise N,N-dimethyltrimethylsilylamine (10.0 g, 85.3 mmol) at 0°C. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give a colorless oil (4.3 g, 83%) as a product. ^{31}P NMR ($CDCl_3$) δ 86.6.

Example 3

Synthesis of Methyl-bis(N,N-diethylamino)phosphine (3)

To a solution of methyldichlorophosphine (5.0 g, 42.76 mmol) in CH_2Cl_2 (50 ml) was added dropwise N,N-diethyltrimethylsilylamine (10.0 g, 85.3 mmol) at -30°C. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give a colorless oil (7.0 g, 86%) as a product. ^{31}P NMR ($CDCl_3$) δ 78.6.

Example 4

Synthesis of Methyl-bis-morpholinophosphine (4)

To a solution of methyldichlorophosphine (2.5 g, 21.4 mmol, 1.9 mL) in CH_2Cl_2 (20 mL) was added dropwise 4-(trimethylsilyl)morpholine (8.4 mL, 7.5 g, 47.0 mmol) at 0°C. The resulting mixture was stirred overnight at room

temperature. The solvent was removed under reduced pressure to give a pale yellow oil (3.6 g, 78%) as a product. ^{31}P NMR ($CDCl_3$) δ 81.6.

Example 5

Synthesis of Methyl-bis(N,N-diisopropylamino)phosphine (5)

To a solution of methyldichlorophosphine (5.0 g, 42.8 mmol, 3.9 mL) in CH_2Cl_2 (200 mL) was added dropwise diisoprophylamine (60 mL, 43.3 g, 0.43 mol) at 78°C. The resulting mixture was stirred overnight at room temperature. The reaction mixture was filtered to remove the resulting salt, and the solvent was removed under reduced pressure to give the crude product as a colorless oil (7.0 g, 67%). ^{31}P NMR ($CDCl_3$ δ 38.4.

Example 6

Synthesis of 2-Cyanoethoxy(N,N-Diisopropylamino) pyrrolidinophosphine (6).

To a solution of chloro(2-Cyanoethoxy)(N,N-Diisopropylamino) phosphine (12.9 g, 54.56 mmol) in CH_2Cl_2 (100 mL) was added dropwise 1-(trimethylsilyl)pyrrolidine (10.0 mL, 8.21 g, 57.29 mmol) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give a pale yellow oil (13.3 g, 95%) as a product. ^{31}P NMR ($CDCl_3$) δ 133.9.

Example 7

Synthesis of 2-Cyanoethoxy(N,N-Diisopropylamino) (N,N-dimethylamino)phosphine (7).

To a solution of chloro(2-Cyanoethoxy)(N,N-Diisopropylamino) phosphine (19.22 g, 81.2 mmol, 18.1 mL) in CH_2Cl_2 (100 mL) was added dropwise N,N-dimethyltrimethylsilylamine (10.0 g, 85.3 mmol) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced

pressure to give a colorless oil (18.7 g, 94%) as a product. ^{31}P NMR ($CDCl_3$) δ 126.3.

Example 8

Synthesis of 2-Cyanoethoxy(N,N-Diethylamino) (N,N-diisopropylamino) phosphine (8).

To solution of chloro(2-Cyanoethoxy)(N,N-Diisopropylamino) phosphine (5.95 g, 25.13 mmol, 5.61 mL) in CH_2Cl_2 (50 mL) was added dropwise N,N-Diethyltrimethylsilylamine (3.84 g, 26.4 mmol, 5.0 mL) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give a colorless oil (6.5 g, 94% as a product. ^{31}P NMR ($CDCl_3$) δ 127.2.

Example 9

Synthesis of 2-Cyanoethoxy(N,N-Diisopropylamino) morpholinophosphine (9).

To a solution of chloro(2-Cyanoethoxy)(N,N-Diisopropylamino) phosphine (10.61 g, 44.82 mmol, 10.0 mL) in CH_2Cl_2 (50 mL) was added dropwise 4-(trimethylsilyl)morpholine (8.76 mL, 7.86 g, 49.31 mmol) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give a colorless oil (12.5 g, 97%) as a product. ^{31}P NMR ($CDCl_3$) δ 125.2.

Example 10

Synthesis of 2-Cyanoethoxy(morpholino) pyrrolidinophosphine (10).

To a solution of 2-Cyanoethoxy(dichloro)phosphine (7.16 g, 41.61 mmol, 5.3 mL) in CH_2Cl_2 (50 mL) was added dropwise 1-(trimethylsilyl)pyrrolidine (7.26 mL, 5.96 g, 41.61 mmol) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed

under reduced pressure to give chloro(2-Cyanoethoxy)pyrrolidinophosphine as a colorless oil. ^{31}P NMR ($CDCl_3$) δ 177.5.

To the solution of chloro(2-Cyanoethoxy) pyrrolidinophosphine in CH_2Cl_2 (50 mL) was added dropwise 4-(trimethylsilyl)morpholine (8.13 mL, 7.29 g, 45.77 mmol) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give a pale yellow oil (9.8 g, 92%) as a product. ^{31}P NMR ($CDCl_3$) δ 134.2

Example 11

Synthesis of 2-Cyanoethoxy(N,N-dimethylamino) morpholinophosphine (11).

To a solution of 2-Cyanoethoxy(dichloro)phosphine (4.29 g, 24.97 mmol, 3.2 mL) in CH_2Cl_2 (50 mL) was added dropwise N,N-dimethyltrimethylsilylamine (2.93 g, 24.97 mmol, 4.0 mL) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give chloro(2-Cyanoethoxy)(N,N-dimethylamino)phosphine as a colorless oil. ^{31}P NMR ($CDCl_3$) δ 174.7.

To the solution of chloro(2-Cyanoethoxy)(N,N-dimethylamino)phosphine in CH_2Cl_2 (50 mL) was added dropwise 4-(trimethylsilyl) morpholine (4.86 mL, 4.36 g, 27.39 mmol) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give a pale yellow oil (5.0 g, 93%) as a product. ^{31}P NMR ($CDCl_3$) δ 133.5.

Example 12

Synthesis of N,N-Diisopropylamino(methyl) pyrrolidinophosphine (12).

To a solution of chloro(N,N-Diisopropylamino)methylphosphine (5.0 g, 27.53 mmol) in CH_2Cl_2 (50 mL) was added dropwise 1-(trimethylsilyl)pyrrolidine (5.3 mL) 4.34 g, 30.3

mmol) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give a colorless oil (5.5 g, 93%) as a product. ^{31}P NMR ($CDCl_3$) δ 48.7.

Example 13

Synthesis of N,N-Diisopropylamino(methyl)(N,N-dimethylamino)phosphine (13).

To a solution of chloro(N,N-Diisopropylamino)methylphosphine (6.2 g, 34.1 mmol, 6.2 mL) in CH_2Cl_2 (50 mL) was added dropwise N,N-dimethyltrimethylsilylamine (4.39 g, 37.45 mmol) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give a colorless oil (4.3 g, 90%) as a product. ^{31}P NMR ($CDCl_3$) δ 50.6.

Example 14

Synthesis of N,N-Diethylamino(N,N-diisopropylamino)methylphosphine (14).

To a solution of chloro(N,N-Diisopropylamino)methylphosphine (5.0 g, 27.53 mmol) in CH_2Cl_2 (50 mL) was added dropwise N,N-diethyltrimethylsilylamine (4.4 g, 30.28 mmol, 5.7 mL) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give a colorless oil (5.0 g, 83%) as a product. ^{31}P NMR ($CDCl_3$) δ 56.6.

Example 15

Synthesis of N,N-Diisopropylamino(methyl)morpholinophosphine (15).

To a solution of chloro(N,N-Diisopropylamino)methylphosphine (5.0 g, 27.53 mmol, 5.0 mL) in CH_2Cl_2 (50 mL) was added dropwise 4-(trimethylsilyl)morpholine (5.4 mL, 4.8 g, 30.28 mmol) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was

removed under reduced pressure to give a pale yellow oil (6.1 g, 96%) as a product. ^{31}P NMR ($CDCl_3$) δ 58.8.

Example 16

Synthesis of Methyl(morpholino)pyrrolidinophosphine (16).

To a solution of methyldichlorophosphine (5.0 g, 42.76 mmol) in CH_2Cl_2 (50 mL) was added dropwise 1-(trimethylsilyl)pyrrolidine (7.5 mL, 6.1 g, 42.8 mmol) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give chloro(methyl) pyrrolidinophosphine as a colorless oil. ^{31}P NMR (CDCl3) δ 144.8.

To the solution of chloro(methyl)pyrrolidinophosphine in CH_2Cl_2 (50 mL) was added dropwise 4-(trimethylsilyl)morpholine (8.3 mL, 7.5 g, 43.0 mmol) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give a pale yellow oil (8.2 g, 95%) as a product. ^{31}P NMR ($CDCl_3$) δ 72.5.

Example 17

Synthesis of Methyl(N,N-dimethylamino) morpholinophosphine (17).

To a solution of methyldichlorophosphine (5.0 g, 42.76 mmol, 3.8 mL) in CH_2Cl_2 (50 mL) was added dropwise N,N-dimethyl-trimethylsilylamine (5.0 g, 42.76 mmol, 6.9 mL) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give chloro(methyl)(N,N-dimethylamino)phosphine as a colorless oil. ^{31}P NMR ($CDCl_3$) δ 151.3.

To the solution of chloro(methyl)(N,N-dimethylamino) phosphine in CH_2Cl_2 (50 mL) was added dropwise 4-(trimethylsilyl)morpholine (8.3 mL, 7.5 g, 43.0 mmol) at room temperature. The resulting mixture was stirred

overnight at room temperature. The solvent was removed under reduced pressure to give a pale yellow oil (7.1 g, 94%) as a product. ^{31}P NMR ($CDCl_3$) δ 81.6.

Example 18

Synthesis of N,N-Diethylamino (methyl)morpholinophosphine (18).

To a solution of methyldichlorophosphine (10 g, 85.5 mmol, mL) in CH_2Cl_2 (50 mL) was added dropwise N,N-diethyl-trimethylsilylamine (12.43 g, 16.2 mmol) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give chloro(methyl)(N,N-dimethylamino)phosphine as a colorless oil. ^{31}P NMR ($CDCl_3$) δ 147.8.

To the solution of chloro(methyl)(N,N-dimethylamino) phosphine (11.4 g, 81.77 mmol) in CH_2Cl_2 (50 mL) was added dropwise 4-(trimethylsilyl)morpholine (17.43 mL, 15.63 g, 98.12 mmol) at room temperature. The resulting mixture was stirred overnight at room temperature. The solvent was removed under reduced pressure to give a pale yellow oil (14.8 g, 89%) as a product. ^{31}P NMR ($CDCl_3$) δ 81.4.

Example 19

Generation and ^{31}P NMR Spectroscopy Analysis of Nucleoside Methylphosphonamidite Monomers

To a solution of 0.15 mmol of 1 (27.9 mg) and 0.15 mmol 5'-DMT-thymidine (81.7 mg) in $CDCl_3$ was added at room temperature a solution of 5.2 mg of 4,5-dichloroimidazole in THF (0.05 ml) or 0.1 ml of 0.45 M tetrazole solution in acetonitrile. After stirring for 10 minutes at room temperature, the solution was transferred to an NMR tube and examined by NMR spectrometry, with the chemical shift correlated to 85% H_3PO_4. The results showed 97% of the product to be the expected nucleoside phosphoramidite

product. Similar results were obtained using each of the reagents 2-18 in place of 1.

Example 20

Synthesis of Oligonucleoside Methylphosphonates

The oligonucleotide methylphosphonothioate and methylphosphonate were synthesized on a 1 micromole scale following the standard protocol using an automated synthesizer (Millipore 8909 Expedite™, Bedford, MA), modified as follows. Nucleoside methylphosphonamidite was generated *in situ* using 1 or 2 as a 0.1 M solution in acetonitrile and THF (1:1) and 0.2-0.3 equivalents tetrazole or 4,5-dichloroimidazole. A 16-mer oligonucleotide was synthesized in which there were 10 methylphosphonate linkages at the 3' end and 5 phosphorothioate linkages at the 5' end. A conventional phosphorothioate oxidation protocol (Beaucage reagent) was used for phosphorothioate linkages. For methylphosphonate limkages, the protocol was modified by oxidizing prior to capping and extending the wash after deblocking to collect displaced trityl. A low-water-content oxidizing agent (0.1 M I_2 in THF/lutidine/H_2O, 74.75/25/0.25) was used to minimize backbone hydrolysis. Following synthesis, the support-bound oligonucleotide was dried in vaccuum and the oligonucleotide was cleaved from the CPG support using ammonia-saturated methanol at 55 degrees C for 2 hours. Trityl analysis and reverse phase HPLC showed the stepwise yield to be greater than 97%. For oligonucleotide methylphosphonothioate, the iodine oxidation step is replaced by sulfurization with 3H-1,2-benzodithiol-3-one-1,1-dioxide (Beaucage reagent).

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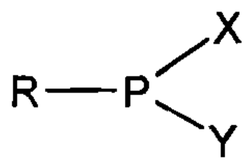
CLAIMS:

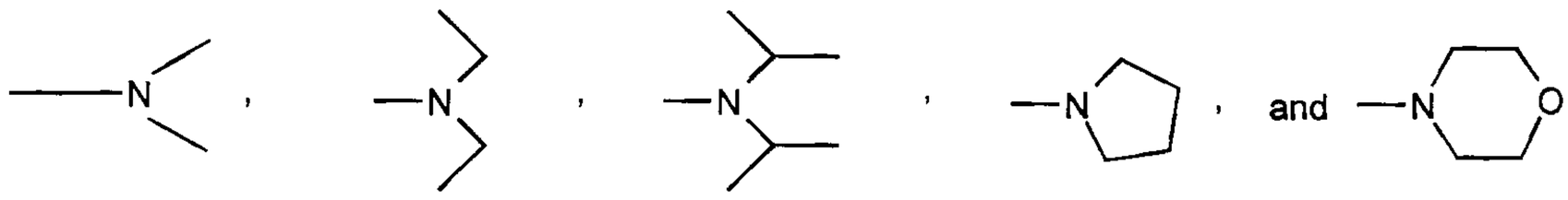
1. A bifunctional phosphitylating reagent having the general structure (II):



(II)

wherein R is an alkyl, aryl, aralkyl, alkoxy, aroxy, aralkoxy, thioalkyl, thioaryl, or thioaralkyl group having from one to 20 carbon atoms and being unsubstituted or up to fully substituted with halogen and/or nitrogen constituents;

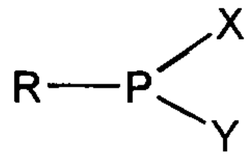
and wherein X and Y are different from each other and are selected from the group consisting of



provided that when R is methoxy, X or Y is not diisopropylamino when the other is morpholino, and that when R is ethoxy, that X or Y is not diisopropylamino when the other is diethylamino.

2. The bifunctional phosphitylating reagent according to claim 1 wherein R is CH_3O-, NCC_2H_4O-, CH_3-, NCC_2H_4S-, or $PhCOSCH_2S$-, wherein Ph is phenyl or 2,4-dichlorophenyl.

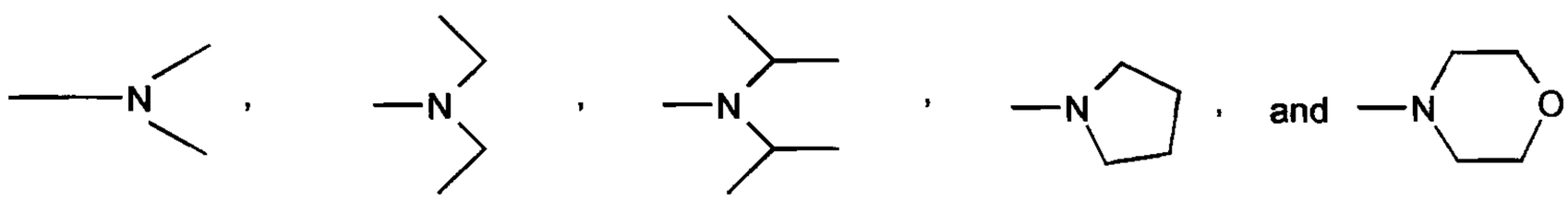
3. A process for generating 5'-protected nucleoside phosphoramidites or P-substituted phosphonamidites, the process comprising reacting a bifunctional phosphitylating reagent having the general structure (II):



(II)

wherein R is an alkyl, aryl, aralkyl, alkoxy, aroxy, aralkoxy, thioalkyl, thioaryl, or thioaralkyl group having from one to 20 carbon atoms and being unsubstituted or up to fully substituted with halogen and/or nitrogen constituents;

and wherein X and Y are different from each other and are selected from the group consisting of

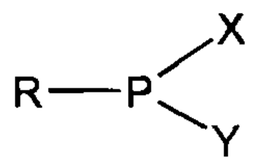


provided that when R is methoxy, X or Y is not diisopropylamino when the other is morpholino and that when R is ethoxy, that X or Y is not diisopropylamino when the other is diethylamino;

with a 5'-protected nucleoside in the presence of a weak acid to produce a 5'-protected nucleoside phosphoramidite or P-substituted phosphonamidite.

4. The process according to claim 3, wherein R is CH_3O-, NCC_2H_4O-, CH_3-, NCC_2H_4S-, or $PhCOSCH_2CH_2S$-, wherein Ph is phenyl or 2,4-dichlorophenyl.

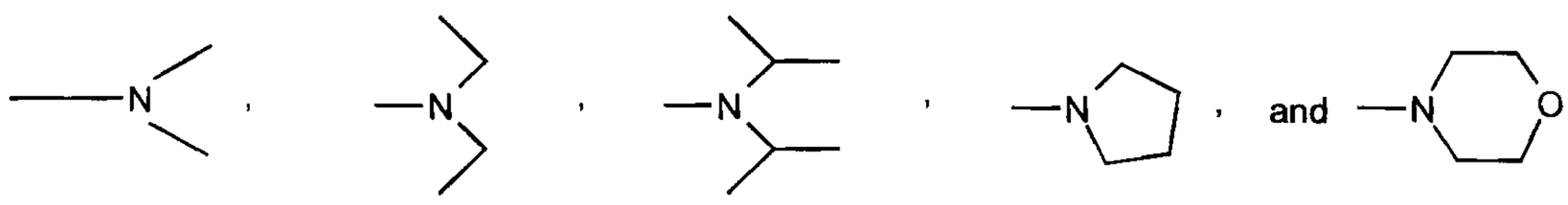
5. A process for synthesising an oligonucleoside containing one or more P-substituted internucleoside linkages which comprises generating a 5'-protected nucleoside phosphoramidite or nucleoside P-substituted phosphonamidite *in situ* by reacting a bifunctional phosphitylating reagent having the general structure (II):



(II)

wherein R is an alkyl, aryl, aralkyl, alkoxy, aroxy, aralkoxy, thioalkyl, thioaryl, or thioaralkyl group having from one to 20 carbon atoms and being unsubstituted or up to fully substituted with halogen and/or nitrogen constituents;

and wherein X and Y are different from each other and are selected from the group consisting of



with a 5'-protected nucleoside in the presence of a weak acid to produce a 5'-protected nucleoside phosphoramidite or 5'-protected nucleoside P-substituted phosphonamidite.

6. The process according to claim 5, wherein R is CH_3O-, NCC_2H_4O-, CH_3-, NCC_2H_4S-, or $PhCOSCH_2CH_2S$-, wherein Ph is phenyl or 2,4-dichlorophenyl.

7. A process for synthesising P-substituted oligonucleotides, comprising generating a 5'-protected nucleoside-P-substituted phosphonamidite *in situ* and coupling the P-substituted phosphonamidite of the 5'-protected nucleoside-P-substituted phosphonamidite with an unprotected 5' end of a nucleoside by a process according to claim 5, wherein R is an alkyl, aryl or aralkyl group having from one to 20 carbon atoms and being unsubstituted or up to fully substituted with halogen and/or nitrogen constituents.

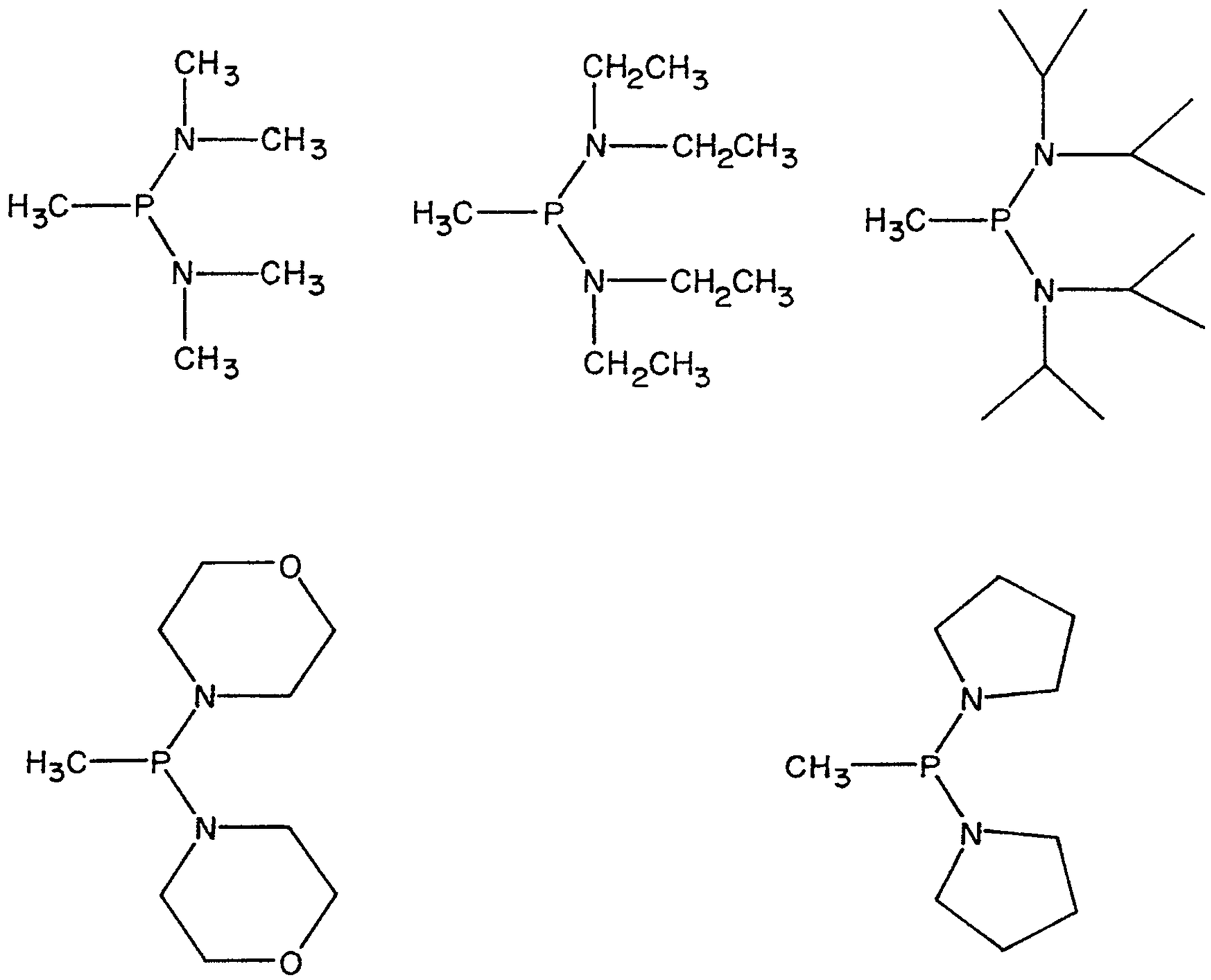
8. A process for synthesising P-substituted oligonucleotides, comprising generating a 5'-protected nucleoside-P-substituted phosphoramidite *in situ* and coupling the P-substituted phosphoramidite of the 5'-protected nucleoside-P-substituted phosphoramidite with an unprotected 5' end of a nucleoside by a process according to claim 5, wherein R is an alkoxy, aroxy, aralkoxy, thioalkyl, thioaryl, or thioaralkyl group having from one to 20 carbon atoms and being unsubstituted or up to fully substituted with halogen and/or nitrogen constituents.

9. Use of a bifunctional phosphitylating reagent of claim 1 or 2 for synthesis of an oligonucleotide.

SMART & BIGGAR

OTTAWA, CANADA

PATENT AGENTS


CH3
N
CH3
H3C
P
N
CH3
CH3
CH2CH3
N
CH2CH3
H3C
P
N
CH2CH3
CH2CH3
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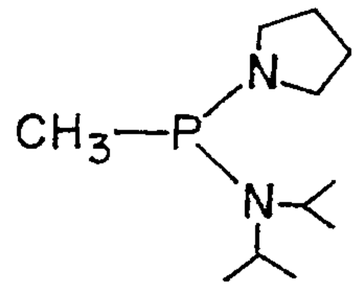
H3C
P
N
O
N
H3C
P
N
O
CH3
P
N
N

FIG. 1



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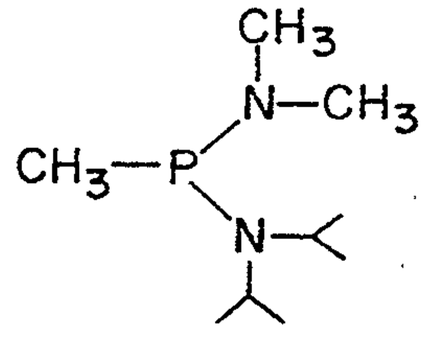

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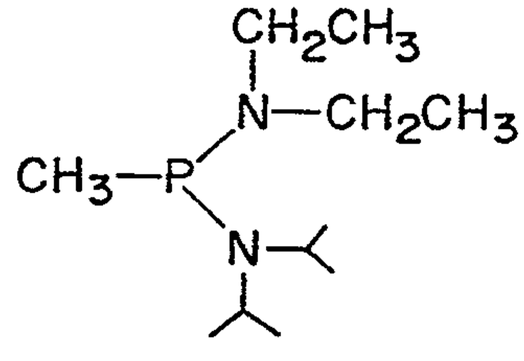

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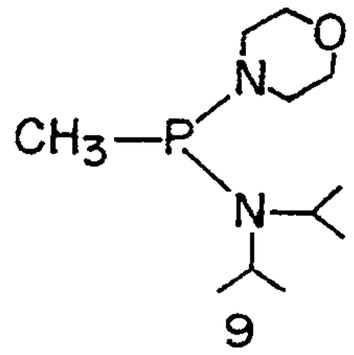

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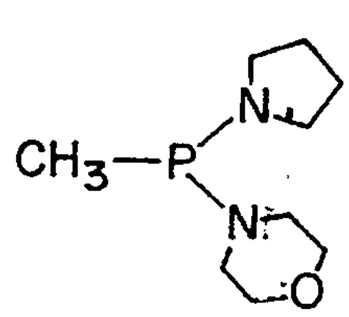

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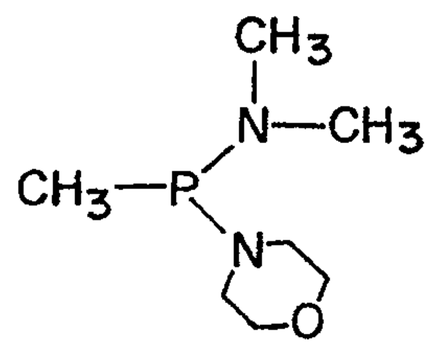

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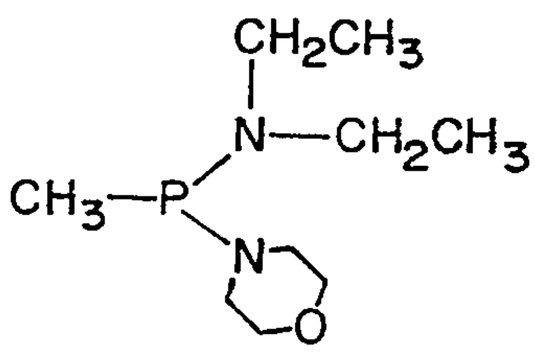

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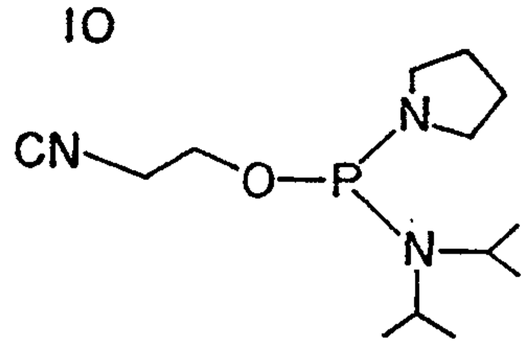

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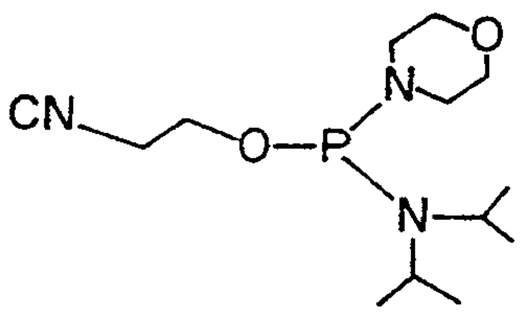

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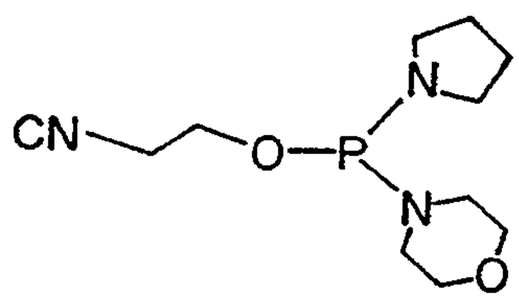

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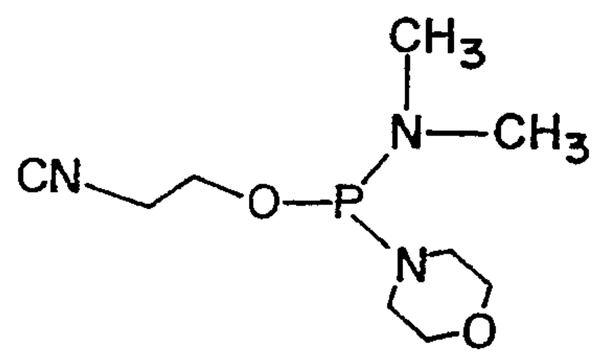

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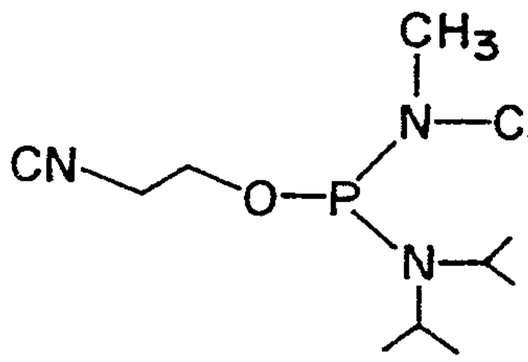

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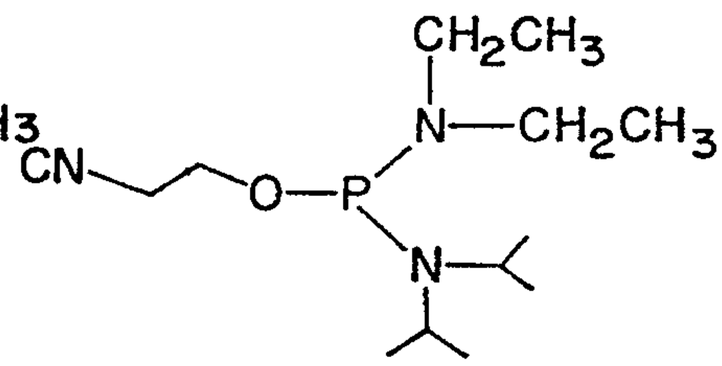

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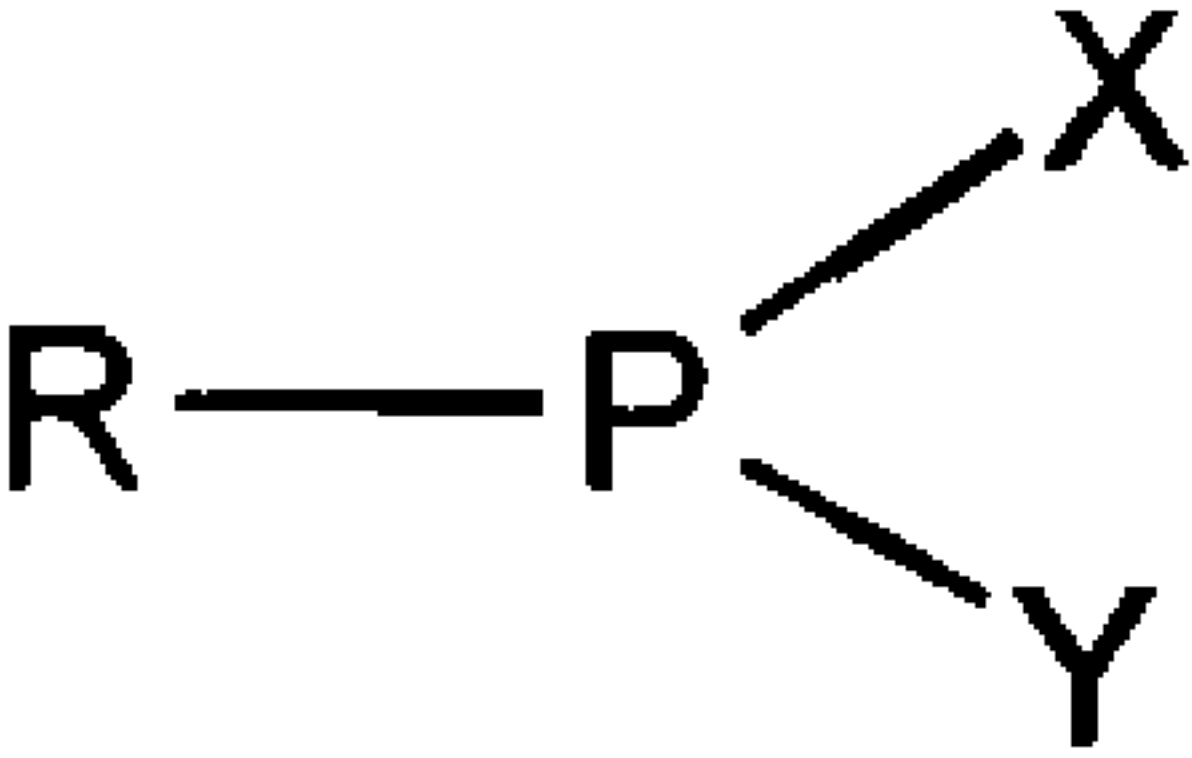
FIG. 2



(II)