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CA 2291688 C 2008/01/29

(11)(21) **2 291 688**

(12) **BREVET CANADIEN**
CANADIAN PATENT

(13) **C**

(86) Date de dépôt PCT/PCT Filing Date: 1998/05/26
(87) Date publication PCT/PCT Publication Date: 1998/12/03
(45) Date de délivrance/Issue Date: 2008/01/29
(85) Entrée phase nationale/National Entry: 1999/11/26
(86) N° demande PCT/PCT Application No.: US 1998/010653
(87) N° publication PCT/PCT Publication No.: 1998/054198
(30) Priorité/Priority: 1997/05/30 (US08/865,666)

(51) Cl.Int./Int.Cl. *C07H 21/00* (2006.01), *C07D 285/16* (2006.01)

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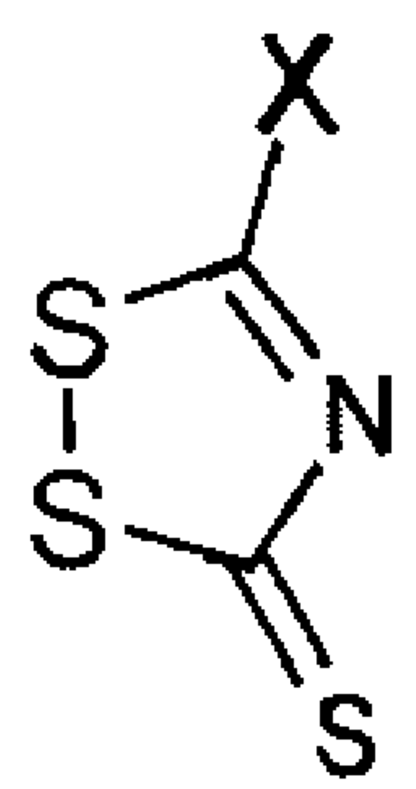
(54) Titre : NOUVEAUX REACTIFS A TRANSFERT DE SOUFRE POUR LA SYNTHESE DES OLIGONUCLEOTIDES
(54) Title: NOVEL SULFUR TRANSFER REAGENTS FOR OLIGONUCLEOTIDE SYNTHESIS



Formula I

(57) Abrégé/Abstract:
In our research, two commercially available compounds, 3-amino-1,2,4-dithiazole-5-thione (1) and xanthane hydride (2), and their derivatives 3-6 are found to be potential sulfur-transfer reagents. The efficiency and optimization of these new sulfur-transfer reagents were investigated by solid-phase synthesis of dinucleotide and oligonucleotide phosphorothioates. The results show that both compounds (1) and (2) are highly efficiency sulfurizing reagents, and better than 99 % sulfur transfer efficiency can be achieved at each step. In contrast to Beaucage reagent, these novel sulfur-transfer reagents are very stable in various solvents, and are available in bulk quantities at low cost. Due to these advantages, compounds (1) and (2) can be considered alternatives to Beaucage reagent, especially in large-scale preparation of oligonucleotide phosphorothioates. Furthermore, compounds (1) and (2) were modified to enhance their solubility in acetonitrile. Three types of structure, as described as Formulae (I), (II) and (III), are considered as potential efficient sulfur-transfer reagents based on our results.

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : C07H 21/00, C07D 277/00

A1

(11) International Publication Number: WO 98/54198

(43) International Publication Date: 3 December 1998 (03.12.98)

(21) International Application Number: PCT/US98/10653

(22) International Filing Date: 26 May 1998 (26.05.98)

(30) Priority Data:
08/865,666 30 May 1997 (30.05.97) US

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(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: NOVEL SULFUR TRANSFER REAGENTS FOR OLIGONUCLEOTIDE SYNTHESIS

(57) Abstract

In our research, two commercially available compounds, 3–amino–1,2,4–dithiazole–5–thione (1) and xanthane hydride (2), and their derivatives 3–6 are found to be potential sulfur–transfer reagents. The efficiency and optimization of these new sulfur–transfer reagents were investigated by solid–phase synthesis of dinucleotide and oligonucleotide phosphorothioates. The results show that both compounds (1) and (2) are highly efficiency sulfurizing reagents, and better than 99 % sulfur transfer efficiency can be achieved at each step. In contrast to Beaucage reagent, these novel sulfur–transfer reagents are very stable in various solvents, and are available in bulk quantities at low cost. Due to these advantages, compounds (1) and (2) can be considered alternatives to Beaucage reagent, especially in large–scale preparation of oligonucleotide phosphorothioates. Furthermore, compounds (1) and (2) were modified to enhance their solubility in acetonitrile. Three types of structure, as described as Formulae (I), (II) and (III), are considered as potential efficient sulfur–transfer reagents based on our results.

NOVEL SULFUR TRANSFER REAGENTS FOR OLIGONUCLEOTIDE SYNTHESIS

Field of the Invention

The invention relates to the chemical synthesis of oligonucleotides and to chemical entities useful in such synthesis. More particularly, the invention relates to sulfurization of the internucleoside linkages of oligonucleotides.

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. Oligonucleotide phosphorothioates are of considerable interest in nucleic acid research and are among the analogues tested as oligonucleotide therapeutics. Oligonucleotides phosphorothioates contain internucleotide linkages in which one of the nonbridging oxygen atoms of the phosphate group is replaced by a sulfur atom. 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); and Uhlmann and Peyman, *Chemical Reviews*, 90: 543-584 (1990); 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 automated synthesis. Beaucage and Carruthers, *Tetrahedron Lett.* 22: 1859-1862 (1981), discloses the use of deoxynucleoside phosphoramidites in polynucleotide synthesis. Agrawal and Zamecnik, U.S. Patent No. 5,149,798 (1992), discloses optimized synthesis of oligonucleotides by the H-phosphonate approach.

These latter approaches have been used to synthesize oligonucleotides having a variety of modified internucleotide 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 et al., *Biochemistry* 27: 7237 (1988), discloses synthesis of oligonucleotide phosphoramidates using phosphoramidite chemistry. Agrawal et al., *Proc. Natl. Acad. Sci. USA* 85: 7079-7083 (1988), discloses synthesis of oligonucleotide phosphoramidates and phosphorothioates using H-phosphonate chemistry.

Solid phase synthesis of oligonucleotides by each of the foregoing processes 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. Internucleoside linkages are formed between the 3' functional group of the incoming nucleoside and the 5' hydroxyl group of the 5'-most nucleoside of the nascent, support-bound oligonucleotide. In the phosphoramidite approach, the internucleoside linkage is a phosphite linkage, whereas in the H-phosphonate approach, it is an H-phosphonate internucleoside linkage. To create the sulfur-containing phosphorothioate internucleoside linkage, the phosphite or H-phosphonate linkage must be oxidized by an appropriate sulfur transfer reagent. In the H-phosphonate approach, this sulfurization is carried out on all of the H-phosphonate linkages in a single step following the completion of oligonucleotide chain assembly, typically using elemental sulfur in a mixed solvent, such as CS_2/pyridine. In contrast, the phosphoramidite approach allows stepwise sulfurization to take place after each coupling, thereby providing the capability to control the state of each linkage in a site-specific manner. Based on superior coupling efficiency, as well as the capacity to control the state of each linkage in a site-specific manner, the phosphoramidite approach appears to offer advantages.

Refinement of methodologies is still required, however, particularly when making a transition to large-scale synthesis (10 μmol to 1 mmol and higher). See Padmapriya et al., *Antisense Res. Dev.* 4: 185 (1994). Several modifications of the standard phosphoramidite processes have already been reported to facilitate the synthesis (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)) and isolation

(Kuijpers et al., *Nucl. Acids Res.* 18: 5197 (1990); and Reddy et al., *Tetrahedron Lett.* 35: 4311 (1994)) of oligonucleotides.

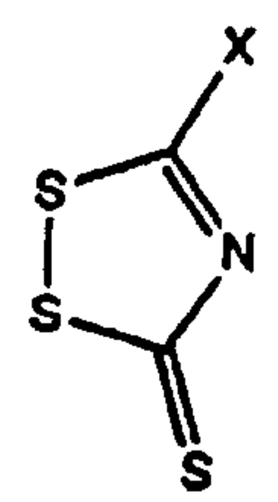
It is imperative that an efficient sulfur transfer reagent is used for the synthesis of oligonucleotide phosphorothioates via the phosphoroamidite approach. Elemental sulfur is not efficient due to poor solubility and slow sulfurization reaction. A number of more efficient sulfurizing reagents have been reported in recent years. These include phenylacetyl disulfide, (Kamer et al., *Tetrahedron Lett.* 30: 6757-6760 (1989)), *H*-1,2-benzodithiol-3-one-1,1-dioxide (Beaucage reagent)(Iyer et al., *J. Org. Chem.* 55: 4693-4699 (1990)), tetraethylthiuram disulfide (TETD)(Vu et al., *Tetrahedron Lett.* 32: 3005-3008 (1991)), dibenzoyl tetrasulfide (Rao et al., *Tetrahedron Lett.* 33: 4839-4842 (1992)), bis(*O,O*-diisopropoxyphosphinothioyl) disulfide (S-Tetra)(Stec et al., *Tetrahedron Lett.* 33: 5317-5320 (1993)), benzyltriethyl-ammonium tetrathiomolybate (BTTM) (Rao et al., *Tetrahedron Lett.* 35: 6741-6744 (1994)), bis(p-toluenesulfonyl) disulfide (Effimov et al., *Nucl. Acids Res.* 23: 4029-4033 (1995)), 3-ethoxy-1,2,4-dithiazoline-5-one (EDITH)(Xu et al., *Nucleic Acid Res.* 24:1602-1607 (1996)), and 1,2,4-dithiazolidine-3,5-dione (DtsNH)(Xu et al., *Nucleic Acid Res.* 24:1602-1607 (1996)). Both Beaucage reagent and TETD are commercially available. Beaucage reagent has been widely used, however, its synthesis and stability are not optimal. In addition, the by-product formed by Beaucage reagent during sulfurization, 3*H*-2,1-benzoxanthiolan-3-one-1-oxide, is a potential oxidizing agent that can lead to undesired phosphodiester linkages under certain conditions. Therefore, its application in large-scale synthesis of oligonucleotide phosphorothioates may not be particularly suitable. We report two commercially available compounds 1 and 2 and novel analogues thereof as potential alternative sulfurizing reagents.

There is, therefore, a continuing need to develop new sulfur transfer reagents and processes for sulfurizing oligonucleotides. Ideally, such sulfur transfer reagents should be inexpensive to make, stable in storage, and highly efficient.

BRIEF SUMMARY OF THE INVENTION

The invention provides new processes for sulfur transfer reagents in sulfurizing oligonucleotides. The processes according to the invention yield inexpensive to make, stable in storage, and highly efficient in sulfurization.

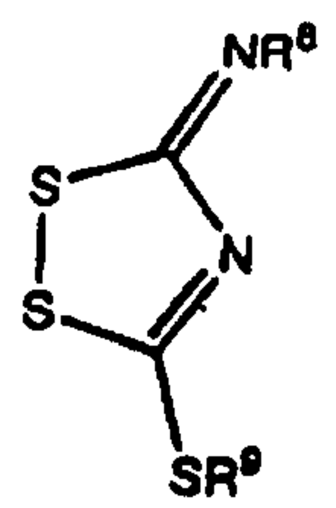
In a first aspect, the invention provides novel sulfur transfer reagents having the structure according to Formula I:



Formula I

wherein X is R^1, NR^2R^3, NR^4COR^5, SR^6, OR^7; each R^1, R^2, R^3, R^4, and R^5, is independently H or an alkyl or aromatic organic group; and each R^6 and R^7 is independently an alkyl or aromatic organic group.

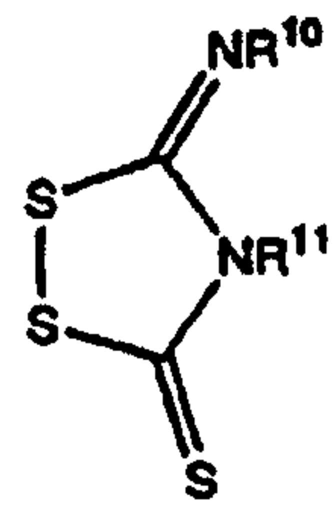
In a second aspect, the invention relates to novel sulfur transfer reagents having the general structure according to Formula II:



Formula II

wherein R^8 is H or an organic group; and R^9 is an organic group.

Another aspect of the invention provides for novel sulfur transfer reagents having the general structure according to Formula III:

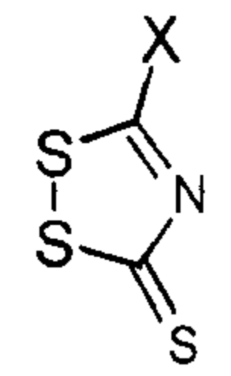


Formula III

wherein R^{10} and R^{11} are each independently H or an organic group.

In a fourth aspect, the invention provides novel processes for adding a sulfur group to an internucleoside linkage of an oligonucleotide using the novel sulfur transfer reagents according to the invention. In preferred embodiments, the novel processes according to the invention comprise contacting an oligonucleotide having at least one sulfurizable internucleoside linkage with a novel sulfur transfer reagent according to the invention for a time sufficient for sulfurization of the sulfurizable internucleoside linkage(s) to occur.

According to one aspect of the present invention, there is provided a sulphur transfer reagent having the general structure according to Formula I



Formula I

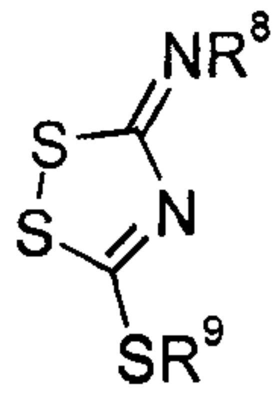
wherein X is R^1, NR^2R^3, NR^4COR^5, SR^6 or OR^7; each R^1, R^2, R^3, R^4 and R^5, is independently H or an alkyl or aromatic organic group; and each R^6 and R^7 is independently an alkyl or aromatic organic group:

provided that:

when X is NR^2R^3 that R^2 and R^3 are not both H or are not both CH_3; and

when X is $NHCOR^5$, R^5 can not be an alkyl group of C_8 or greater.

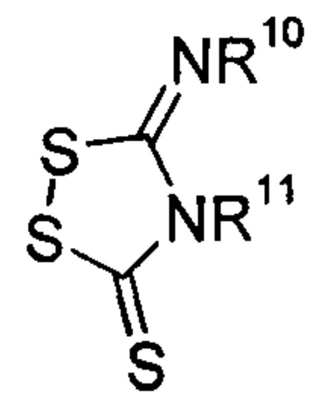
According to another aspect of the present invention, there is provided a sulphur transfer reagent having the general structure according to Formula II



Formula II

wherein R^8 is H or an alkyl or aromatic organic group; and R^9 is an alkyl or aromatic organic group.

According to still another aspect of the present invention, there is provided a sulphur transfer reagent having the general structure according to Formula III

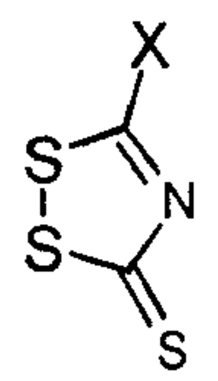


Formula III

wherein R^{10} is an alkyl or aromatic organic group and R^{11} is H;

provided that R^{10} is not NCOalkyl where the alkyl group is C_8 or greater.

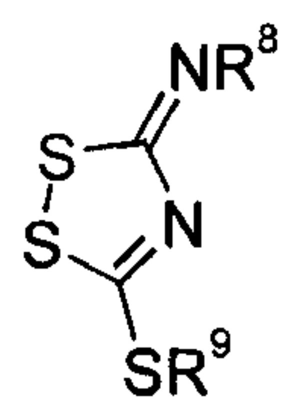
According to yet another aspect of the present invention, there is provided a process for adding a sulphur group to an internucleoside linkage of an oligonucleotide, the process comprising contacting an oligonucleotide having at least one sulfurizable internucleoside linkage with a sulphur transfer reagent of Formula (I);



Formula I

wherein X is R^1, NR^2R^3, NR^4COR^5, SR^6, OR^7; each R^1, R^2, R^3, R^4 and R^5, is independently H or an alkyl or aromatic organic group; and each R^6 and R^7 is independently an alkyl or aromatic organic group;

Formula (II);



Formula II

wherein R^8 is H or an alkyl or aromatic organic group; and R^9 is an alkyl or aromatic alkyl or aromatic organic group; or

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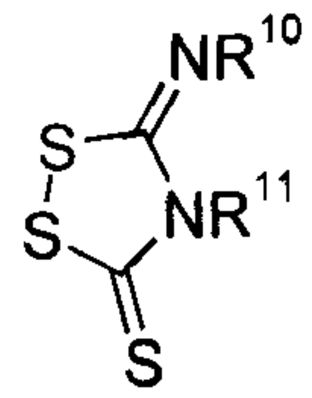
Formula (III);

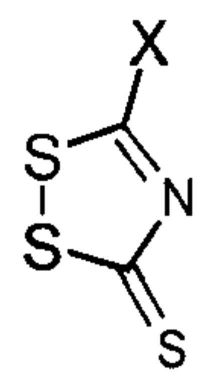


Formula III

wherein R^{10} and R^{11} are each independently H or an alkyl or aromatic organic group:

for a time sufficient for sulfurization of the sulfurizable internucleoside linkage(s) to occur.

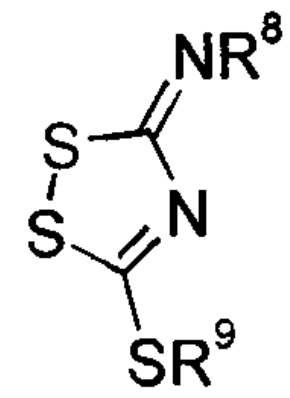
According to a further aspect of the present invention, there is provided a process for the synthesis of oligonucleotides comprising contacting an oligonucleotide having at least one sulfurizable internucleoside linkage with a sulfur transfer reagent, wherein the sulfur transfer agent is of Formula (I);



Formula I

wherein X is R^1, NR^2R^3, NR^4COR^5, SR^6, OR^7; each R^1, R^2, R^3, R^4 and R^5, is independently H or an alkyl or aromatic organic group; and each R^6 and R^7 is independently an alkyl or aromatic organic group;

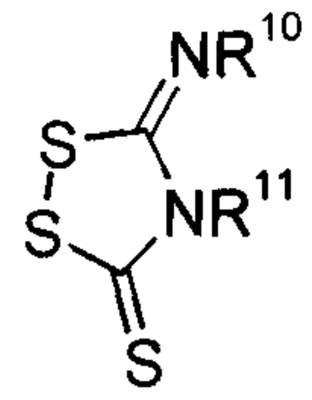
Formula (II);



Formula II

wherein R^8 is H or an alkyl or aromatic organic group; and R^9 is an alkyl or aromatic organic group; or

Formula (III);

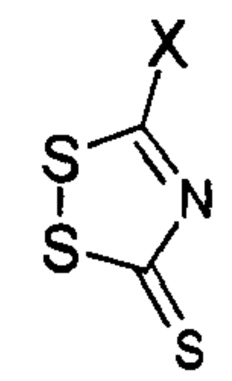


Formula III

wherein R^{10} and R^{11} are each independently H or an alkyl or aromatic organic group.

According to yet a further aspect of the present invention, there is provided a process for the synthesis of oligonucleotides comprising a process for adding a sulfur group to an internucleoside linkage as described herein.

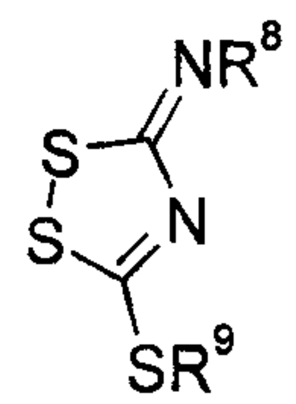
According to still a further aspect of the present invention, there is provided use of a compound of Formula (I);



Formula I

wherein X is R^1, NR^2R^3, NR^4COR^5, SR^6, OR^7; each R^1, R^2, R^3, R^4 and R^5, is independently H or an alkyl or aromatic organic group; and each R^6 and R^7 is independently an alkyl or aromatic organic group;

Formula (II);



Formula II

wherein R^8 is H or an alkyl or aromatic organic group; and R^9 is an alkyl or aromatic organic group; or

Formula (III);

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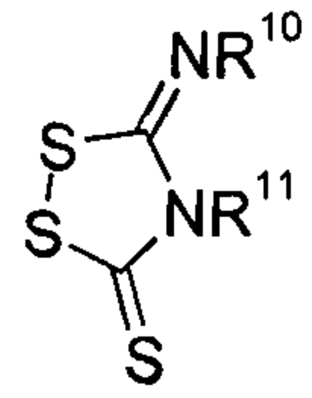


Formula III

wherein R^{10} and R^{11} are each independently H or an alkyl or aromatic organic group;

for the synthesis of oligonucleotides.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows the HPLC of the standard DMT protected T-T phosphothioate dimer. Figure 1A shows the HPLC of the standard P=S dimer. Figure 1B shows the coinjection of P=S and P=O dimers.

Figure 2 shows the HPLC of DMT protected T-T phosphothioate dimer synthesized with compound 1 as a sulfur transfer reagent. Figure 2A represents sulfurization conditions with 4 equiv, 1 min. Figure 2B represents sulfurization conditions with 4 equiv, 5 min. Figure 2C represents sulfurization conditions with 12 equiv, 1 min. Figure 2D represents sulfurization conditions with 12 equiv, 5 min.

Figure 3 is the HPLC of DMT protected T-T phosphothioate dimer prepared with compound 2 as a sulfur transfer reagent.

Figure 4 is the HPLC of DMT protected T-T phosphothioate dimer prepared using compound 3 as a sulfur transfer reagent.

Figure 5 is the HPLC of DMT protected T-T phosphothioate dimer synthesized with compound 4 as a sulfur transfer reagent.

Figure 6 shows the HPLC of SEQ ID NO:1 synthesized with compound 1 as a sulfur transfer reagent. Figure 6A represents 1 min of sulfurization in each synthetic cycle. Figure 6B represents 2 min of sulfurization in each synthetic cycle.

Figure 7 represents the CE of SEQ ID NO:1 synthesized with compound 1 as a sulfur transfer reagent, where the sulfurization occurred for 1 min.

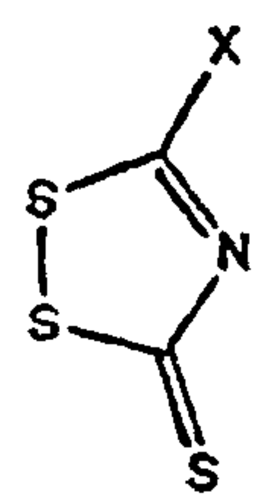
Figure 8 represents the CE of SEQ ID NO: 1 synthesized with compound 1 as a sulfur transfer reagent, where the sulfurization occurred for 2 min.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention relates to the chemical synthesis of oligonucleotides and to chemical entities useful in such synthesis. More particularly, the invention relates to sulfurization of the internucleoside linkages of oligonucleotides. The patents and publications identified in this specification are within the knowledge of those skilled in this field.

The invention provides new sulfur transfer reagents and processes for their use in sulfurizing oligonucleotides. The sulfur transfer reagents according to the invention are inexpensive to make, stable in storage, and highly efficient in sulfurization.

In a first aspect, the invention provides novel sulfur transfer reagents having the structure according to Formula I:



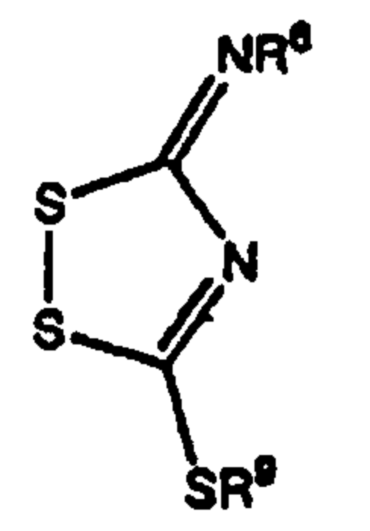
Formula I

wherein X is R^1, NR^2R^3, NR^4COR^5, SR^6, OR^7; each R^1, R^2, R^3, R^4, and R^5, is independently H or an alkyl or aromatic organic group; and each R^6 and R^7 is independently an alkyl or aromatic organic group.

In a preferred embodiment, the sulfur transfer reagent having Formula I is 3-amino-1,2,4-dithiazole-5-thione (1), xanthane hydride (2), 3-*N*-acetyl-3-amino-1,2,4-dithiazole-5-thione (3), 3-*N*-trimethylacetyl-3-amino-1,2,4-dithiazole-

5-thione (4), 3-*N*-benzoyl-3-amino-1,2,4-dithiazole-5-thione (5), or 3-*N*-benzenesulfonyl-3-amino-1,2,4-dithiazole-5-thione (6).

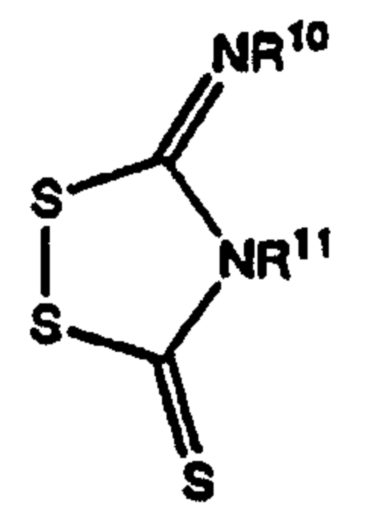
In a second aspect, the invention relates to novel sulfur transfer reagents having the general structure according to Formula II:



Formula II

wherein R^8 is H or an organic group; and R^9 is an organic group.

Another aspect of the invention provides for novel sulfur transfer reagents having the general structure according to Formula III:



Formula III

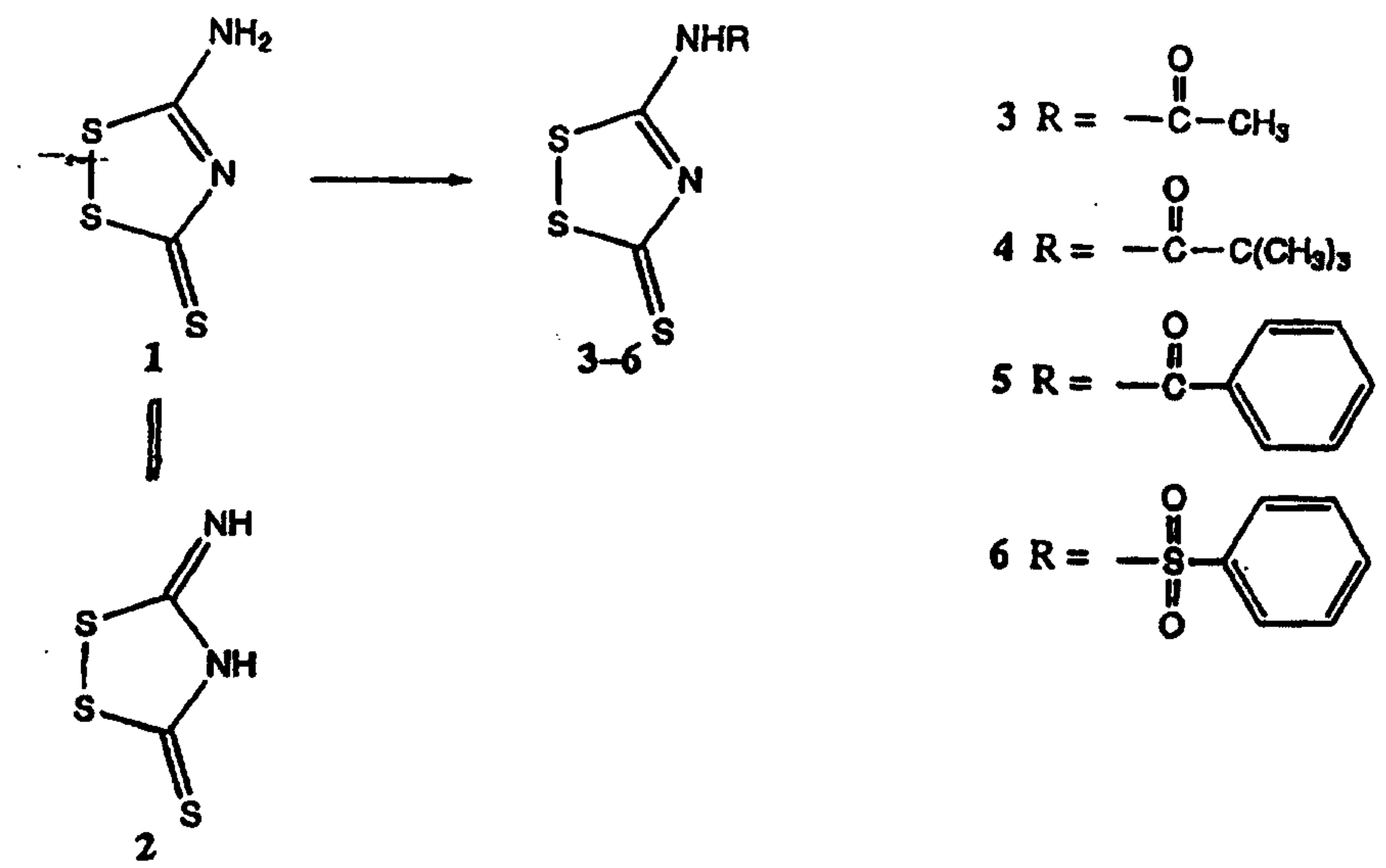
wherein each R^{10} and R^{11} is independently H or an organic group.

In a preferred embodiment, the sulfur transfer reagent having Formula III is 3-amino-1,2,4-dithiazole-5-thione (1), xanthane hydride (2), 3-*N*-acetyl-3-amino-1,2,4-dithiazole-5-thione (3), 3-*N*-trimethylacetyl-3-amino-1,2,4-dithiazole-5-thione (4), 3-*N*-benzoyl-3-amino-1,2,4-dithiazole-5-thione (5), or 3-*N*-benzenesulfonyl-3-amino-1,2,4-dithiazole-5-thione (6).

The compounds 1 and 2, 3-amino-1,2,4-dithiazole-5-thione and xanthane hydride respectively, are commercially available from several chemical companies, including Lancaster, Crescent Chemicals, Maybridge, and TCI America. The purity of compounds **1** and **2** obtained is higher than 98%, and both compounds can be directly used in oligonucleotide synthesis without any additional purification. These compounds have been used in the rubber industry as vulcanization reagents. However, these compounds, to our best knowledge, have not been applied in the synthesis of oligonucleotides.

Derivatives of compound **1** may be easily synthesized. Starting from compound **1**, 3-*N*-acetyl-3-amino-1,2,4-dithiazole-5-thione (**3**), 3-*N*-trimethylacetyl-3-amino-1,2,4-dithiazole-5-thione (**4**), 3-*N*-benzoyl-3-amino-1,2,4-dithiazole-5-thione (**5**), and 3-*N*-benzenesulfonyl-3-amino-1,2,4-dithiazole-5-thione (**6**) were conveniently prepared by solid-phase phosphoramidite approach in a better than 70% yield according to Scheme 1.

Scheme 1



As explained in greater detail below, the reaction conditions included acetic anhydride/pyridine for **3** (96%); trimethyl acetic anhydride/Et_3N for **4** (70%); benzoyl chloride/Et_3N for **5** (70%); and benzene sulfonyl chloride/Et_3N for **6** (76%). The final products can be purified by a simple precipitation.

Stability and solubility studies of the sulfur transfer reagents were performed. Compounds **1-6** are stable in CH_3CN, pyridine-CH_3CN (1:9), and pyridine for more than one week. No precipitation occurred during testing period. All the testing reagents are stable during the operation of automatic DNA synthesizer, no clogging or other problems were observed during the syntheses.

Parent compounds **1** and **2** can be dissolved in CH_3CN to form a 0.01 M solution. Their solubility can be increased with addition of pyridine [0.02 M in pyridine-CH_3CN (1:9); 0.5 M in neat pyridine]. Derivatization of the parent compounds also can improve the solubility in CH_3CN (>0.02 M), e.g., compound **4** has a solubility better than 1 M in neat CH_3CN.

Accordingly, it has been demonstrated that the oligonucleotide phosphorothioates can be efficiently prepared by solid-phase phosphoramidite approach using 3-amino-1,2,4-dithiazole-5-thione (**1**), xanthane hydride (**2**), and their corresponding derivatives. Compounds **1** and **2** are commercially available and relatively inexpensive compared with currently used sulfurizing reagents, such as Beaucage reagent and EDITH. Due to its high efficiency and low cost, compounds **1** and **2**, and their appropriately modified analogues can be considered as an advantageous alternative to Beaucage reagent, especially in large-scale preparation of oligonucleotide phosphorothioates.

In another aspect, the invention provides novel processes for adding a sulfur group to an internucleoside linkage of an oligonucleotide using the novel sulfur transfer reagents according to the invention. In preferred embodiments, the novel processes according to the invention comprise contacting an oligonucleotide having at least one sulfurizable internucleoside linkage with a novel sulfur transfer reagent according to the invention for a time sufficient for sulfurization of the sulfurizable internucleoside linkage(s) to occur. Each sulfurizable internucleoside linkage preferably contains a phosphorous (III) atom. In a particularly preferred embodiment, the sulfurizable internucleoside linkage is a phosphite, thiophosphite, H-phosphonate, thio-H-phosphonate, or alkylphosphite (especially methylphosphite) internucleoside linkage. Preferably, the sulfurization reaction would be allowed to proceed to a sulfur transfer efficiency greater than that expected for the prior art compounds, as measured by ^{31}P-NMR. In typical synthesis conditions such efficiency is achieved within from about 1 to about 5 minutes reaction time with the novel transfer reagents. Typically, the reaction takes place in pyridine, THF, or mixtures thereof. For purposes of this aspect of the invention, the term oligonucleotide includes linear polymers of two or more natural deoxyribonucleotide, ribonucleotide, or 2'-O-substituted ribonucleotide monomers, or any combination thereof. The term oligonucleotide also encompasses such polymers having chemically modified bases or sugars and/or non-nucleosidic analogs linked by phosphodiester bonds or analogs thereof ranging in size from a few monomeric units, e.g., 2-3, to several hundred monomeric units and/or having additional substituents, including without limitation lipophilic groups, intercalating agents, diamines and adamantane. In particular, oligonucleotides may also include non-natural oligomers having phosphorous-containing internucleoside linkages whose phosphorous (III) precursors are amenable to sulfurization, (See, e.g., Takeshita et al., *J. Biol. Chem* 282: 10171-10179 (1987).) For purposes of the invention, the term "2'-O-substituted" means substitution of the 2' position of the pentose moiety with an -O-lower 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 halogen, hydroxy, trifluoromethyl, cyano, nitro, acyl, acyloxy, alkoxy, carboxy, carbalkoxy, or amino groups; or with a hydroxy, an amino or a halogen group, but not with a 2'-H group. Such oligonucleotides may include any of the internucleoside linkages which are known in the art, including without limitation phosphorothioate, phosphorodithioate, alkylphosphonate (especially methylphosphonate), phosphoramidate, amide (PNA), carbamate, and alkylphosphonothioate linkages. In a preferred embodiment, the oligonucleotide is bound to a solid support, but such oligonucleotides may be sulfurized in solution phase as well.

The efficiency of these new sulfur-transfer reagents was first evaluated by solid-phase syntheses of dinucleotide phosphorothioate, 5'-DMT-TT-OH-3'. (Figure 1.) Synthesis was performed at 1.0 µmol scale using the standard phosphorothioate protocol ("THIO 1µmol"). The dinucleotide phosphorothioate was analyzed by reverse-phase HPLC. The results show that a better than 99% sulfur transfer efficiency was achieved using compounds 1 and 2. (Figures 2 and 3, respectively.) Compounds 3-4 were also found to be efficient sulfur-transfer reagents. (Figures 4-5.)

To further evaluate the usefulness of compounds 1 and 2 as efficient sulfurizing reagents, an oligonucleotide phosphorothioate, 5'-CTCTCGCACCCATCTCTCTCCTTCT-3' (SEQ ID NO:1), was synthesized at 1.0 µmol scale using a 0.02 M solution in CH_3CN/pyridine (9:1) for 1 or 2 min of sulfurization in each synthetic cycle. After ammonolytic release from CPG and deprotection, the crude oligonucleotide phosphorothioate was analyzed by ion exchange-HPLC and CE. (Figures 6-8.) The results show that more than 99.5% sulfur transfer efficiency was achieved at each step, and a yield better than 80% has been achieved in these syntheses (see Figure 3).

Examples

The following examples are intended to further illustrate certain preferred embodiments of the invention and are not intended to be limiting in nature.

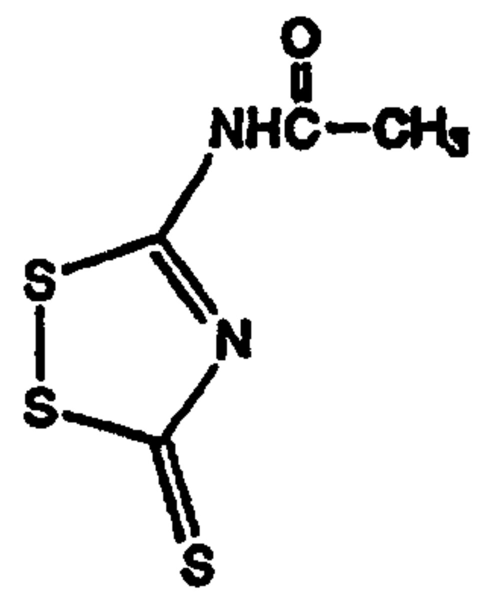
In general, anhydrous pyridine and CH_2Cl_2 were purchased from Aldrich (Milwaukee, WI). Anhydrous CH_3CN was purchased from J. T. Baker Inc. (Phillipsburg, NJ). dT-CPG, 5'-DMT-thymidine cyanoethyl phosphoramidite, Cap A, Cap B, activator, oxidizing and deblock solutions were purchased from PerSeptive Biosystems, (Framingham, MA). Beaucage reagent (^{3}H-1,2-benzodithiol-3-one-1,1-dioxide) was purchased from R. I. Chemical (Orange, CA). All other chemicals were purchased from Aldrich. ^{31}P NMR spectra (121.65 MHz) and ^1H NMR spectra (300 MHz) were recorded on a Varian UNITY 300 (the chemical shift was correlated to 85% H_3PO_4 and tetramethylsilane, respectively). Dinucleotide and oligonucleotide syntheses were performed on an automated nucleic acid synthesizer (8909 Expedite™, Millipore, Bedford, MA). Reverse phase HPLC was performed on a Waters 600E pump with a Waters 440 absorbance detector, Waters 746 integrator, and a Nova-Pak C18 (3.9 X 150 mm) column, using a linear gradient of CH_3CN-aqueous NH_4OAc (0.1 M) (4:1) and 0.1 M aqueous NH_4OAc from 1:9 to 3:2 over a period of 40 min, flow rate 2 mL/min, detection at 260 nm. Ion-exchange HPLC analyses were performed on a Beckman System Gold 126 with a Beckman 166 absorbance detector on a NUCEOPAC PA-100 column (4 x 50 mm) using a linear gradient of Buffer A (25 mM of Tris-HCl and 1 mM EDTA, CH_3CN, pH=8) and Buffer B (2 M NaCl and buffer A) from 100% A to 100% B over a period of 5 min, then maintained at 100% B for 3 min, flow rate 2 mL/min, detection at 254 nm. Capillary electrophoresis was performed on a Beckman P/ACE System 5010. Samples were injected for 5 seconds and analyzed for 40 min.

The compound 3-amino-1,2,4-dithiazole-5-thione (1) was commercially available at 98% purity from several chemical companies, including Lancaster, Crescent Chemicals, and Maybridge, and can be directly used without further purification.

The compound xanthane hydride (2) was commercially available from TCI America at 98% purity, and can be directly used without any further purification.

Example 1

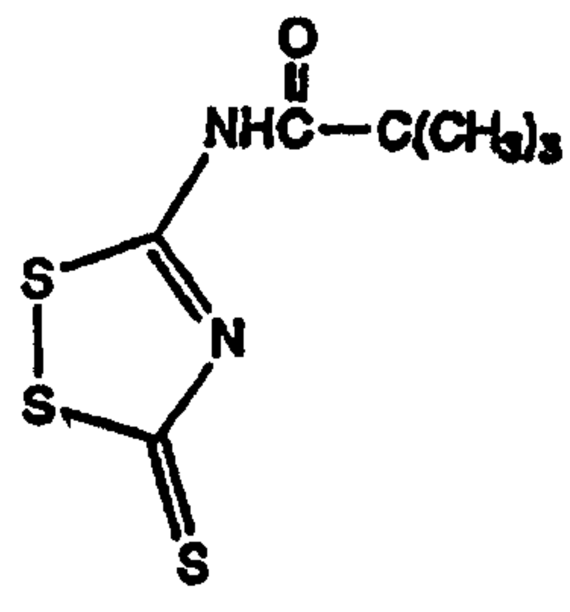
Synthesis of 3-*N*-acetyl-3-amino-1,2,4-dithiazole-5-thione (3)



Neat acetic anhydride (1.49 mL, 16 mmol) was added dropwise to the suspension of 3-amino-1,2,4-dithiazole-5-thione (compound 1, 2.0 g, 13 mmol) in the mixture of pyridine-CH_3CN (1:5, 50 mL) over a period of 30 min. The resultant clear yellow solution was stirred at 25°C for 1 h, then concentrated under reduced pressure. The resultant yellow solid was dissolved in EtOAc (500 mL), washed with 10% aqueous citric acid (500 mL), H_2O (2 x 500 mL), then brine (500 mL), and then dried over Na_2SO_4. Evaporation of the organic solvent gave the title yellow solid. Yield: 2.50 g (96%); m.p. 229.6-230.1° C.

Example 2

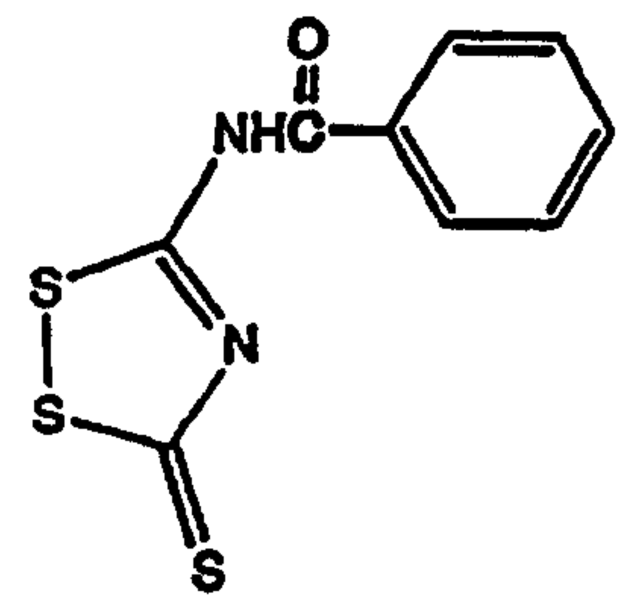
Synthesis of 3-*N*-trimethylacetyl-3-amino-1,2,4-dithiazole-5-thione (4)



Neat trimethylacetic anhydride (3.20 mL, 16 mmol) was added to the suspension of 3-amino-1,2,4-dithiazole-5-thione (compound 1, 2.0 g, 13 mmol) in the mixture of Et_3N-CH_2Cl_2 (1:5, 30 mL) in one portion. A clear yellow solution was obtained in 10 min, and stirred at 25°C for 2 h, and then concentrated under reduced pressure. The resultant yellow solid was dissolved in EtOAc (100 mL), washed with 10% aqueous citric acid (2 x 100 mL), H_2O (2 x 100 mL), then brine (100 mL), and then dried over NA_2SO_4. Organic solvent was removed under reduced pressure, the resultant yellow solid was treated with hexane (100 mL) and stored at 4 °C for 2 h. The yellow precipitate was collected by filtration, washed with hexane (3 x 5 mL), and dried *in vacuo*. Yield: 2.17 g (70%); m.p. 179.6-179.6°C.

Example 3

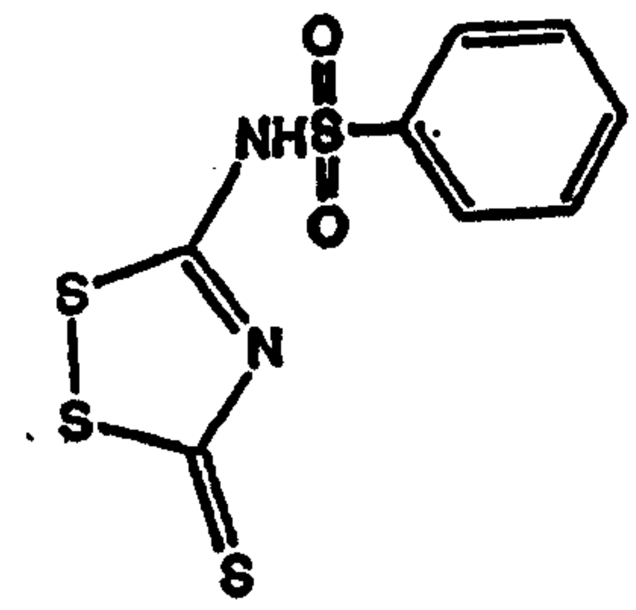
Synthesis of 3-*N*-benzoyl-3-amino-1,2,4-dithiazole-5-thione (5)



3-Amino-1,2,4-dithiazole-5-thione (compound **1**, 1.0 g, 6.6 mmol) was suspended in the mixture of Et_3N-CH_2Cl_2 (1:5, 20 mL), followed by addition of benzoic chloride (0.92 mL, 1.2 equiv). A clear yellow solution was obtained in 5 min. Reaction solution was stirred at 25°C for 2 h, then concentrated under reduced pressure to remove organic solvent. The resultant yellow solid was treated with EtOAc (200 mL), the insoluble solid was removed by filtration, and the EtOAc layer was washed with 10% aqueous citric acid (2 x 200 mL), H_2O (2 x 200 mL), brine (200 mL), and dried over Na_2SO_4. Evaporation of EtOAc gave a yellow solid, which was treated with CH_2Cl_2 (100 mL), then followed by addition of hexane (100 mL). The resultant solid was removed by filtration, and the filtrate was removed under reduced pressure to give a yellow solid. Yield: 1.17 g (70%).

Example 4

Synthesis of 3-*N*-benzenesulfonyl-3-amino-1,2,4-dithiazole-5-thione (6)



Except that benzene sulfonyl chloride was used instead of benzoic chloride, the reaction conditions and work-up process are identical to the preparation of compound 5. Yield: 1.46 g (76%).

Example 5

Stability and Solubility Studies of Xanthane Hydride, 3-Amino-1,2,4-dithiazole-5-thione, and Their Corresponding Derivatives in CH_3CN

The solubility and stability studies were carried out in CH_3CN, pyridine-CH_3CN (1:9), and pyridine at 25°C in all the cases. The saturated solution was dried, and the solubility was determined by the weight of the testing compounds in the exact volume of testing solution. The stability was determined based on either TLC or HPLC analyses.

Example 6

Synthesis of Dinucleotide Phosphorothioate

Dimer was assembled on a PerSeptive DNA/RNA (Millipore 8909 Expedite™, Millipore, Bedford, MA) on a 0.1 μmol scale using the synthesis protocol "THIO 1 μmol" (Expedite software version 1.01), starting from DMT-T-Su-CPG (500 Å, loading: 60 μmol/g). Sulfurizing reagents were prepared in either CH_3CN or pyridine-CH_3CN (1:9) at a concentration of 0.02 M unless specified. Sulfurization was carried out using 4 equiv or 12 equiv of sulfurizing reagents for 1 or 5 min reaction, respectively. Final cleavage was carried out by treatment using concentrated ammonium hydroxide (1 μmol/1 mL) at 25°C for 1 h. CPG and other insoluble residues were removed by filtration, and the ammonium hydroxide solution was dried by lyophilization. HPLC analysis was carried out using a linear gradient of 0.1 M aqueous NH_4OAc and CH_3CN-aqueous NH_4OAc (0.1 M) (4:1) from 1:9 to 3:2 over a period of 40 min, flow rate 1.0 mL/min, detection at 260 nm. 5'-DMT-T(P=S)-T-OH-3' diastereomers were eluted at t_R = 31.6 min and t_R = 31.7 min. The corresponding P=O dimer was eluted at t_R = 28.4 min. (Figure 1.)

Example 7

Synthesis of a Oligonucleotide Phosphorothioate (5'-CTCTCGCACCCATCTCTCTCCTTCT-3' (SEQ ID NO:1))

The chain assembly was carried out using the same protocol as described in the dinucleotide phosphorothioate synthesis. Sulfurizing reagent (compound 1) was prepared at a concentration of 0.02 M in pyridine-CH_3CN (1:9), and sulfurization was carried out using 12 equiv for 1 or 2 min, respectively. Ion exchange HPLC and CE analyses were performed to evaluate the synthesis of this oligomer.

SEQUENCE LISTING

(1) GENERAL INFORMATION:

(i) APPLICANT: HYBRIDON, INC.

(ii) TITLE OF INVENTION: NOVEL SULFUR TRANSFER REAGENTS FOR OLIGONUCLEOTIDE SYNTHESIS

(iii) NUMBER OF SEQUENCES: 1

(iv) CORRESPONDENCE ADDRESS:
(A) ADDRESSEE: SWABEY OGILVY RENAULT
(B) STREET: 1981 McGill College Avenue, Suite 1600
(C) CITY: Montréal
(D) STATE: Québec
(E) COUNTRY: CANADA
(F) ZIP: H3A 2Y3

(v) COMPUTER READABLE FORM:
(A) MEDIUM TYPE: Floppy disk
(B) COMPUTER: IBM PC compatible
(C) OPERATING SYSTEM: PC-DOS/MS-DOS
(D) SOFTWARE: PatentIn Release #1.0, Version #1.30

(vi) CURRENT APPLICATION DATA:
(A) APPLICATION NUMBER: 2,291,688
(B) FILING DATE: 26-MAY-1998
(C) CLASSIFICATION:

(vii) PRIOR APPLICATION DATA:
(A) APPLICATION NUMBER: PCT/US98/10653
(B) FILING DATE: 26-MAY-1998

(vii) PRIOR APPLICATION DATA:
(A) APPLICATION NUMBER: US 08/865,666
(B) FILING DATE: 30-MAY-1997

(viii) ATTORNEY/AGENT INFORMATION:
(A) NAME: Côté, France
(B) REGISTRATION NUMBER: 4166
(C) REFERENCE/DOCKET NUMBER: 9351-28 FC

(ix) TELECOMMUNICATION INFORMATION:
(A) TELEPHONE: 514-845-7126
(B) TELEFAX: 514-288-8389

(2) INFORMATION FOR SEQ ID NO:1:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 25 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

CA 02291688 2000-05-29

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

CTCTCGCACC CATCTCTCTC CTTCT 25

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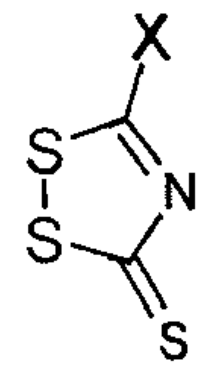
CLAIMS:

1. A sulphur transfer reagent having the general structure according to Formula I



Formula I

wherein X is R^1, NR^2R^3, NR^4COR^5, SR^6 or OR^7; each R^1, R^2, R^3, R^4 and R^5, is independently H or an alkyl or aromatic organic group; and each R^6 and R^7 is independently an alkyl or aromatic organic group:

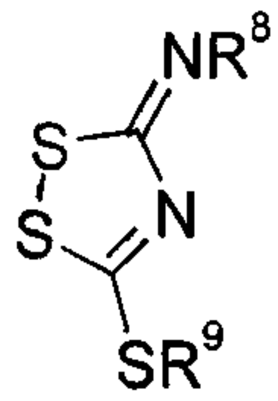
provided that:

when X is NR^2R^3 that R^2 and R^3 are not both H or are not both CH_3; and

when X is $NHCOR^5$, R^5 can not be an alkyl group of C_8 or greater.

2. A sulphur transfer reagent according to claim 1 selected from 3-N-acetyl-3-amino-1,2,4-dithiazole-5-thione, 3-N-trimethylacetyl-3-amino-1,2,4-dithiazole-5-thione, 3-N-benzoyl-3-amino-1,2,4-dithiazole-5-thione, and 3-N-benzenesulfonyl-3-amino-1,2,4-dithiazole-5-thione.

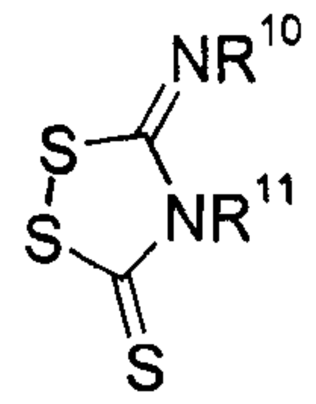
3. A sulphur transfer reagent having the general structure according to Formula II



Formula II

wherein R^8 is H or an alkyl or aromatic organic group; and R^9 is an alkyl or aromatic organic group.

4. A sulphur transfer reagent having the general structure according to Formula III

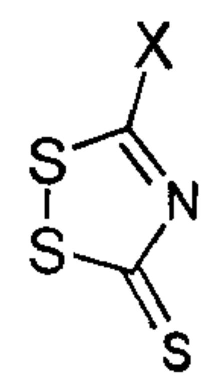


Formula III

wherein R^{10} is an alkyl or aromatic organic group and R^{11} is H;

provided that R^{10} is not NCOalkyl where the alkyl group is C_8 or greater.

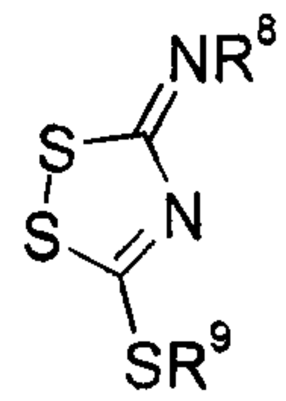
5. A process for adding a sulphur group to an internucleoside linkage of an oligonucleotide, the process comprising contacting an oligonucleotide having at least one sulfurizable internucleoside linkage with a sulphur transfer reagent of Formula (I);



Formula I

wherein X is R^1, NR^2R^3, NR^4COR^5, SR^6, OR^7; each R^1, R^2, R^3, R^4 and R^5, is independently H or an alkyl or aromatic organic group; and each R^6 and R^7 is independently an alkyl or aromatic organic group;

Formula (II);



Formula II

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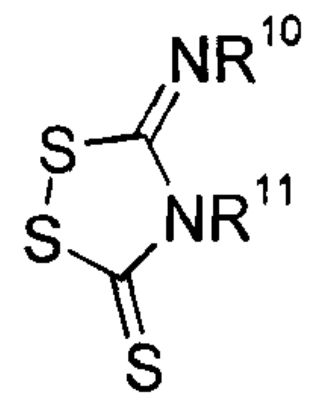
wherein R^8 is H or an alkyl or aromatic organic group; and R^9 is an alkyl or aromatic alkyl or aromatic organic group; or

Formula (III);



Formula III

wherein R^{10} and R^{11} are each independently H or an alkyl or aromatic organic group:

for a time sufficient for sulfurization of the sulfurizable internucleoside linkage(s) to occur.

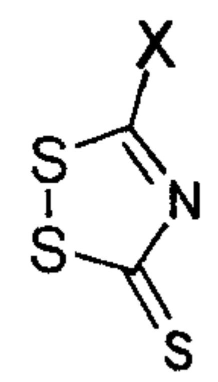
6. A process according to claim 5 wherein the sulfur transfer agent is 3-amino-1,2,4-dithiazole-5-thione, xanthane hydride, 3-N-acetyl-3-amino-1,2,4-dithiazole-5-thione, 3-N-trimethylacetyl-3-amino-1,2,4-dithiazole-5-thione, 3-N-benzoyl-3-amino-1,2,4-dithiazole-5-thione, or 3-N-benzenesulfonyl-3-amino-1,2,4-dithiazole-5-thione.

7. A process according to either claim 5 or claim 6, wherein each sulfurizable internucleoside linkage contains a phosphorous (III) atom.

8. A process according to any one of claims 5 to 7, wherein the sulfurizable internucleoside linkage is a phosphite, thiophosphite, H-phosphonate, thio-H-phosphonate, or alkylphosphite internucleoside linkage.

9. A process according to any one of claims 5 to 8, wherein the sulfurization reaction is allowed to proceed from about 1 to about 5 minutes.

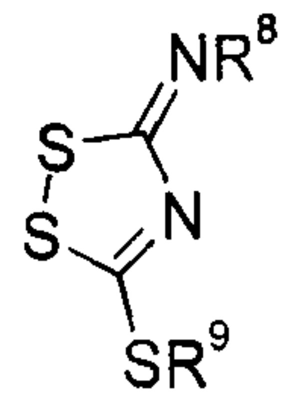
10. A process for the synthesis of oligonucleotides comprising contacting an oligonucleotide having at least one sulfurizable internucleoside linkage with a sulfur transfer reagent, wherein the sulfur transfer agent is of Formula (I);



Formula I

wherein X is R^1, NR^2R^3, NR^4COR^5, SR^6, OR^7; each R^1, R^2, R^3, R^4 and R^5, is independently H or an alkyl or aromatic organic group; and each R^6 and R^7 is independently an alkyl or aromatic organic group;

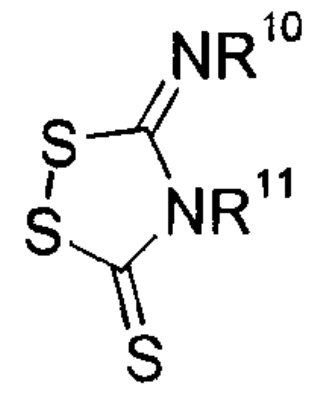
Formula (II);



Formula II

wherein R^8 is H or an alkyl or aromatic organic group; and R^9 is an alkyl or aromatic organic group; or

Formula (III);



Formula III

wherein R^{10} and R^{11} are each independently H or an alkyl or aromatic organic group.

11. A process according to claim 10 wherein the sulfur transfer reagent is 3-amino-1,2,4-dithiazole-5-thione.

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12. A process according to claim 10 wherein the sulfur transfer reagent is xanthane hydride.

13. A process according to claim 10 wherein the sulfur transfer reagent is 3-N-acetyl-3-amino-1,2,4-dithiazole-5-thione.

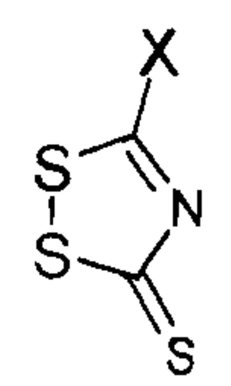
14. A process according to claim 10 wherein the sulfur transfer reagent is 3-N-trimethylacetyl-3-amino-1,2,4-dithiazole-5-thione.

15. A process according to claim 10 wherein the sulfur transfer reagent is 3-N-benzoyl-3-amino-1,2,4-dithiazole-5-thione.

16. A process according to claim 10 wherein the sulfur transfer reagent is 3-N-benzenesulfonyl-3-amino-1,2,4-dithiazole-5-thione.

17. A process for the synthesis of oligonucleotides comprising a process for adding a sulfur group to an internucleoside linkage as defined in any one of claims 5 to 9.

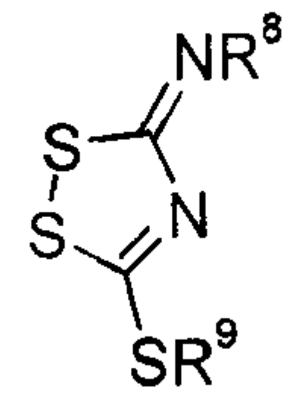
18. Use of a compound of Formula (I);



Formula I

wherein X is R^1, NR^2R^3, NR^4COR^5, SR^6, OR^7; each R^1, R^2, R^3, R^4 and R^5, is independently H or an alkyl or aromatic organic group; and each R^6 and R^7 is independently an alkyl or aromatic organic group;

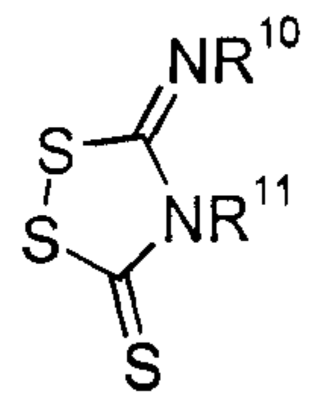
Formula (II);



Formula II

wherein R^8 is H or an alkyl or aromatic organic group; and R^9 is an alkyl or aromatic organic group; or

Formula (III);



Formula III

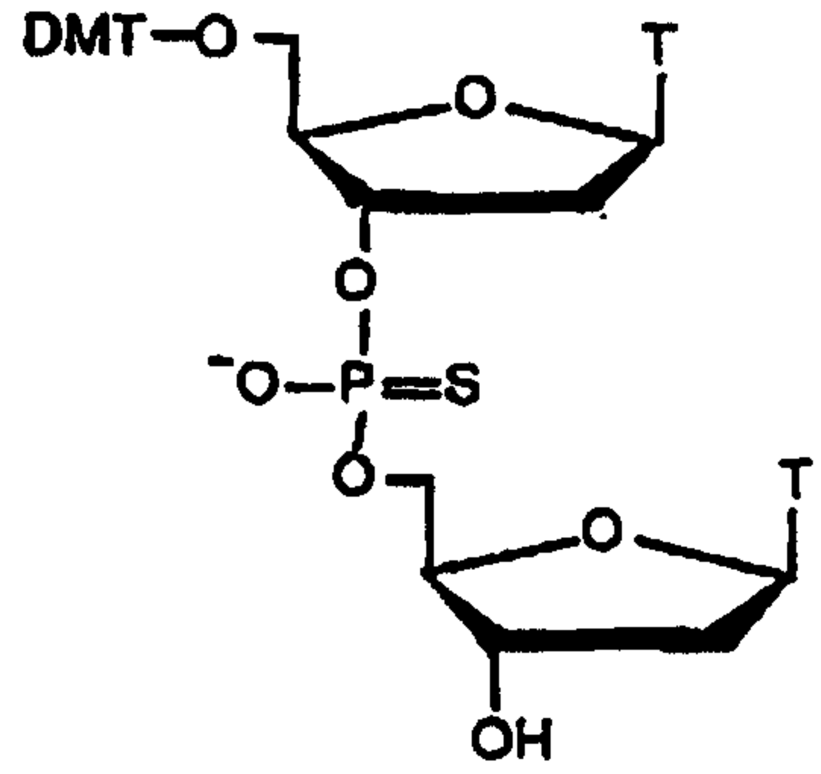
wherein R^{10} and R^{11} are each independently H or an alkyl or aromatic organic group;

for the synthesis of oligonucleotides.

19. Use according to claim 18 wherein the compound of Formula (I), (II) or (III) is selected from the group consisting of 3-amino-1,2,4-dithiazole-5-thione, xanthane hydride, 3-N-acetyl-3-amino-1,2,4-dithiazole-5-thione, 3-N-trimethylacetyl-3-amino-1,2,4-dithiazole-5-thione, 3-N-benzoyl-3-amino-1,2,4-dithiazole-5-thione, and 3-N-benzenesulfonyl-3-amino-1,2,4-dithiazole-5-thione.

SMART & BIGGAR
OTTAWA, CANADA

PATENT AGENTS



(Standard)

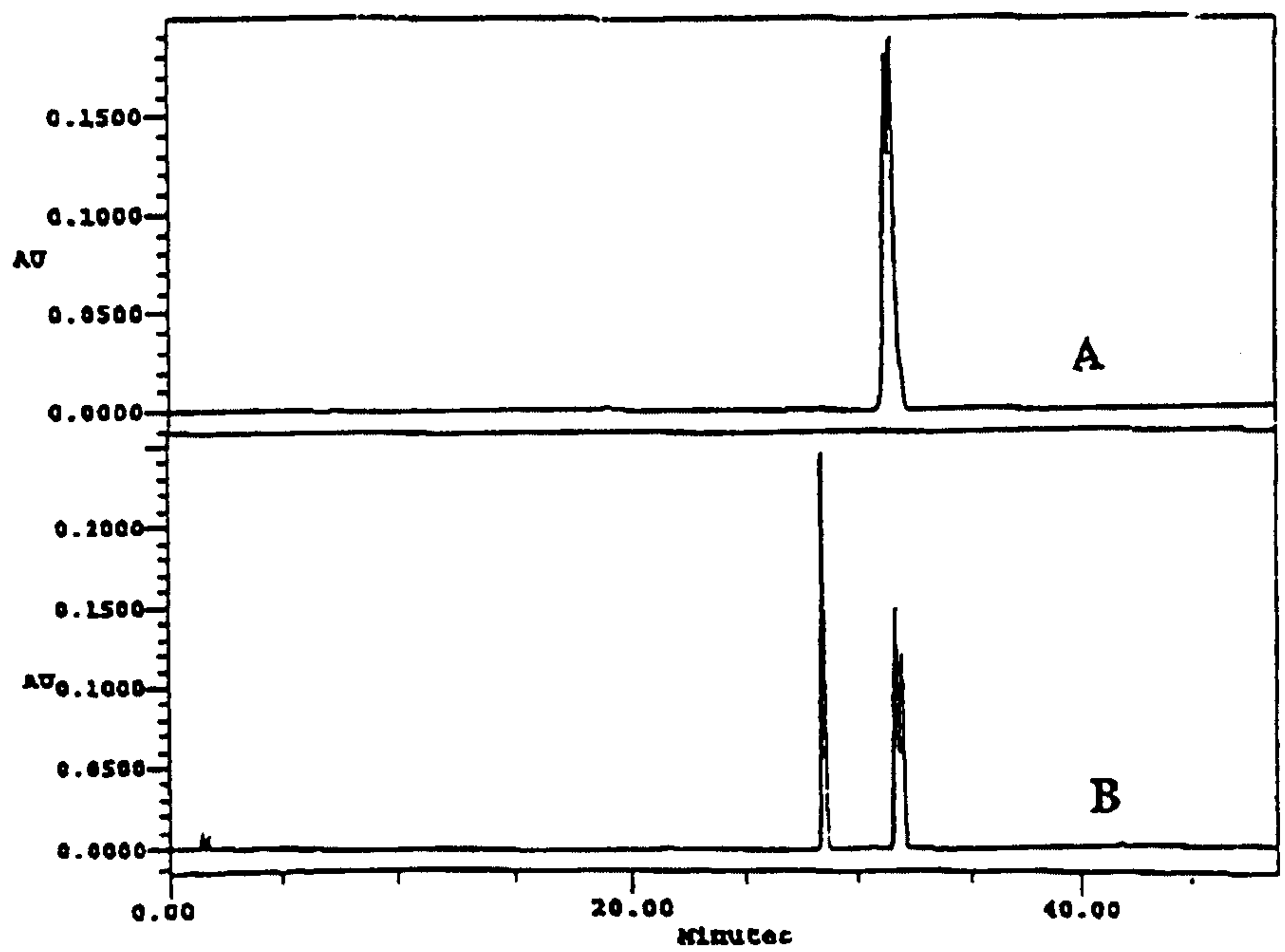


Figure 1. HPLC of standard DMT protected T-T phosphothioate dimer. HPLC was carried on a Nova-Pak C18 column (60 Å, 3.9 x 150 mm) using a linear gradient of 0.1 M aqueous NH_4OAc and CH_3CN–aqueous NH_4OAc (0.1 M) (4:1) from 1:9 to 3:2 over a period of 40 min, detection at 254 nm, flow rate 1.0 mL/min. A: standard P=S dimer; B: coinjection of P=S and P=O dimers.

Sy esis of 5'-DMT- T(P=S)-T-C.1 Using 3-Amino-1,2,4-Dithiazole-5-Thione

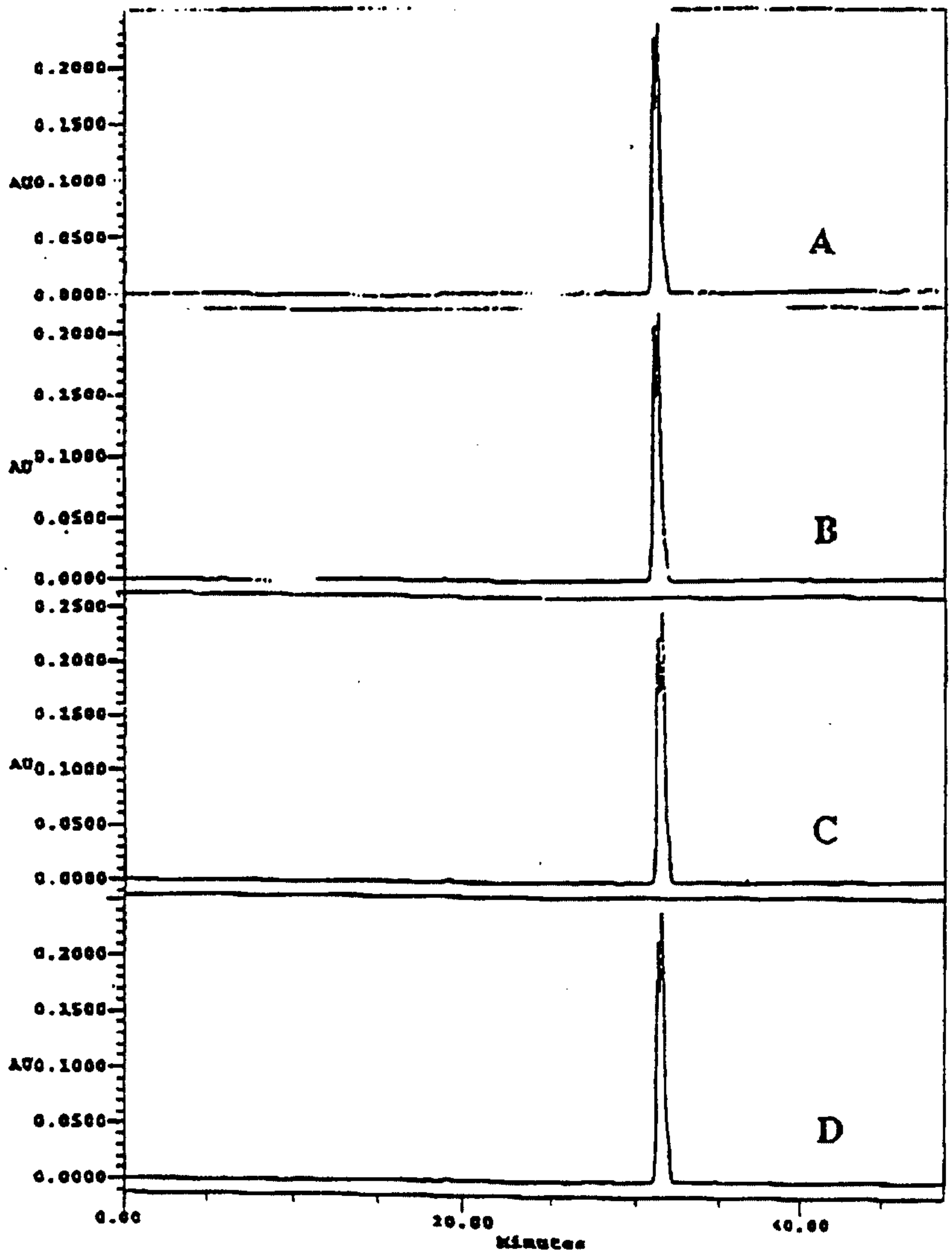


Figure 2. HPLC of DMT protected T-T phosphothioate dimer prepared using 3-amino-1,2,4-dithiazole-5-thione as sulfurizing reagent. HPLC conditions as Figure 1. Sulfurization was carried out at a concentration of 0.02 M in pyridine–CH_3CN (1:9): A: 4 equiv, 1 min (purity, 98.3%; P=O, 0.32%); B: 4 equiv, 5 min (purity, 98.5%; P=O, 0.28%); C: 12 equiv; 1 min (purity, 98.3%; P=O, 0.44%);; D: 12 equiv, 5 min (purity, 98.5%; P=O, 0.38%).

Synthesis of 5'-DMT- T(P=S)-T-OH Using Xanthane Hydride

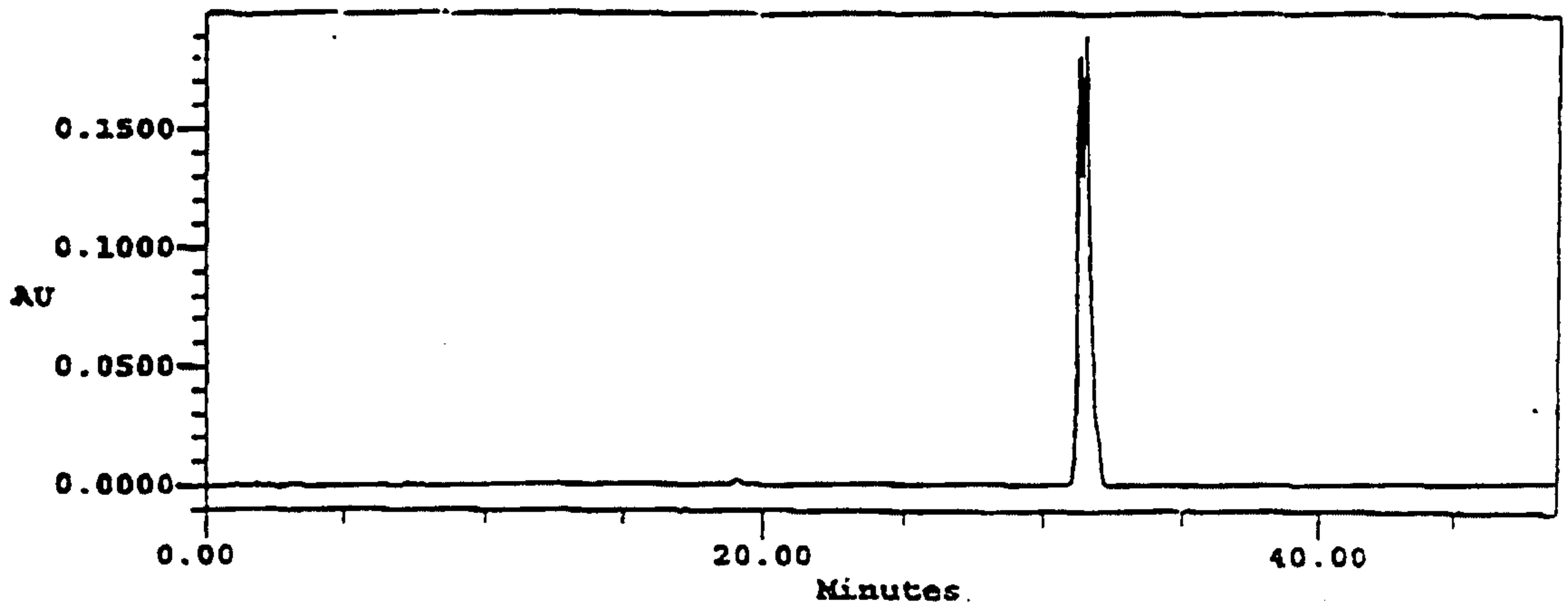


Figure 3. HPLC of DMT protected T-T phosphothioate dimer prepared using xanthane hydride as sulfurizing reagent. HPLC conditions as Figure 1. Sulfurization was carried out in pyridine–CH_3CN (1:9) at a concentration of 0.02 M (12 equiv) for 5 min. Purity: 98.5%; P=O: 0.35%.

Synthesis of 5'-DMT- T(P=S)-T-OH

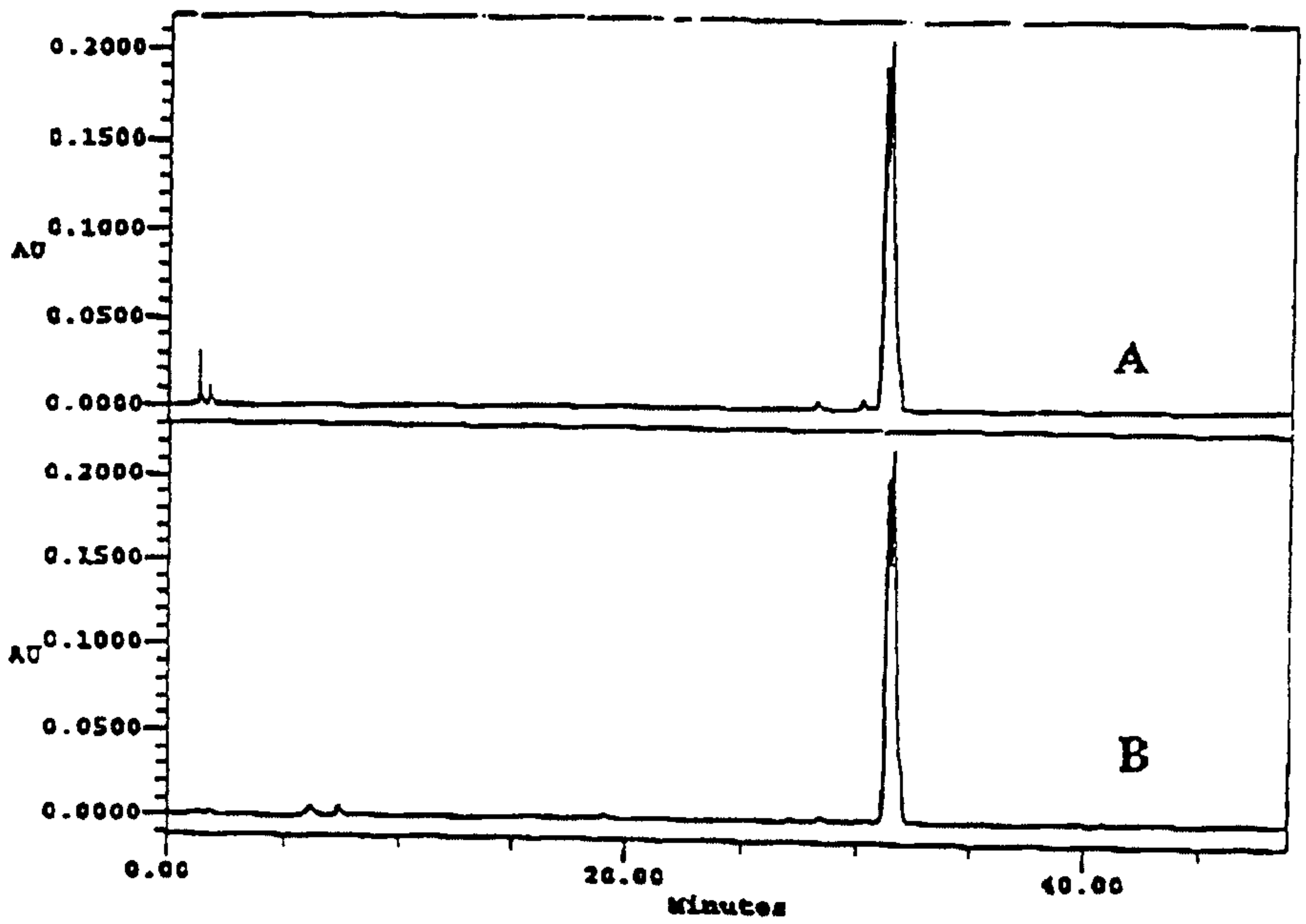


Figure 4. HPLC of DMT protected T-T phosphothioate dimer prepared using 3-*N*-acetyl-3-amino-1,2,4-dithiazole-5-thione as sulfurizing reagent. HPLC conditions as Figure 1. Sulfurization was carried out: A: 0.02 M (12 equiv) in pyridine–CH_3CN (1:9), 1 min (purity: 96.6%, P=O, 1.5%); B: : 0.02 M (12 equiv) in CH_3CN, 5 min (purity: 96.6%, P=O, 1.5%).

Synthesis of 5'-DMT- T(P=S)-T-OH

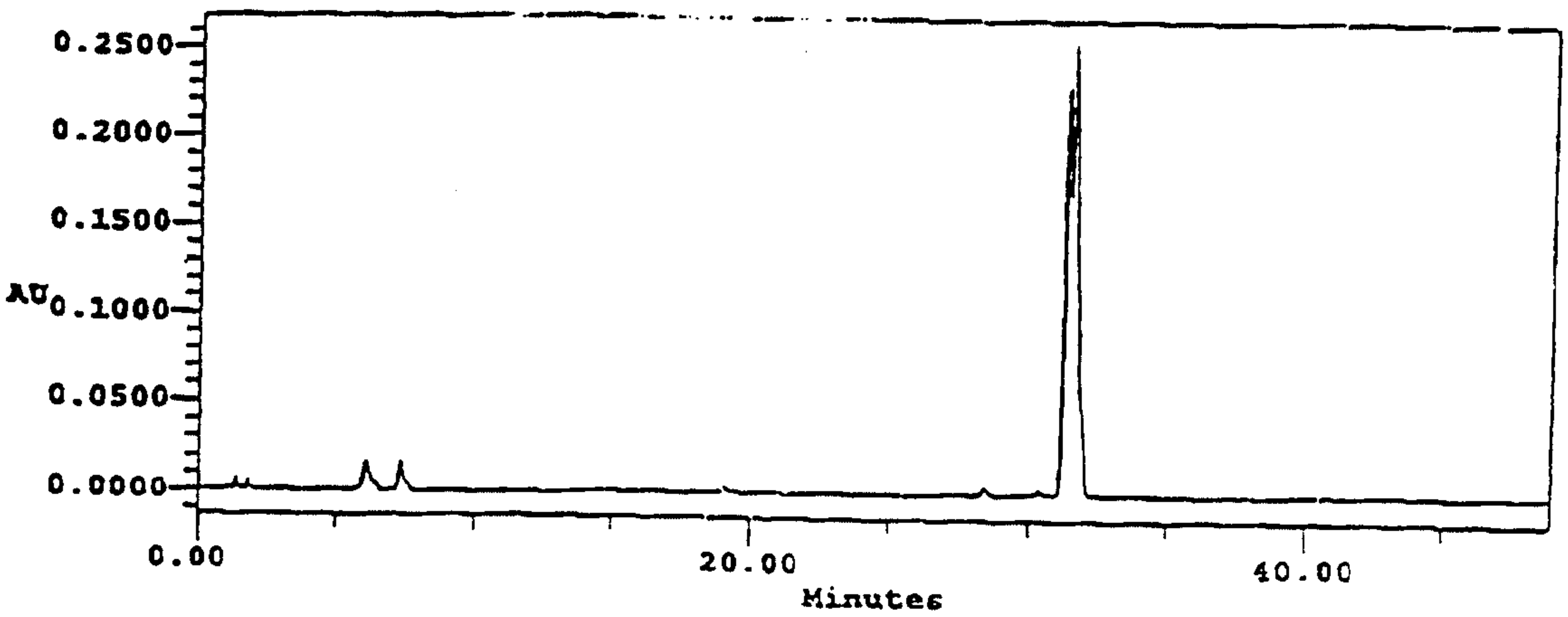


Figure 5. HPLC of DMT protected T-T phosphothioate dimer prepared using 3-*N*-trimethylacetyl-3-amino-1,2,4-dithiazole-5-thione as sulfurizing reagent. HPLC conditions same as Figure 1. Sulfurization was carried out in CH_3CN at a concentration of 0.06 M (12 equiv) for 5 min (purity: 90.7%; 1.09%).

SEQ ID NO:1

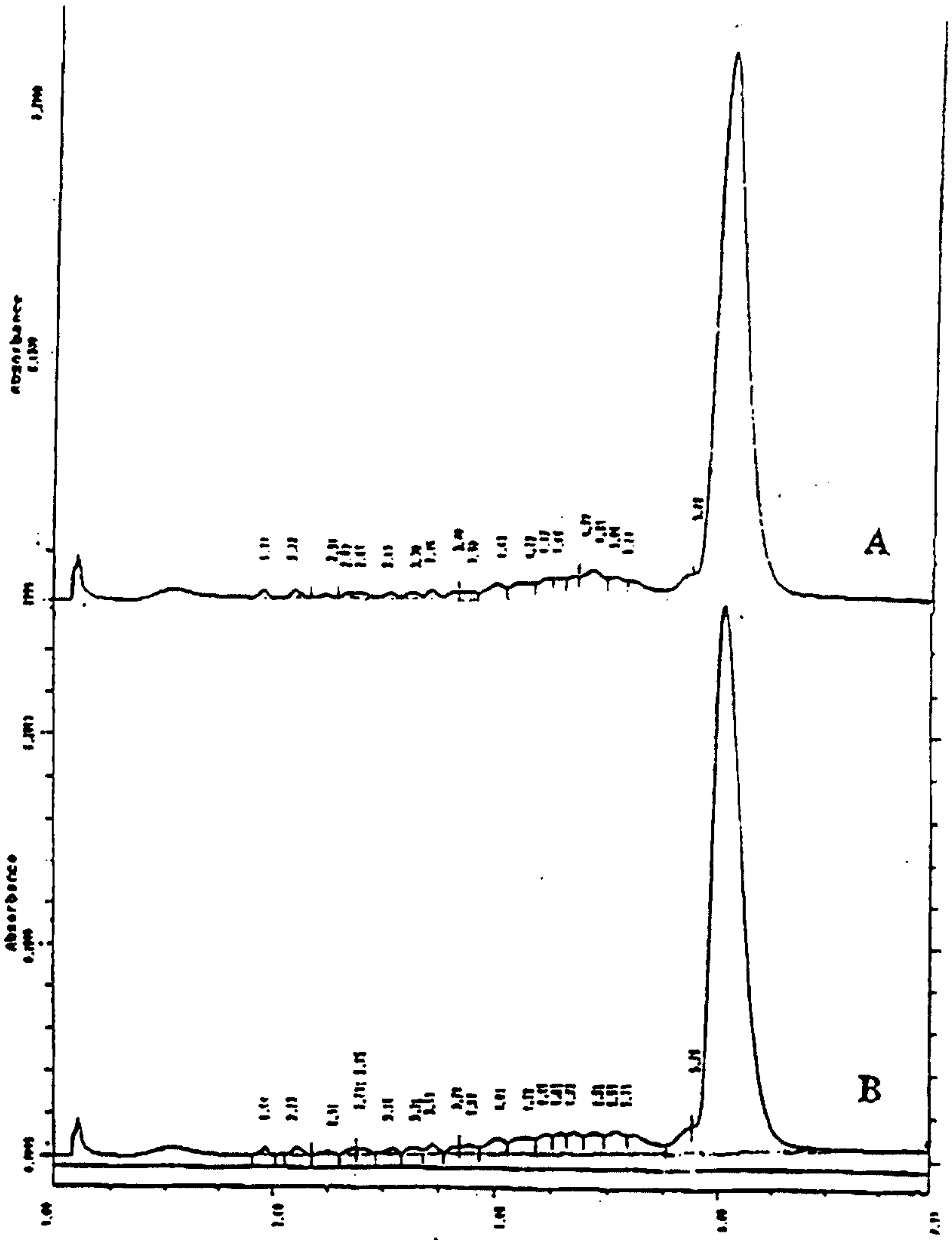


Figure 6. Ion-exchange HPLC of SEQ ID NO:1 prepared using 3-amino-1,2,4-diazole-5 thione (1) as sulfurizing reagent. HPLC conditions see General in Experimental Section. Sulfurization was carried out at a concentration of 0.02 M (12 equiv) in pyridine–CH_3CN (1:9): A: 1 min (purity, 80.7%; total P=O, 2.48%; 0.103% P=O per step); B: 2 min (purity, 81.6%; total P=O, 2.38%; 0.099% P=O per step).

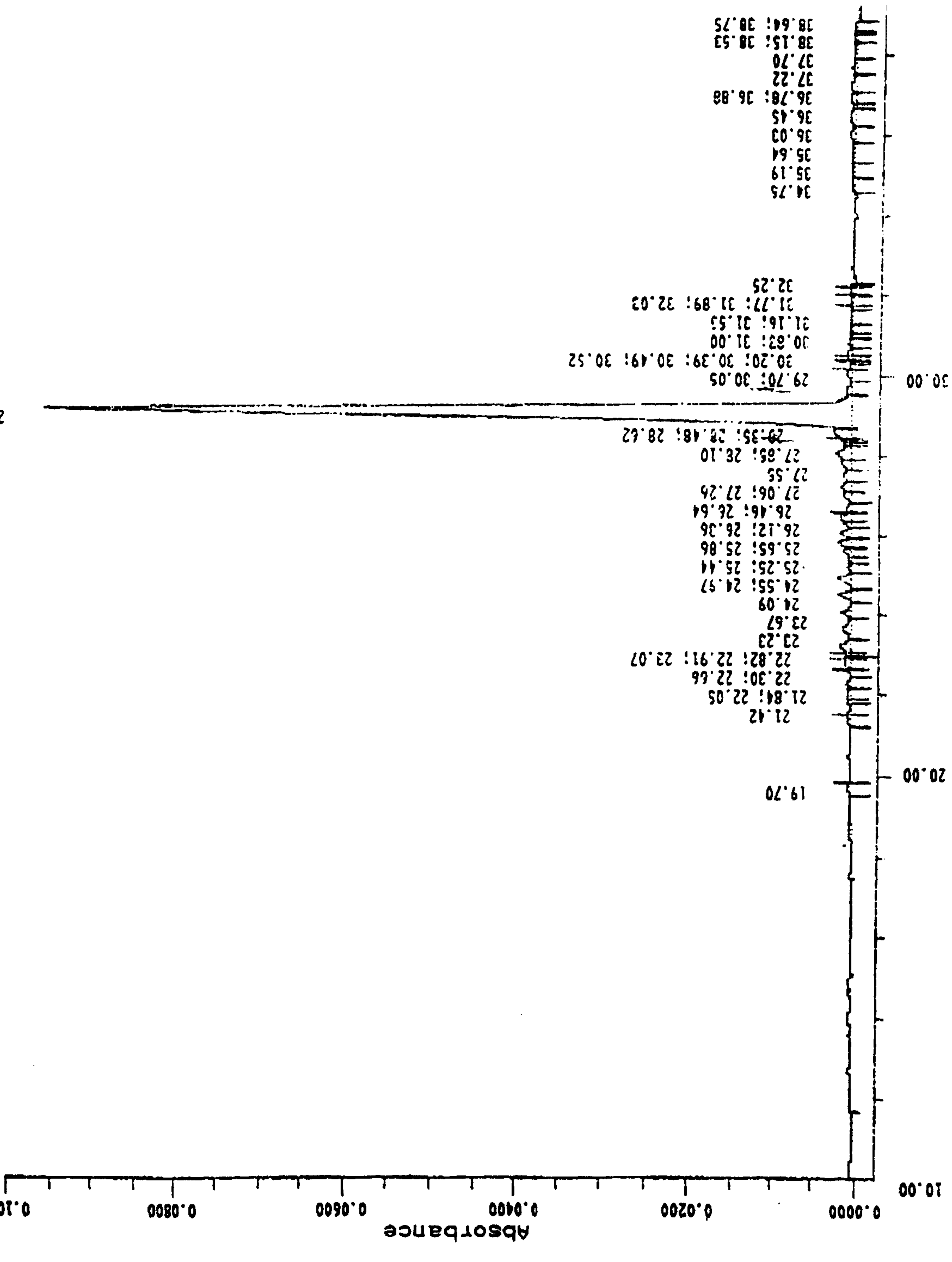


Figure 7

Synthesis of SEQ ID NO:1 with Compound 1, 1 min

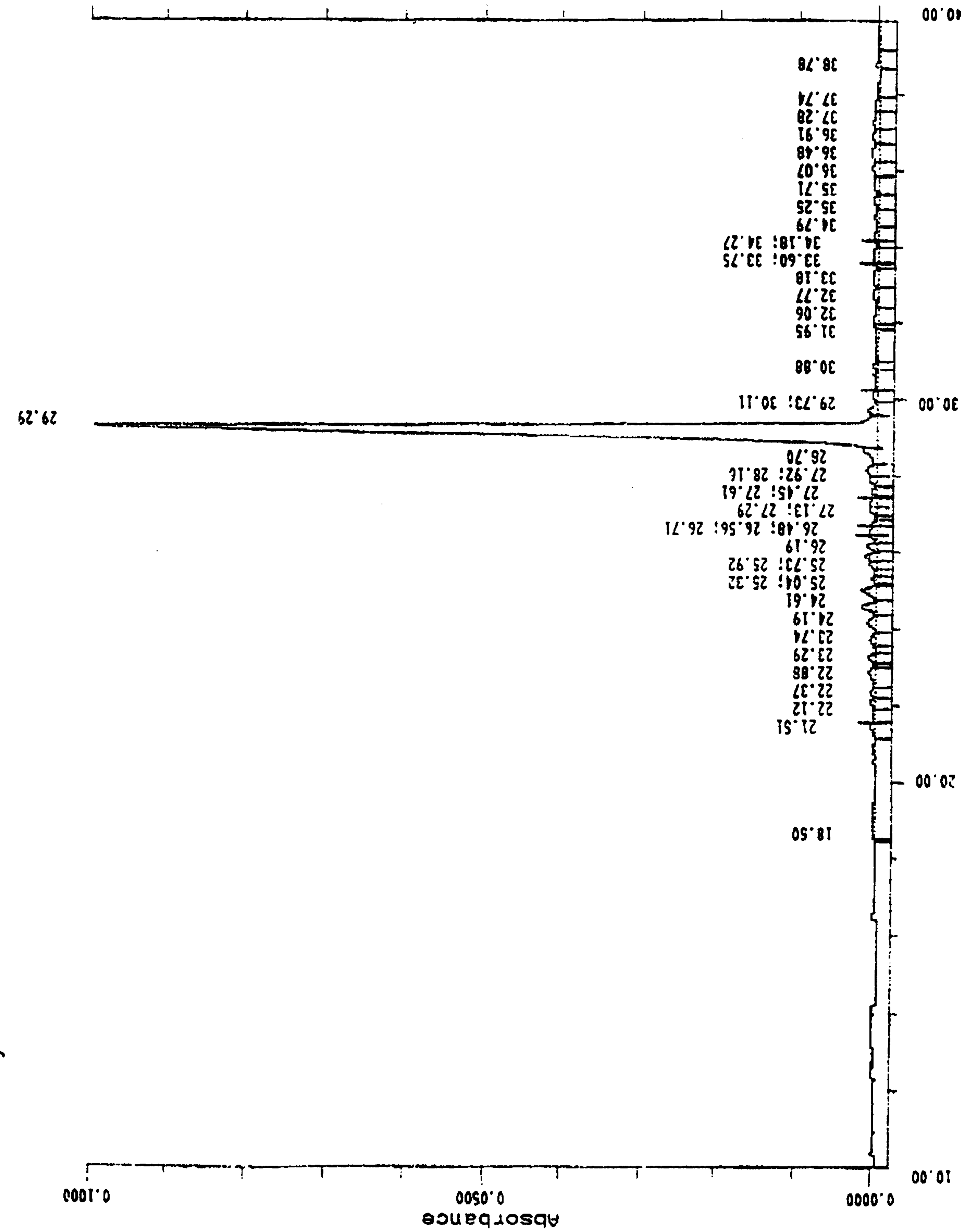
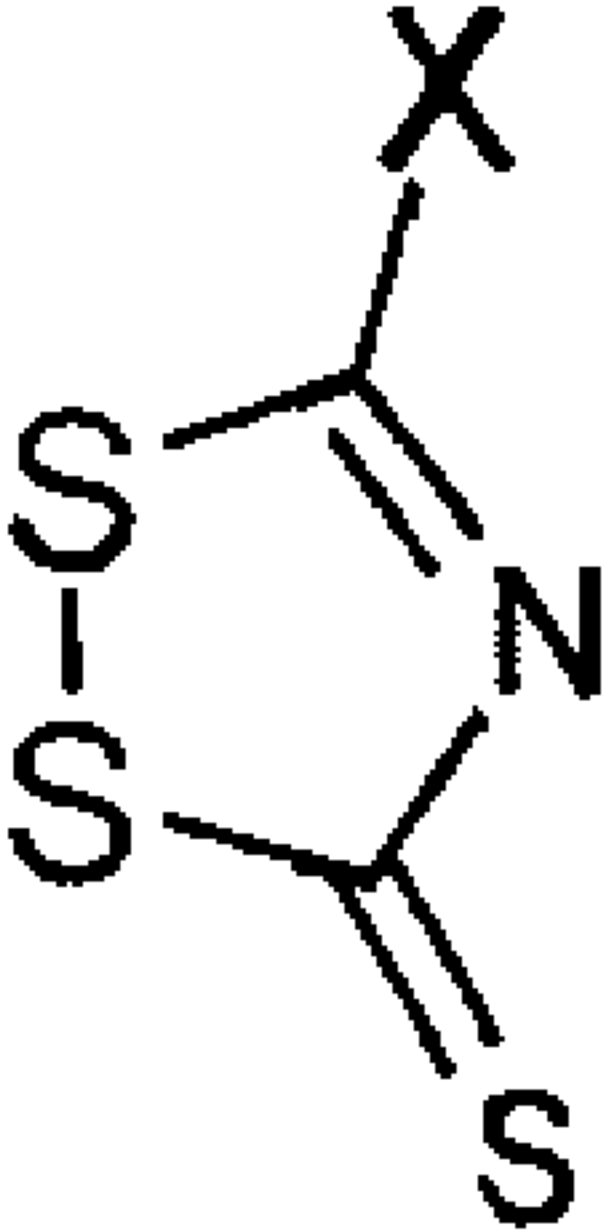


Figure 8

Synthesis of SEQ ID NO:1 with Compound 1, 2 min



Formula I