UDC 547.722 + 547.128 + 543.424

FURAN ORGANOSILICON COMPOUNDS.

XIII.* Vibration Spectra of Furan Organosilicon Compounds

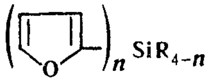
E. Ya. Lukevits and M. G. Voronkov

Khimiya Geterotsiklicheskikh Soedinenii, Vol. 2, No. 3, pp. 332–340, 1966

Studies are made of the IR spectra of 2-furylorganylsilanes, 2-furylorganylhydrosilanes, β-(2-furyl)ethylsilanes, 2-furfurylamino-, 2-furfuryloxy-, and 2-furfurylmercaptosilanes, organosilicon esters and amides of furan carboxylic acids, and 2, 5-disubstituted furylorganosilanes, and of Raman spectra of β-(2-furyl)-ethylsilanes. Absorption band frequencies of furan ring bonds in furan organosilicon derivatives are discussed. Inductive constants and effective electronegativities of 2-furyl and 5-methyl-2-furyl groups are calculated from the experimental values of ν Si—H for 2-furylorganylhydrosilanes and 5-methyl-2-furylorganylhydrosilanes, showing that the −I effects of the two groups are considerably greater than that of the phenyl group.

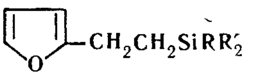
The Raman spectra of all 2-substituted furans so far investigated have characteristic lines at 600, 625, 888, 925, 1020, 1080, 1153, 1230, 1390, 1460 (1505), 1575 (1605), 3122, and 3153 cm^{-1}. The corresponding IR absorption spectra maxima are at 605 ± 5, 629 ± 9, 752 ± 27, 883 ± 8, 937 ± 22, 1010 ± 10, 1076 ± 4, 1158 ± 7, 1220 ± 20, 1391 ± 14, 1491 ± 21, 1584 ± 27, 3117 ± 8, 3151 ± 12 cm^{-1}.**

We have now investigated the IR absorption spectra of 2-furylorganylsilanes (I–VI), 2-furylorganylhydrosilanes (VII–XI, XXX), β-(2-furyl)ethylsilanes (XII–XVII), 2-furfurylamino-, 2-furfuryloxy- and 2-furfurylmercaptosilanes (XVIII–XX), organosilicon esters of pyromucic and 3-(2-furyl)propionic acids (XXI–XXIII), the trimethylsilylamide of pyromucic acid (XXIV), and 2, 5-substituted furylorganylsilanes (XXV–XXIX), and the Raman spectra of β-(2-furyl)-ethylsilanes (XIV–XVII):

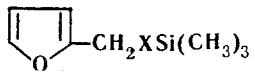


I n=1; R=CH_3
II n=2; R=CH_3
III n=3; R=CH_3
IV n=4
V n=1; R=C_2H_5
VI n=1; R=C_6H_5

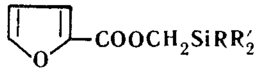
VII R=R′=CH_3
VIII R=CH_3; R′=C_2H_5
IX R=CH_3; R′=C_3H_7
X R=R′=C_2H_5
XI R=CH_3; R′=2-furyl
XXX R=R′=2-furyl



XII R=CH_3; R′=Cl
XIII R=R′=CH_3
XIV R=CH_3; R′=C_2H_5
XV R=CH_3; R′=C_3H_7
XVI R=R′=C_2H_5
XVII R=R′=C_2H_5O

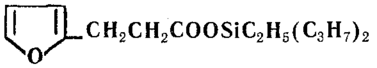


XVIII X=NH
XIX X=O
XX X=S

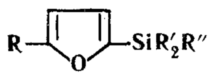


XXI R=R′=CH_3
XXII R=CH_3; R′=CH_3O

XXIII



XXIV



XXV R=R′=R″=CH_3
XXVI R=CH_3; R′=R″=C_2H_5
XXVII R=$(CH_3)_3Si$; R′=R″=CH_3
XXVIII R=R′=CH_3; R″=H
XXIX R=CH_3; R′=C_2H_5; R″=H

Comparison of the results obtained with data in the references enables the characteristic absorption frequencies of organosilicon derivatives of furan to be determined, and some regularities in the spectra of the latter to be uncovered.

---

*For Part XII see [1].

**For a bibliography relating to vibration spectra of furan and its derivatives, containing 90 references to papers published up to 1965, see [2].

Table 1 gives characteristic frequencies of the furyl group of silicon substituted furans.

Valence vibrations of the C—H bonds of the furan ring. The IR absorption spectra of furylorganosilanes I–VI have two maxima at 3144 ± 4 and 3115 ± 3 cm^{-1}, corresponding to ν (C—H) of the furan ring. For organosilicon esters of pyromucic acid XXI–XXII, the similar frequencies are somewhat higher (at 3155 and 3130 cm^{-1}). However, these bands are of low intensity, and, in most cases, the first of them is quite diffuse. So, to identify the furyl group in organosilicon derivatives of furan, it is safer, when making use of these two frequencies, to use the Raman spectra, where both are more intense. The Raman spectra of β-(2-furyl)silanes XIV–XVII show lines at 3151 ± 1 and 3118 ± 2 cm^{-1}, with the latter always more intense. In that region 2, 5-disubstituted furylorganosilanes XXV–XXIX absorb only at 3115 ± 5 cm^{-1}, the lowest frequency being observed in the spectrum of 2, 5-bis(trimethyldilyl)-furan.

It can be considered that the line of maximum frequency is basically conditioned by vibrations of the C—H bond at the α position in the furan ring [3], since with α monosubstituted furans its intensity is lower than that of the second line, while with α, α' disubstituted derivatives, it is generally absent, (as too is the band of the corresponding deformation vibrations δ (C—H), at 885 cm^{-1}). This corresponds to the difference in reactivity between the α and β C—H bonds in the furan ring, and to the different chemical shifts of the α and β protons in the PMR spectra of furan and its derivatives [4–6], as well as to results of quantum mechanical calculations [7–15].

Furan ring skeletal vibrations. The absorption maxima in the regions 1610–1558 cm^{-1}, 1512–1470 cm^{-1}, and 1405–1377 cm^{-1} correspond to the valence vibrations of the furan ring in 2-substituted furans.

In the cases of the 2-furylorganylsilanes I–VI the bands in those regions are of low intensity, and can hardly serve for characterization. In the 1600–1400 cm^{-1} range, an absorption band at 1546 ± 2 cm^{-1} is most characteristic of the 2-furylorganylsilanes I–VI. For the 2-furylorganylhydrosilanes VII–XI, the band at 1552 ± 6 cm^{-1} is generally the only one in that region.

All furan organosilicon compounds with a silicon atom directly linked to the furan ring, exhibit absorption bands at 1596 ± 6 cm^{-1}, and more intensely at 1507 ± 5 cm^{-1}. For compounds where a carbonyl group is directly conjugated with the furan ring (XXI, XXII, XXIV), these frequencies are lowered to 1584 ± 4 and 1486 cm^{-1}, respectively. The corresponding Raman spectrum lines are intense, the 1506 cm^{-1} line being considerably stronger than the one at 1596 cm^{-1}, and is most intense in the spectra of β-(2-furyl)ethylsilanes XIV–XVII.

All the silicon-substituted furan which we have investigated exhibits an absorption band at 1388 ± 14 cm^{-1}, with the frequency shifted over a comparatively wide range.

The 1010 ± 10 cm^{-1} absorption band, due to breathing vibration of the furan ring [16–18], is present in the spectra of all furan organosilicon compounds: 1013 ± 3 cm^{-1} for 2-furylorganylsilanes I–VI, 1013 cm^{-1} for 2-furylorganylhydrosilanes VII–X, 1008 ± 4 cm^{-1} for β-(2-furyl)ethylsilanes, 1020 ± 2 cm for XIX–XXIII, and 1018 ± 4 cm^{-1} for 2, 5-silicon-substituted furans. The intensity of this band increases with increase in the number of furan rings linked to the central silicon atom. A frequency 1140 cm^{-1} in the Raman spectra has been ascribed to breathing of the furan ring [3]. With the spectra of furan organosilicon compounds, this mode of vibration can be connected with the 1154 ± 6 cm^{-1} band, less intense than the 1013 ± 9 cm^{-1} one, and unchanged in intensity when the number of furan rings is raised. Generally this band corresponds to deformation vibrations of C—H in the furan ring [18].

The vibration spectra of 2-substituted furans exhibit, in the 740–600 cm^{-1} region, three absorption bands: 720 ± ± 20, 629 ± 9, and 605 ± 5 cm^{-1}, corresponding to furan ring deformation vibrations [17, 18]. For furan organosilicon compounds the corresponding frequencies are 713 ± 13, 630 ± 5, and 599 ± 3 cm^{-1}. Further, the spectra of compounds with a silicon atom directly linked to the furan ring, exhibit a frequency 660 ± 5 cm^{-1}, absent from the spectra of 2-alkylfurans [19], and from those of compounds XIV–XVII, XX–XXIII, where the silicon atom is separated from the furan ring by other atoms. Possibly the appearance of this frequency is connected with vibrations of the bond between the silicon atom and the furan ring.

It should also be mentioned that the absorption band in the 713 ± 13 cm^{-1} region, corresponding to deformation vibration of the furan ring, may overlap with the band arising from completely symmetric valence vibration of the Si—C bond, in these compounds, making identification difficult.

Deformation vibrations of C—H bonds in the furan ring. Bands in the ranges 1240–1200, 1165–1150, and 1080–1072 cm^{-1}, as well as a band at ~1250 cm^{-1}, correspond to planar vibrations of C—H bonds in the furan ring.

An absorption band at about 1255 cm^{-1} is also found in the spectra of the organosilicon compounds. However, in almost every case, it completely overlaps with an intense absorption band due to deformation vibrations of the methyl group attached to the silicon atom. Thus on passing from trimethyl(2-furyl)silane (I) to methyl tri(2-furyl)silane (III), this band does not increase in intensity, but, instead, decreases, and this is bound up with the decrease in number of methyl groups connected with the central silicon atom. Compounds not containing the Si—CH_3 group either completely fail to show this band, or else it is present at low intensity.

An absorption band at 1207 ± 5 cm^{-1} is exhibited by all the furan organosilicon compounds. In some cases (XVIII, XIX), this frequency is increased to 1222 cm^{-1}, while with carbonyl compounds (XXI–XXIV) it is cut to 1190 cm^{-1}. The intensity increases with increase in number of furan rings linked to the silicon atom. All the spectra have absorption bands at 1154 ± 6 and 1070 ± 9 cm^{-1}, though the former frequency is lacking in the spectra of the 2, 5-disubstituted organosilicon compounds of furan XXV–XXIX.

Table 1

Furyl Group IR Absorption Spectrum Bands for Organosilicon Derivatives of Furan*

Compound number	Valence vibrations of C—H bonds in organosilicon compounds of furan,	Furan ring valence vibrations	Ring breathing	C—H deformation vibrations		Furan ring deformation vibrations***
				planar	out-of plane***	
I	3148 3112	1596 1402 1548	1010	1204 1150 1070	906 889	— —
II	3145 3112	1546 1404	1012	1206 1150 1070	906 889	— —
III	3148 3115	1620 1502 1401 1545	1012	1208 1151 1070	906 889	— —
IV	3145 3117	1565 1492 1397 1549	1016	1213 1156 1074	910 892	596
V	3145 3112	1598 1377 1547	1010	1202 1148 1070	900 889	— —
VI	3140 3115	1585 1484 1379	1012	1206 1152 1075	902 890	595
VII	3120	1558	1013	1210 1153 1075	894 882 912	629 597
VIII	3120	1556 1386	1013	1210 1155 1075	906 885	631 597
IX	3120	1557 1382	1013	1210 1155 1075	909 888	— —
X	3120	1558 1388	1013	1210 1155 1076	905 890	— —
XI	3145 3118	1546 1401	1012	1207 1151 1071	905 889	— —
XII	3118	1590 1502 1398	1012	1205 1150 1071	905 890	— —
XIII	3122	1600 1512 1390	1008 1014	1204 1154 1078	904 889	— —
XIV	—* —	1590 1503 1380	1008	1149 1073	913 883	— —
XIV**	3151 3118	1596 1506 1380	1008	1213 1148 1073 1164	912 883	642
XV	— —	1602 1515 1377	1004	1202 1149 1067	913 883	— —
XV**	3151 3117	1598 1506 1381	1004	1214 1159 1066 1090	916 884	638 585 616
XVI	— —	1594 1503 1377	1005	1212 1148 1070 1165	910 882	— —
XVI**	3152 3118	1594 1506 1386	1013	1213 1157 1075	915 885	635 —
XVII	— —	1593 1503 1388	1004	1204 1140 1079 1166	880	— —
XVII**	3149 3120	1598 1508 1384	1000	1212 1157 1072	887	632 601
XVIII	— —	1591 1502 1380	1013	1218 1149 1060 1086	920 889	— —
XIX	— —	1598 1506 1376	1020	1222 1158 1078	918 889	— —
XX	3122	1598 1509 1389	1020	1209 1158 1061	890	632 599
XXI	3155 3130	1588 1486 1401	1022	1190	922 891	625 599
XXII	3155 3130	1589 1486 1402	1022	1190	922 891	625 599
XXIII	3125	1603 1512 1378	1018	1195 1160 1072	915 891	600
XXIV	3135 3106	1580 1485 1380	1015	1190 1149 1083	890	— —
XXV	3120	1600 1502 1383	1019	1190 1219	924	630 600
XXVI	3115	1596 1497 1380	1016	1217 1075	918	— —
XXVII	3110	1580 1380 1630	1013	1204 1064	928	634
XXVIII	3118	1597 1502 1388	1022	1192 1063	910	630 600
XXIX	3118	1600 1502 1386	1022	1192 1075	916	602

---

*– means that the IR spectrum was not observed in this region.

**Raman spectrum.

***The third band frequency is not given, since, in most cases, it was overlapped by the absorption band of the other two groups.

The out-of-plane deformation vibrations of the C—H bonds of the furan ring have bands in the ranges 960–915, 891–875, and 780–725 cm^{-1}. According to a paper [17], a band in the range 1035–1020 cm^{-1} also corresponds to them. However, this latter frequency is not characteristic of the spectra of furan organosilicon compounds, and the absorption band at ~755 cm^{-1} overlaps the $Si—CH_3$ vibration band. At the same time, all the compounds studied absorb at 910 ± ± 10 cm^{-1}. With organosilicon esters of pyromucic acid (XXI, XXII), this frequency is raised to 922 cm^{-1}, and to 928 cm^{-1} with 2, 5-bis(trimethylsilyl) furan (XXVII). A band at 887 ± 4 cm^{-1} is characteristic of 2-substituted furan organosilicon compounds, and this band is not found with 2, 5-disubstituted furylsilanes.

The inductive constants of the 2-furyl and 5-methyl-2-furyl groups. The frequency of the valence vibrations of the Si—H bond in molecules of the type RR'R"SiH is an additive quantity [20–23], which is a linear function of the effective electronegativity of the RR'R"Si-(X_c), or of the total inductive effect of the substituents R, R', and R". Each of these substituents brings to the value of ν (Si—H) its own particular contribution (E_i), which is proportional to its inductive action, characterized by the aliphatic polar constant σ^*

$$\nu_{Si-H} = \sum_i E_i = a + b \sum_i \sigma^*_i = kX_c,$$

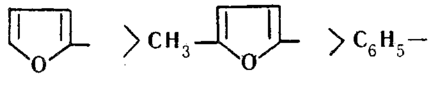
where the constants are a = 2106, b = 17.5, k = 1011. Using the above equation, and the experimental values of ν (Si—H) from the spectra of 2-furylorganylsilanes and 5-methyl-2-furylorganylsilanes, we calculated the inductive constants of the 2-furyl and 5-methyl-2-furyl groups (see Table 2).†

Table 2

The ν (Si—H) Vibration Frequencies of Furan Organosilicon Compounds of the Type RR'R"SiH, and Inductive Constants of 2-Furyl (Fu) and 5-Methyl-2-furyl (M) Groups

R	R′	R″	$\nu_{Si—H}$, cm^{-1}	E, cm^{-1}	X_c	x
Fu	Fu	Fu	2181	727	2.157	0.719
Fu	Fu	CH_3	2157	725	2.134	0.718
Fu	CH_3	CH_3	2142	729	2.119	0.723
Fu	CH_3	n-C_3H_7	2137	728	2.114	0.723
Fu	CH_3	C_2H_5	2136	730	2.113	0.723
Fu	C_2H_5	C_2H_5	2130	732	2.107	0.723
	Mean			729±2		0.722 ±0.002
M	CH_3	CH_3	2137	724	2.114	0.718
M	C_2H_5	C_2H_5	2125	727	2.102	0.718
	Mean			725±2		0.718 ±0.000

Using the ν (Si—H) frequencies of tri(2-furyl)silane and diethyl (2-furyl)silane, the aliphatic polar constant of the 2-furyl group was found by calculation to be +1.50 ± 0.07. The values obtained for the inductive constants E, σ^*, and x_c of the 2-furyl group (729, 1.5, 0.722), and 5-methyl-2-furyl group (725, ~1.3, 0.718) are considerably greater than those for the phenyl group (708.8, 0.600, 0.701), indicating that the –I effect of these groups decreases in the following order:



Experimental

The IR spectra of the organosilicon compounds were determined using UR-10 and IKS-14 spectrophotometers. The spectra of compounds IV, VI, and XII were measured in CCl_4 solution, of XXX in hexane (1–2% concentration), of XXIV, in nujol and hexachlorobutadiene mulls. The IR spectra of the other compounds were measured using the pure liquids.

The Raman spectra of compounds XIV–XVII were taken with an ISP-51 instrument.

---

† The spectroscopic inductive constants for Me, Et, and n-Pr were taken as 706.7, 699.0, and 702.7, respectively.

Below are listed IR spectra absorption frequencies and Raman spectra $\Delta\nu$ values for the furan organosilicon compounds under investigation. Relative intensities in brackets (vs–very strong, s–strong, a–average, w–weak, vw–very weak, sh–sharp, wi–wide, d–double).

Trimethyl(2-furyl)silane (I), cm^{-1}. 700(38), 747(77), 762(80), 817(56), 848(90), 857(93), 889(48), 906(62), 1010(67), 1040(44), 1056(45), 1070(44), 1110(68), 1150(46), 1181(21), 1204(46), 1252(77), 1329(22), 1360(28), 1402(33), 1458(33), 1548(42), 1596(19), 2900(41), 2960(65), 3112(36), 3148(34).

Dimethyldi(2-furyl)silane (II), cm^{-1}. 751(86), 789(85), 816(85), 841(78), 857(47), 889(49), 906(62), 1012(80), 1035(41), 1070(45), 1114(76), 1150(48), 1181(21), 1206(59), 1255(67), 1360(38), 1404(32), 1452(48), 1546(45), 2902(34), 2962(51), 3040(35), 3112(40), 3145(36).

Methyltri(2-furyl)silane (III), cm^{-1}. 735(72), 755(90), 793(87), 825(48), 860(30), 889(57), 906(69), 1012(87), 1035(52), 1070(59), 1117(82), 1151(52), 1180(31), 1208(70), 1255(52), 1320(18), 1360(48), 1401(29), 1451(64), 1502(23), 1545(56), 1568(24), 1620(28), 2905(31), 2968(38), 3115(41), 3148(39).

Tetra(2-furyl)silane (IV) (in CCl_4), cm^{-1}. 596(50), 653(64), 705(32), 810(100), 856(26), 876(28), 892(46), 910(72), 1016(89), 1074(43), 1126(90), 1156(52), 1213(76), 1255(29), 1366(54), 1397(12), 1456(68), 1492(32), 1549(81), 1565(60), 3117(57), 3145(30).

Triethyl(2-furyl)silane (V), cm^{-1}. 710(65), 730(75), 745(89), 814(33), 855(18), 889(36), 900(48), 951(29), 978(38), 1010(83), 1021(71), 1070(41), 1107(66), 1148(48), 1180(20), 1202(49), 1239(45), 1358(29), 1377(32), 1412(46), 1456(55), 1547(35). 1598(18), 2879(83), 2915(77), 2940(72), 2959(87), 3112(39), 3145(35).

Triphenyl(2-furyl)silane (VI) (in CCl_4), cm^{-1}. 595(16), 664(40), 688(43), 702(85), 719(84), 755(94), 810(100), 890(21), 902(28), 1012(52), 1034(10), 1075(6), 1120(73), 1152(24), 1191(27), 1206(37), 1261(18), 1304(15), 1335(15), 1361(17), 1379(14), 1430(44), 1452(16), 1484(24), 1550(29), 1585(16), 1612(11), 3000(35), 3020(33), 3056(39), 3071(48), 3115(20), 3140(12).

Dimethyl(2-furyl)silane (VII), cm^{-1}. 597(39), 629(33), 663(35), 708(36), 712(28), 754(79), 777(72), 803(44), 825(51), 855(73), 882(86), 894(76), 912(84), 1013(67), 1075(51), 1116(69), 1153(43), 1185(24), 1210(45), 1260(70), 1368(32), 1410(28), 1462(37), 1558(34), 2142(82), 2911(46), 2970(70), 3120(22).

Methylethyl(2-furyl)silane (VIII), cm^{-1}. 597(33), 631(25), 665(17), 705(24), 715(32), 752(80), 820(60), 841(80), 885(73), 906(52), 976(46), 1013(69), 1075(33), 1116(65), 1155(41), 1186(23), 1210(45), 1237(32), 1260(52), 1367(29), 1386(27), 1420(30), 1463(40), 1556(33), 2136(84), 2882(62), 2900(51), 2920(56), 2942(55), 2967(77), 3120(16).

Methylpropyl (2-furyl)silane (IX), cm^{-1}. 752(85), 806(57), 820(64), 858(86), 861(85), 888(82), 909(75), 1013(79), 1075(66), 1116(68), 1155(42), 1210(55), 1261(66), 1341(33), 1368(30), 1382(32), 1412(34), 1464(47), 1557(34), 2137(76), 2875(57), 2915(50), 2935(57), 2967(75), 3120(10).

Diethyl(2-furyl)silane (X), cm^{-1}. 700(46), 722(59), 751(72), 808(82), 815(83), 860(27), 890(30), 905(36), 960(30), 980(52), 1013(75), 1076(44), 1116(60), 1155(38), 1188(20), 1210(40), 1240(40), 1368(26), 1388(26), 1420(32), 1466(44), 1558(30), 2130(69), 2884(60), 2900(48), 2920(52), 2942(50), 2965(70), 3120(19).

Di(2-furyl)methylsilane (XI), cm^{-1}. 695(25), 754(88), 792(40), 820(83), 835(83), 857(56), 879(72), 889(68), 905(68), 974(25), 1012(80), 1035(50), 1071(56), 1117(77), 1151(48), 1181(29), 1207(60), 1255(52), 1320(19), 1360(37), 1401(29), 1452(53), 1546(45), 2157(63), 2910(34), 2967(42), 3118(38), 3145(35).

[β-(2-Furyl)ethyl] methyldichlorosilane (XII) (in CCl_4), cm^{-1}. 755(100), 810(100), 856(47), 890(64), 905(66), 932(45), 1012(79), 1071(38), 1115(28), 1150(72), 1170(37), 1182(36), 1205(44), 1230(47), 1260(68), 1330(48), 1398(41), 1430(37), 1450(23), 1502(51), 1535(12), 1555(7), 1590(40), 2858(34), 2910(50), 2930(42), 2951(37), 3118(24).

[β-(2-Furyl)ethyl] trimethylsilane (XIII), cm^{-1}. 734(74), 755(38), 780(42), 800(50), 846(89), 860(88), 870(89), 889(56), 904(60), 935(31), 1008(52), 1014(56), 1030(39), 1078(41), 1154(55), 1170(31), 1184(32), 1204(36), 1218(33), 1235(38), 1258(82), 1332(36), 1390(24), 1412(26), 1448(33), 1512(35), 1574(24), 1600(34), 2856(30), 2905(49), 2931(41), 2961(72), 3122(20).

[β-(2-Furyl)ethyl] methylethylsilane (XIV) Raman spectrum, $\Delta\nu$, cm^{-1}. 298(0), 408(0), 453(1 wi), 552(3), 576(5), 642(0.5 wi d), 721(0.5 wi), 754(0.5 wi), 796(0.5 wi), 850(0.5), 883(2 sh), 912(0), 930(1), 974(1), 1008(2 wi), 1052(0.5), 1073(2), 1112(0.5), 1148(0.5), 1164(0.5 d), 1194(0.5), 1213(1), 1228(2), 1326(0 wi), 1380(4), 1412(4), 1448(3 d), 1464(3 d), 1506(10), 1582(1), 1596(2), 2732(0.5), 2878(8), 2906(8), 2934(1), 293434(1), 2934(1), 3151(3). Ir cm^{-1}: 723(vs), 749(s), 792(vs), 817(s), 883(w), 898(vw), 913(vw), 923(w), 963(w), 1008(vs), 1073(w), 1149(a), 1196(w), 1233(a), 1252(vs), 1326(vw), 1380(w), 1415(w), 1442(w), 1460(w), 1503(vw), 1558(vw), 1590(vw).

2-Furylethylmethyldipropylsilane (XV), Raman spectrum, $\Delta\nu$, cm^{-1}. 322(0), 352(0), 392(0), 411(0), 458(1), 562(0.5), 585(1), 616(0.5), 638(0.5), 682(0.5), 720(1), 751(0.5), 773(0), 796(0.5), 826(0.5), 852(0.5), 884(1 sh), 896(1 sh), 916(0.5 sh), 930(0.5), 955(0), 1004(2), 1031(3), 1066(2 d), 1090(2 d), 1114(0.5), 1134(0), 1159(0 wi)

1199(2), 1214(0.5), 1229(1 sh), 1248(0), 1292(0.5 wi), 1330(0.5), 1381(4), 1408(4), 1450(6), 1506(10), 1584(2), 1598(2), 2738(3), 2846(0), 2861(8), 2897(8), 2930(4), 2958(7), 3046(0), 3117(4), 3151(3), IR cm^{-1}. 720(vs), 743(s), 789(s), 821(vs), 883(a), 895(a), 913(a), 927(w), 965(w), 1004(vs), 1027(a), 1067(vs), 1149(s), 1202(s), 1229(a), 1254(vs), 1289(vw), 1335(a), 1411(a), 1457(s), 1515(a), 1588(a), 1602(w).

[β-(2-Furyl)ethyl]triethylsilane (XVI), Raman spectrum, $\Delta\nu$, cm^{-1}: 300(1), 454(1 wi), 547(2), 566(2), 635(0.5), 727(0.5), 766(0), 795(2 sh), 827(0.5), 852(0.5 sh), 885(1.5 sh), 915(1), 929(1 sh), 975(1.5), 1013(4), 1075(4), 1116(0), 1157(0.5 wi), 1197(1 sh), 1213(0.5), 1233(2 sh), 1305(2 sh), 1386(6), 1418(1.5), 1457(3 wi), 1506(10), 1583(1), 1594(1), 2879(8), 2911(6), 2937(1), 2956(4), 3118(3), 3152(2). IR cm^{-1}: 724(vs), 742(vs), 768(s), 778(s), 847(vw), 882(w), 910(vw), 923(w), 968(a), 1005(vs), 1070(s), 1148(a), 1165(w), 1193(w), 1212(w), 1237(s), 1323(w), 1377(w), 1414(a), 1440(a), 1457(a), 1503(w), 1560(vw), 1570(vw), 1594(w).

[β-(2-Furyl)ethyl]triethoxysilane (XVII) Raman spectrum, $\Delta\nu$, cm^{-1}. 601(0 wi), 632(0), 648(0), 714(0 wi), 798(0 wi), 854(0.5 sh), 887(1 sh), 934(0.5), 1000(1), 1072(3), 1157(0), 1212(0), 1232(0.5), 1294(1 wi), 1384(4), 1412(1), 1485(0.5), 1508(10), 1598(3), 2843(0), 2885(5 wi d), 2928(10), 2956(5), 3021(0), 3120(3), 3149(1.5). IR cm^{-1}: 730(s), 744(a), 788(s), 810(s), 880(w), 932(s), 959(vs), 998(a), 1004(a), 1022(w), 1079(vs), 1102(vs), 1140(vs), 1166(vs), 1184(s), 1204(a), 1230(w), 1290(w), 1327(w), 1366(w), 1388(a), 1438(a), 1480(w), 1503(w), 1593(vw).

Trimethyl(2-furfurylamino)silane (XVIII), cm^{-1}. 690(37), 735(72), 758(57), 780(44), 808(54), 845(85), 855(82), 872(77), 889(64), 920(54), 935(39), 965(28), 1013(58), 1060(68), 1086(66), 1092(60), 1149(64), 1182(33), 1218(35), 1251(75), 1339(30), 1380(33), 1400(46), 1440(31), 1452(27), 1482(22), 1502(34), 1546(21), 1591(26).

Trimethyl(2-furfuryloxy)silane (XIX), cm^{-1}: 742(s), 752(s), 822(a), 850(vs), 876(vs), 889(s), 918(s), 978(vw), 1020(a), 1078(vs), 1092(vs), 1124(s), 1158(vs), 1222(a), 1260(vs), 1358(w), 1376(w), 1413(vw), 1460(vw), 1506(w), 1598(vw).

Trimethyl (2-furfurylmercapto)silane (XX), cm^{-1}: 599(39), 632(50), 693(34), 711(37), 742(81), 761(66), 860(97), 890(42), 940(48), 1020(72), 1061(73), 1158(57), 1209(24), 1260(90), 1389(16), 1412(24), 1460(19), 1509(42), 1598(18), 2861(20), 2905(35), 2934(41), 2962(66), 3122(13).

Trimethyl(2-furoyloxymethyl)silane (XXI), cm^{-1}. 599(30), 625(24), 740(29), 772(83), 795(78), 818(71), 855(58), 870(69), 891(46), 922(29), 970(31), 1022(56), 1100(95), 1130(88), 1190(87), 1238(56), 1272(72), 1326(93), 1401(60), 1432(30), 1486(73), 1588(50), 1735(82), 2847(54), 2928(39), 2954(50), 3130(16), 3155(16).

Methyl(2-furoyloxymethyl) dimethoxysilane (XXII), cm^{-1}: 599(19), 625(14), 740(17), 772(61), 794(55), 818(45), 850(36), 870(42), 891(30), 922(17), 970(18), 1022(36), 1095(82), 1131(68), 1190(68), 1238(38), 1272(50), 1326(79), 1402(40), 1433(19), 1486(51), 1589(32), 1735(71), 2847(34), 2930(25), 2954(32), 3130(12), 3155(12).

Ethyldipropyl[3-(2-furyl)propionoxy]silane (XXIII), cm^{-1}: 600(32), 735(85), 771(70), 808(58), 840(20), 875(24), 891(30), 902(24), 915(25), 931(36), 963(39), 1018(69), 1072(57), 1085(48), 1160(66), 1195(81), 1278(68), 1308(56), 1341(41), 1355(42), 1378(58), 1415(42), 1468(44), 1512(24), 1603(22), 1736(88), 2880(71), 2936(74), 2964(87), 3125(11).

N-trimethylsilyl pyromucamide (XXIV) (nujol mull), cm^{-1}: 857(84), 890(74), 938(62), 1015(56), 1022(62), 1034(51), 1083(52), 1102(45), 1129(64), 1149(41), 1180(69), 1190(68), 1243(75), 1251(80), 1266(65), 1289(79), 1380(76), 1405(77), 1435(81), 1455(80), 1475(83), 1485(82), 1562(76), 1580(68), 1625(82), 1642(81), 3106(53), 3135(60), 3246(60), 3360(50), 3415(24); (in hexachlorobutadiene) 1240(52), 1250(63), 1263(40), 1285(58), 1378(48), 1402(56), 1418(62), 1428(63), 1449(62), 1474(71), 1559(46), 3105(64), 3134(72), 3242(73), 3345(62), 3408(38).

Trimethyl(5-methyl-2-furyl)silane (XXV), cm^{-1}: 600(18), 630(44), 665(28), 698(37), 708(29), 758(62), 784(63), 848(80), 924(70), 961(69), 988(51), 1019(69), 1050(35), 1101(44), 1126(54), 1190(62), 1219(60), 1254(92), 1334(34), 1383(31), 1410(33), 1452(42), 1463(38), 1502(62), 1600(41), 1630(25), 2910(54), 2968(80), 3120(23).

Triethyl(5-methyl-2-furyl)silane (XXVI), cm^{-1}: 722(65), 734(66), 779(57), 834(19), 918(38), 956(41), 985(41), 1016(72), 1075(27), 1186(48), 1217(45), 1238(39), 1329(24), 1380(25), 1414(36), 1452(46), 1497(43), 1596(32), 1630(24), 2886(90), 2920(85), 2947(84), 2970(100), 3115(29).

2, 5-Bis(trimethylsilyl)furan (XXVII), cm^{-1}: 634(57), 665(25), 700(61), 758(76), 791(78), 830(84), 850(85), 928(90), 1013(85), 1064(69), 1176(84), 1204(27), 1252(94), 1269(76), 1296(69), 1328(34), 1380(33), 1408(53), 1452(37), 1460(38), 1546(43), 1562(24), 1580(21), 1630(22), 2908(52), 2968(80), 3110(26).

Dimethyl(5-methyl-2-furyl)silane (XXVIII), cm^{-1}: 600(23), 630(35), 658(30), 670(30), 711(29), 745(58), 776(70), 790(69), 844(76), 865(60), 910(81), 932(70), 965(58), 990(43), 1022(62), 1063(64), 1130(45), 1192(47), 1221(50), 1260(74), 1335(30), 1388(30), 1460(34), 1502(52), 1597(36), 2137(77), 2865(38), 2930(58), 2970(66), 3118(22).

Diethyl(5-methyl-2-furyl)silane (XXIX), cm^{-1}: 602(28), 660(28), 699(50), 723(64), 790(72), 810(80), 839(85), 916(30), 928(37), 976(62), 990(54), 1022(74), 1075(65), 1128(36), 1192(40), 1222(44), 1240(49), 1335(25), 1386(29), 1418(34), 1465(46), 1502(46), 1600(32), 2125(77), 2883(70), 2920(65), 2929(61), 2945(66), 2966(80), 3118(18).

We are greatly indebted to A. Grinvald and S. Aleksandrov for determining the spectra.

REFERENCES

1. E. Ya. Lukevits and M. G. Voronkov, KhGS [Chemistry of Heterocyclic Compounds], p. 328, 1966.
2. E. Ya. Lukevits, Master's Thesis, Riga, 1965.
3. E. V. Sobolev, V. T. Aleksan'yan, R. A. Karakhanov, I. F. Bel'skii, and V. A. Ovodova, Zh. str. khim., 4, 358, 1963.
4. R. F. M. White, in: Physical Methods in Heterocyclic Chemistry, [A. R. Katritzky, ed.], Academic Press New York-London, vol. 2, p. 103, 1963.
5. S. Gronowitz, G. Sörlin, B. Gestblom, and R. A. Hoffman, Ark. Kemi, 19, 483, 1963.
6. A. N. Egorochkin, E. Ya. Lukevits, and M. G. Voronkov, KhGS [Chemistry of Heterocyclic Compounds], p. 499, 1965.
7. M. M. Kreevoy, J. Am. Chem. Soc., 80, 5543, 1958.
8. R. D. Brown and B. A. W. Coller, Austr. J. Chem., 12, 152, 1959.
9. A. Mangini and C. Zauli, J. Chem. Soc., 2210, 1960.
10. J. R. Morris and F. L. Pilar, Chem. Ind., 469, 1960.
11. F. L. Pilar and J. R. Morris, J. Chem. Phys., 34, 389, 1961.
12. J. Ridol, Physical Methods in Heterocyclic Chemistry, [A. R. Katritzky, ed.], Academic Press, New York-London, vol. 1, p. 145, 1963.
13. D. S. Sappenfield and M. Kreevoy, Tetrahedron, 19, suppl. 2, 157, 1963.
14. M. K. Orloff and D. D. Fitts, J. Chem. Phys., 38, 2334, 1963.
15. O. E. Polansky and P. Schuster, Mon., 95, 281, 1964.
16. A. R. Katritzky and I. M. Lagowski, J. Chem. Soc., 657, 1959.
17. D. Bîrcâ-Gălăteanu, C. Demetrescu, M. Elian, and L. Măntoiu, Rev. chim. (Roumaine), 8, 217, 1963.
18. A. R. Katritzky and A. P. Ambler, Physical Methods in Heterocyclic Chemistry, vol. 2, N. Y.-London, 161, 1963.
19. S. A. Giller and A. E. Berzin, KhGS [Chemistry of Heterocyclic Compounds], (in press).
20. A. L. Smith and N. C. Angelotti, Spectrochim. Acta, 15, 412, 1959.
21. H. W. Thomson, Spectrochim. Acta, 16, 238, 1960.
22. V. A. Ponomarenko, Yu. P. Egorov, Izv. AN SSSR, OKhN, 1133, 1960.
23. J. F. Hyde, P. L. Brown, and A. L. Smith, J. Am. Chem. Soc., 82, 5854, 1960.

3 April 1966

Institute of Organic Synthesis,
AS Latv. SSR, Riga