Synthesis of phosphorus (silicon, tin)-containing derivatives of mercaptoketenes and some of their properties

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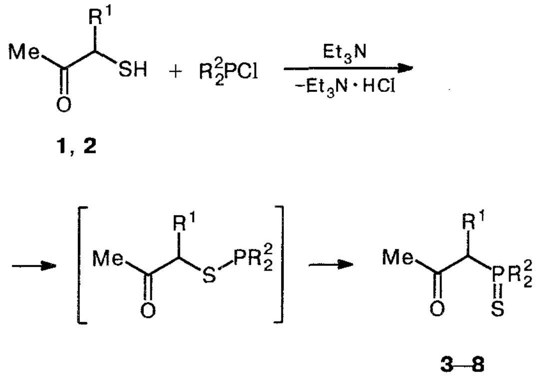
Some new S-phosphorylated, S-silylated, and S-stannylated derivatives of α-mercaptoketones were obtained. The reactions of some of these compounds induced by the temperature and by molecular oxygen as well as the phosphorylation of the Si- and Sn-containing derivatives were studied.

Key words: α-mercaptoketones; phosphorylation; silylation; stannylation; oxidation.

Ketones functionally substituted at the α-position are convenient starting compounds for the synthesis of linear and cyclic metal-containing derivatives. The silylation and phosphorylation of α-oxy- and α-aminocarbonyl compounds is described in a number of reports.[1—5] However, the functionalization of α-mercaptoketones has not been studied.

In this connection, we investigated the phosphorylation, silylation, and stannylation of α-mercaptoacetone (**1**) and 3-mercaptobutanone-2 (**2**) and studied some properties of the resulting products.

It was found that, in the presence of a base, the reactions of mercaptoketones **1** and **2** with chlorodiethylphosphite, chlorodiisopropylphosphite, and 2-chloro-1,3,2-dioxaphospholane yield thiophosphonates (**3**)—(**8**) (δ ^{31}P 83—112 ppm), which were isolated in the individual state by fractionation *in vacuo.*



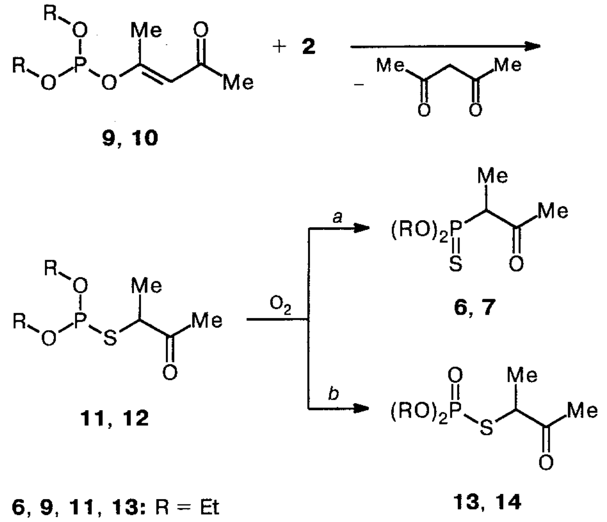
1: $R^1 = H$
2: $R^1 = Me$
3: $R^1 = H, R^2 = OEt$
4: $R^1 = H, R^2 = OPr^i$
5: $R^1 = H, R^2_2 = O(CH_2)_2O$
6: $R^1 = H, R^2 = Et$
7: $R^1 = H, R^2 = OPr^i$
8: $R^1 = Me, R^2_2 = O(CH_2)_2O$

The structure of phosphonates **3**—**8** was confirmed by the IR and ^{1}H NMR spectral data, and their composition was confirmed by elemental analysis. The IR spectrum of phosphonate **4** exhibits the absorption bands (AB) of the P—O—C bonds (990—1020 cm^{-1}), of the carbonyl group (1710 cm^{-1}), and of the stretching vibrations of the methylene group (2940 cm^{-1}). The ^{1}H NMR spectrum of product **4** has a singlet of the protons of the acetyl group at 2.66 ppm, a doublet of the methylene protons at 3.6 ppm ($^2J_{HP}$ = 20 Hz), and two multiplets indicative of the protons of the isopropyl groups. Thus, it proved impossible to obtain mixed thiophosphites by the phosphorylation of α-mercaptoketones with the monochloroanhydrides of the P^{III} acids. To elucidate the reasons for the formation of thiophosphonates **3**—**8**, diethyl- (**9**) and diisopropyl-1-methyl-2-acetylphenylphosphite (**10**) were used as phosphorylating agents. If these reagents are used, a solvent and a base as well as the filtration stage are not necessary, and, therefore, contact with atmospheric oxygen and water can be minimized. When butanone **2** is mixed with vinylphosphites **9** or **10**, the ^{31}P NMR spectrum of the reaction mixture exhibits a signal at 188—190 ppm corresponding to dialkylphosphites (**11**) or (**12**), respectively.

The reaction is complete after 5 h. However, when the receiver is open, the reaction mixture grows warm and its ^{31}P NMR spectrum shows the signal of thiophosphonate (**6** or **7**), which becomes the main component of the solution within 5 min. To investigate the reasons for the isomerization of dialkylphosphites **11** and **12**, we studied the role of the temperature, acidic admixtures (triethylamine hydrochloride), and atmospheric oxygen.

It was found that storing thiophosphites **11** and **12** for 2—3 h at 120 °C and adding catalytic amounts of triethylamine hydrochloride result in no changes in the ^{31}P NMR spectrum. On the other hand, when oxygen was passed through the sample for several minutes, it

Translated from *Izvestiya Akademii Nauk. Seriya Khimicheskaya,* No. 2, pp. 353—357, February, 1995.

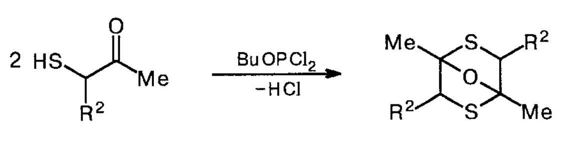


6, 9, 11, 13: R = Et

7, 10, 12, 14: R = Pr^i

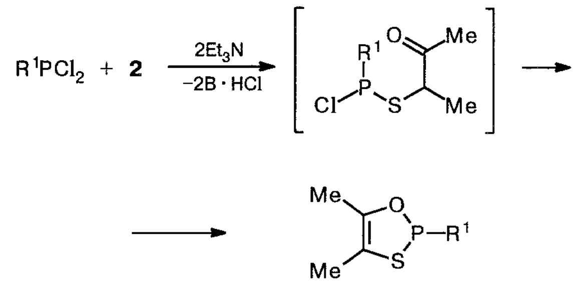
grew much wamer and isomerization products **6** and **7** (direction *a*) were formed. It was also established that the reaction of thiophosphites **11** and **12** with oxygen at −50 to −70 °C yields oxidation products **13** and **14** (direction *b*). Based on the published data[6—8] and our experimental results, we proposed that the most probable scheme of the isomerization is as follows. First, the adduct of the P^{III} thioester with dioxygen is formed, and the latter is converted to an ion-radical pair. The S—C bond of the latter is cleaved to form a cation, a radical, and an anion-radical. Then, the new ion-radical pair easily recombines to give the resulting thiophosphonate. Thus, our attempt to obtain the thiophosphites using chlorodialkylphosphites as the phosphorylating reagents failed due to the catalytic effect of the atmospheric oxygen on their isomerization during the filtration of the reaction mixture.

We also studied the phosphorylation of mercaptoketones with dichloroanhydrides of P^{III} acids and PCl_3. Since the molecules of compounds **1** and **2** contain two functional groups, *viz.*, sulfhydryl and carbonyl groups, these reactions would be expected to yield unsaturated P,O,S-containing five-membered heterocycles. However, the reaction in benzene was only observed with heating, and, regardless of the ratio between the reagents, yielded the bicyclic derivatives not containing phosphorus (**15**, **16**).



1, 2 **15, 16**

Taking into account the published data[9,10] and the obtained experimental results, we concluded that the formation of compounds **15** and **16** is related to the catalytic effect of the HCl formed during the reaction, which promotes the conversion of mercaptoketones **1** and **2** to bicyclic products **15** and **16**, respectively. To exclude the influence of HCl, we carried out the reaction of diethylamidodichlorophosphite and PCl_3 with mercaptobutanone-2 in the presence of two equivalents of triethylamine. As a result, 1,3,2-oxathiaphospholenes **17** and **18**, respectively, were obtained.



17, 18

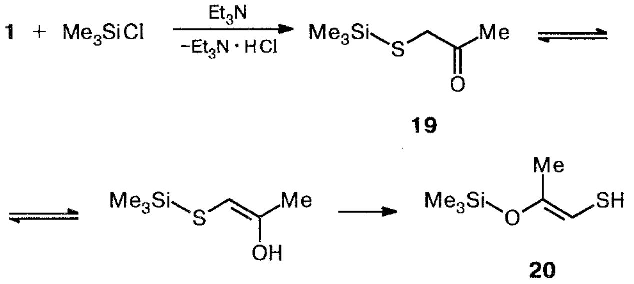
17: R^1 = Cl

18: R^1 = NEt_2

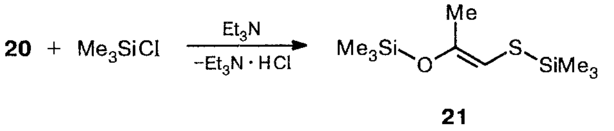
The first stage of the reaction seems to be the phosphorylation of the mercapto group to form chlorothiophosphite. The addition of the electron-withdrawing phosphorus-containing fragment to the sulfur atom results in increased CH-acidity of the group attached to the carbonyl carbon atom and facilitates the elimination of a proton by a base. Then, the anion obtained undergoes cycle closure to form a five-membered cycle.

For the last decade, organosilicon derivatives have been widely used in organic and organometallic synthesis.[9] They are highly effective, for instance, in the functionalization of derivatives of the tri- and tetracoordinated phosphorus atom. An attempt at obtaining the silicon derivatives of α-mercaptoketones seemed to be of interest so that the latter could be used as synthons for attaching ketoalkylthio groups to the phosphorous atom.

Silylation of mercaptoacetone **1** with chlorotrimethylsilane in the presence of triethylamine gives 1-trimethylsilylthiopropanone-2 (**19**). However attempts to isolate this compound by distillation failed due to a severe tar formation. To establish the structure of propanone **19** and to elucidate the reasons for its decomposition, the unrefined product was investigated by IR spectroscopy. After elimination of triethylamine hydrochloride, the IR spectrum of the reaction mixture exhibits an AB at 1710 cm^{-1} corresponding to stretching C=O vibrations. When the product was stored or heated for 4 h, the IR spectrum showed two new bands at 1610 and 2520 cm^{-1} corresponding to the C=C and S—H vibrations, respectively, whereas the AB at 1710 cm^{-1} (C=O) disappeared.

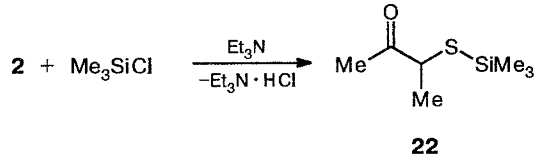


The changes in the IR spectra lead us to the conclusion that ketone **19** converts to vinylmercaptan (**20**) which is polymerized during distillation. Apparently, these transformations, including the 1,4 S→O migration of the trimethylsilyl group, are induced by the formation of the Si—O bond, which is more favourable energetically than the Si—S bond (see Ref. 11). To confirm the structure of vinylmercaptan **20**, it was additionally silylated. As a result, we isolated 1-trimethylsilylthio-2-trimethylsilyloxipropylene-1 (**21**), whose structure and composition were confirmed by the IR and ^{1}H NMR spectral data and elemental analysis.



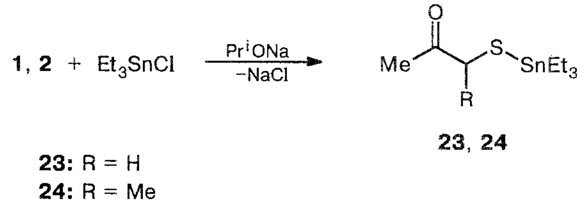
In the IR spectrum of alkene **21**, the AB at 1610 cm^{-1} corresponds to the stretching vibrations of the C=C bond. The ^{1}H NMR spectrum of siloxipropylene-1 **21** exhibits two singlets at 0.40 and 0.57 ppm indicative of the protons of the Me_3SiS- and Me_3SiO-groups, respectively. The protons of the MeC- and CH=C-groups are present in the spectrum as a pair of singlets: 2.00, 2.05 and 4.90, 5.03 ppm, respectively, indicative of the *E*- and *Z*-isomers of compound **21** in the mixture.

Unlike the silylation of mercaptoacetone **1**, the analogous reaction of mercaptobutanone **2** results in the much more stable 3-trimethylsilylthiobutanone-2 (**22**), which was isolated in the individual state by fractionation *in vacuo*.



The IR spectrum of this compound has the AB of a carbonyl group at 1710 cm^{-1}. The ^{1}H NMR spectrum exhibits two singlets at 0.56 and 2.4 ppm corresponding to the protons of the Me_3SiS- and MeC(O)-groups, respectively, a doublet at 1.63 ppm (CH_3CH, ^3J = 7 Hz), and a quadruplet at 3.63 ppm ($CPCH_3$, ^3J = 7 Hz).

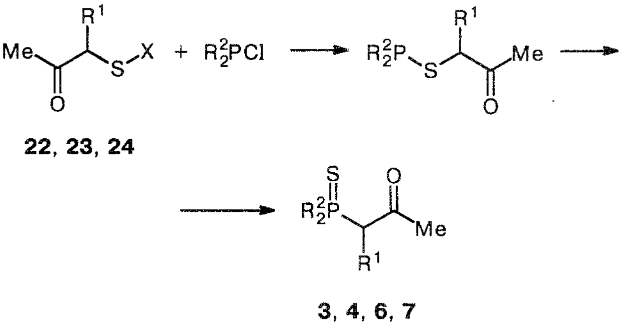
As was shown above, silylated mercaptoacetone **19** undergoes spontaneous intramolecular transformations due to the high affinity of the silicon atom for the oxygen. It might be expected that the replacement of the silicon atom in compound **19** with a tin atom should result in increased stability of the keto-form. In fact, the reactions of mercaptoketones **1** and **2** with chlorotriethylstannane in the presence of sodium isopropylate proceeds with the participation of the mercaptogroups to yield tin-containing ketones (**23** and **24**).



23: R = H
24: R = Me

The IR spectra of these compounds exhibit AB of a carbonyl group at 1710 cm^{-1}. The ^{1}H NMR spectrum of ketone **23** contains two singlets for the methyl (δ 2.66 ppm) and methylene (δ 3.63 ppm) protons with integral intensity ratios 3 : 2, and a multiplet for the protons of the ethyl groups at the tin atom in the 1.60—1.75 ppm interval.

Compounds **22**, **23**, and **24** react with trivalent phosphorus monochloroanhydrides for a period of several hours at ~20 °C to form thiophosphites, which are then isomerized to the corresponding thiophosphonates **3**, **4**, **6**, and **7**.



Experimental

The ^{31}P NMR spectra were recorded on an NMR KGU-4 instrument (10.2 MHz) using an 85 % solution of H_3PO_4 as the external standard. The ^{1}H NMR spectra were registered on a Varian T-60 spectrometer with TMS as the internal standard. The IR spectra were obtained on an UR-20 spectrometer in the 400—3600 cm^{-1} frequency range.

General procedure for the synthesis of thiophosphonates 3—8. Chlorodiethylphosphite, chlorodiisopropylphosphite, or chloroethylenephosphite, respectively, was added dropwise with stirring at 0—5 °C to a mixture of equimolar amounts of α-mercaptoketone **1**, **2** and triethylamine in water-free benzene or diethyl ether. The reaction mixture was stored for

Table 1. The characteristics of the synthesized thiophosphonates

Compound	Yield (%)	B.p. /°C (*p*/Torr)	n_D^{20}	Found / Calculated (%) C	H	P	S	Molecular formula
3	78	85—87 (0.03)	1.4875	40.83 40.49	6.05 6.69	14.64 14.83	14.78 15.31	$C_7H_{14}O_3PS$
4	74	89—91 (0.03)	1.4862	45.89 45.56	7.25 7.59	13.49 13.08	14.02 13.50	$C_9H_{18}O_3PS$
5	61	93—96 (0.02)	— (m.p. 78 °C)	34.02 33.33	5.52 5.00	17.05 17.22	—	$C_5H_9O_3PS$
6	79	93—95 (0.03)	1.4795	42.63 42.85	8.01 7.58	13.74 13.83	13.98 14.28	$C_8H_{17}O_3PS$
7	58	95—98 (0.02)	1.4811	—	—	11.93 12.30	12.93 12.69	$C_{10}H_{21}O_3PS$
8	57	98—102 (0.02)	— (m.p. 69 °C)	37.20 37.11	5.50 5.67	16.10 15.97	16.30 16.49	$C_6H_{11}O_3PS$

12 h, triethylamine hydrochloride was separated, and the solvent was removed. Thiophosphonates **3—8** were isolated by fractionation *in vacuo* (Table 1).

***O,O*-Diethyl-1-methyl-2-oxopropylthiophosphate (13).** Vinylphosphite **9** (10.4 g, 47 mmol) was mixed with butanone **2** (5.0 g, 47 mmol) at 0—5 °C. The reaction mixture was stored for 2 h at 20 °C, cooled to −50 to −70 °C, and oxygen was bubbled through the mixture for 15 min. Fractionation *in vacuo* gave 5.8 g (52 %) of thiophosphate **13**, b.p. 98—101 °C (0.02 Torr). ^{31}P NMR, δ: 24 s. Found (%): P, 12.64; S, 12.99. $C_8H_{17}O_4PS$. Calculated (%): P, 12.90; S, 13.32.

***O,O*-Diisopropyl-1-methyl-2-oxopropylthiophosphate (14).** Compound **14** was prepared from phosphite **10** (9.9 g, 40 mmol) and butanone **2** (4.2 g, 40 mmol) analogously to compound **13**, yield 58 % (5.8 g), b.p. 100—102 °C (0.02 Torr). ^{31}P NMR, δ: 23 s. Found (%): P, 11.69; S, 11.57. $C_{10}H_{21}O_4PS$. Calculated (%): P, 11.56; S, 11.90.

2,5-Dimethyl-2,5-endoxi-1,4-dithiane (15). A solution of mercaptoacetone **1** (1.8 g, 20 mmol) and dichlorobutylphosphite (1.75 g, 10 mmol) in absolute benzene (70 mL) was boiled until the evolution of HCl was over. After fractionation, compound **15** was obtained in 64 % yield (1.04 g), b.p. 43—44 °C (0.03 Torr), d_4^{20} 1.2155, n_D^{20} 1.5469. Found (%): C, 44.52; H, 6.39; S, 39.21. $C_6H_{10}OS_2$. Calculated (%): C, 44.44; H, 6.17; S, 39.50.[12]

2,3,5,6-Tetramethyl-2,5-endoxi-1,4-dithiane (16). A. Analogously, compound **16** was obtained from mercaptobutanone **2** (2.08 g, 20 mmol) and dichlorobutylphosphite (1.75 g, 10 mmol). The yield was 62 % (1.18 g), b.p. 45 °C (0.02 Torr), d_4^{20} 1.1321, n_D^{20} 1.5228. Found (%): C, 50.13; H, 7.49; S, 33.26. $C_8H_{14}OS_2$. Calculated (%): C, 50.52; H, 7.36; S, 33.68.

B. Based on a mixture of butanone **2** (2.08 g, 20 mmol) and PCl_3 (1.37 g, 10 mmol), compound **16** was obtained in 58 % yield (1.10 g), b.p. 47—48 °C (0.03 Torr), n_D^{20} 1.5225.

2-Chloro-4,5-dimethyl-1,3,2-oxathiophospholene (17). Butanone **2** (5.2 g, 50 mmol) was added dropwise to a mixture of PCl_3 (6.87 g, 50 mmol) and triethylamine (10.1 g, 100 mmol) in water-free benzene (60 mL) with stirring and cooling to −10 °C. After the separation of triethylamine hydrochloride, fractionation *in vacuo* gave compound **17** in 31 % (2.61 g) yield, b.p. 42—44 °C (0.02 Torr). ^{31}P NMR, δ: 208 s. Found (%): C, 28.35; H, 3.69; H, 18.51. C_4H_6ClOPS. Calculated (%): C, 28.57; H, 3.57; P, 18.45.

2-Diethylamono-4,5-dimethyl-1,3,2-oxathiaphospholene (18). Similarly, compound **18** was obtained from dichlorodiethylaminophosphine (8.7 g, 50 mmol), butanone **2** (5.2 g, 50 mmol), and triethylamine (10.1 g, 100 mmol). The yield was 66 % (6.76 g), b.p. 48 °C (0.03 Torr), d_4^{20} 1.0779, n_D^{20} 1.5276. ^{31}P NMR, δ: 144 s. Found (%): C, 47.03; H, 7.96; P, 15.31. $C_8H_{16}NOPS$. Calculated (%): C, 46.83; H, 7.80; P, 15.12.

1-Trimethylsilylthio-2-trimethylsilyloxipropylene-1 (21). Chlorotrimethylsilane (10.85 g, 100 mmol) was added dropwise to a mixture of mercaptoacetone **1** (4.5 g, 50 mmol) and triethylamine (10.1 g, 100 mmol) in acetonitrile (100 mL) with stirring at 0—8 °C. After 2 h, triethylamine hydrochloride was separated, and compound **21** was isolated by fractionation. The yield was 20 % (2.34 g), b.p. 71—73 °C (10 Torr), d_4^{20} 1.0179, n_D^{20} 1.4611. Found (%): C, 45.93; H, 9.55. $C_9H_{22}OSSi_2$. Calculated (%): C, 46.15; H, 9.40.

3-Trimethylsilylthiobutanone-2 (22). Chlorotrimethylsilane (5.42 g, 50 mmol) was added dropwise to a solution of butanone **2** (5.2 g, 50 mmol) and triethylamine (5.05 g, 50 mmol) in diethyl ether (150 mL) with stirring and cooling to 0—5 °C. After 2 h, triethylamine hydrochloride was separated, and compound **22** was isolated by fractionation. The yield was 75 % (6.6 g), b.p. 35—36 °C (0.05 Torr), n_D^{20} 1.4730. Found (%): C, 50.51; H, 9.54; S, 19.11. $C_7H_{16}OSSi$. Calculated (%): C, 50.60; H, 9.63; S, 19.26.

3-Triethylstannylthiopropanone-2 (23). Mercaptoacetone **1** (9 g, 100 mmol) was added to a solution of sodium metal (2.3 g, 100 mmol) in isopropanol (60 g, 100 mmol), and chlorotriethylstannane (24.1 g, 100 mmol) was added dropwise with stirring at 0—5 °C. Sodium chloride was removed, and compound **23** was isolated by fractionation. The yield was 36 % (10.7 g), b.p. 86—88 °C (0.04 Torr), d_4^{20} 1.3465, n_D^{20} 1.5289. Found (%): C, 36.59; H, 6.67; S, 10.98. $C_9H_{20}OSSn$. Calculated (%): C, 36.73; H, 6.80; S, 10.88.

3-Triethylstannylthiobutanone-2 (24). Similarly, compound **24** was obtained from isopropanol (60 g, 100 mmol), sodium metal (2.3 g, 100 mmol), butanone **2** (10.4 g, 100 mmol), and chlorotriethylstannane (24.1 g, 100 mmol). The yield was 44 % (13.5 g), b.p. 74—76 °C (0.02 Torr), d_4^{20} 1.3047, n_D^{20} 1.5215. Found (%): C, 38.94; H, 7.57; S, 10.77; Sn, 38.52.

$C_{10}H_{22}OSSn$. Calculated (%): C, 38.96; H, 7.14; S, 10.38; Sn, 38.31.

The reaction of *S*-silylated and *S*-stannylated mercaptoketones with chlorophosphites (general procedure). Diethyl or chlorodiisopropylphosphite (0.05 mol) was added dropwise to silicon (tin)-containing ketones **22—24** with stirring at 5—10 °C. The reaction mixture was stored for 8 h at ~20 °C, and compounds **3**, **4**, **6**, and **7**, respectively, were isolated by fractionation *in vacuo*.

3: yield 83 %, b.p. 85—87 °C (0.03 Torr), n_D^{20} 1.4873.
4: yield 81 %, b.p. 90—91 °C (0.04 Torr), n_D^{20} 1.4869.
6: yield 70 %, b.p. 92—94 °C (0.02 Torr), n_D^{20} 1.4780.
7: yield 73 %, b.p. 96—98 °C (0.03 Torr), n_D^{20} 1.4803.

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Received June 9, 1994;
in revised form September 26, 1994