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Crystal structures analysis of Spiro Pyrrolidine derivatives

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Abstract: Three Spiro Pyrrolidine compounds (1, 2 and 3) were crystallized by slow evaporation method. Crystal data were collected using BRUKER SMART APEX II CCD X-ray diffractometer. The structures were solved by direct method and refined on F^2 by full-matrix least-squares procedures using the SHELXL programs. The compound 1((6'R)-ethyl 7'-((3aS,6R,6aS)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[3,2-d][1,3]dioxol-5-yl)-2-oxo-3',6',7',7a'-tetrahydro-1'H-spiro[indoline-3,5'-pyrrolo[1,2-c]thiazole]-6'-carboxylate) crystallizes in orthorhombic P 2_1 2_1 2_1 space group and the final R_1 is 0.046. The compound 2 **(**(6'R)-7'-((3aS,6R,6aS)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[3,2-d][1,3]dioxol-5-yl)-6'-(4-chlorobenzoyl)-3',6',7',7a'-tetrahydro-1'H-spiro[indene-2,5'-pyrrolo[1,2c]thiazole]-1,3-dione) crystallizes in monoclinic $P2_1$ space group and the final R_1 is 0.042. The compound 3 (3'-(4-chlorobenzoyl)-1'-methyl-4'-((3aR,5R,5aS,8aS,8bR)-2,2,7,7-tetramethyltetra hydro-3aH-bis[1,3]dioxolo[4,5-b:4',5'-d]pyran-5-yl)-2H-spiro[acenaphthylene-1,2'-pyrrolidin]-2-one) crystallizes in monoclinic $P2_1$ space group and the final R_1 is 0.065.

Key Words: Spiro Pyrrolidine derivatives, crystal structure.

Introduction

Spiro Pyrrolidine compounds are of great biological importance. Spiro compounds are a particular class of naturally occurring substances characterized by highly pronounced biological properties[1-2]. Spiro-pyrrolidine derivatives are unique tetracyclic 5-HT (2 A) receptor antagonists[3-4]. These derivatives possess anticonvulsant[5] and anti-influenza virus[6] activities. Substituted pyrrolidines possess anti-microbial and anti-fungal activity against various pathogens[7]. The spiro-pyrrolidine ring system is also found in pheromones, antibiotics[8] and antitumour agents[9-10]. In view of this importance, we have undertaken the crystal structure determination of the title compound, a pyrrolidine derivative, and the results are presented here.

Experimental

X-ray Structure Determination: Single crystals of the three compounds suitable for x-ray diffraction were obtained by slow evaporation method. Three dimensional intensity data were collected on a Bruker[11] SMART APEX CCD Diffractometer using graphite monochromatized Mo-Kα radiation (λ= 0.71073 Å) at the CAS in crystallography and Biophysics, University of Madras, Chennai. The structures were solved by direct method and refined on F^2 by full-matrix least-squares procedures using the SHELXTL programs. All non-hydrogen atoms were refined using anisotropic thermal parameters.The hydrogen atoms were included in the structure factor calculation at idealized positions by using a riding model, but not refined. Images were created with the ORTEP-3[12] or MERCURY 3.0 program. The crystallographic data for the three compounds are listed in Table 1.

Table 1. Crystal data and structure refinement for compounds 1, 2 and 3.

Compounds	1	2	3
Empirical formula	$C_{30}H_{34}N_2O_7S_1$	$C_{35}H_{32}Cl_1N_1O_7S_1$	$C_{34}H_{33}Cl_1N_1O_7$
Formula weight	567	646	603
Temperature(K)	293(2)	293(2)	293(2)
Wavelength(Å)	0.71073	0.71073	0.71073
Crystal system, Space group	Orthorhombic $P\,2_1\,2_1\,2_1$	Monoclinic $P2_1$	Monoclinic $P2_1$
Unit cell dimensions			
a(Å)	9.3781(4)	10.0729(4)	11.3547(14)
b(Å)	12.6224(5)	14.6887(5)	10.0578(11)
c(Å)	23.9923(10)	11.1640(4)	14.4324(16)
α(°)	90.00	90.00	90.00
β(°)	90.00	99.013(2)	110.119(7)
γ(°)	90.00	90.00	90.00
Volume(Å^3)	2840.1(2)	1631.41(10)	1547.65(42)
Z, D_{cal} (Mgm^{-3})	4, 1.325	2,1.315	2,1.29
Absorption coefficient (mm^{-1})	0.164	0.230	0.173
F(000)	1200	676	634
Crystal size(mm)	0.30 × 0.25 × 0.20	0.30*0.25*0.20	0.30*0.25*0.30
Theta range for data collection(°)	1.70 to 28.39	1.9 to 28.4	1.5 to 28.2
Limiting indices	-12<=h<=12, -16<=k<=16, -28<=l<=32	-13<=h<=13, -19<=k<=19, -14<=l<=14	- 12<=h<=14, - 13<=k<=13, -19<=l<=19
Reflections collected / unique	27525 / 6528	15714/7084	14199/7459
R(int)	0.061	0.026	0.066
Refinement method	Full-matrix least-squares on F^2	Full-matrix least- squares on F^2	Full-matrixleast-squares on F^2
Data / restraints / parameters	6528 / 0 / 366	7084 / 1/ 408	7459/1/394
Goodness-of-fit on F^2	0.099	1.03	0.986
Final R indices [I>2σ(I)]	R1 = 0.046, wR2 = 0.105	R1=0.042,wR2=0.109	R1=0.065, wR2=0.158
R indices (all data)	R1 = 0.113, wR2 = 0.085	R1=0.057,wR2=0.101	R1=0.111, wR2=0.188
Largest diff. peak and hole(e.Å$^{-3)}$	0.20 and −0.16	0.22 and -0.27	0.48 and -0.25

Synthesis of compound 1: ((6'R)-ethyl 7'-((3aS,6R,6aS)-6-(benzyloxy)-2,2-dimethyltetrahydro furo[3,2-d][1,3]dioxol-5-yl)-2-oxo-3',6',7',7a'-tetrahydro-1'H-spiro[indoline-3,5'-pyrrolo[1,2-c]thiazole]-6'-carboxylate):
A mixture of (*E*)-ethyl 3-((3aS,6R,6aS)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[3,2-d][1,3]dioxol-5-yl)acrylate (300mg, 0.862 mmol), isatin (126mg, 0.862 mmol) and thiazolidine-4-carboxylic acid (114mg, 0.862 mmol) was refluxed at 120 °C in toluene for about 6 hrs under Dean stark reaction condition to give (6'R)-ethyl 7'-((3aS,6R,6aS)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[3,2-d][1,3]dioxol-5-yl)-2-oxo-3',6',7',7a'-tetra hydro-1'H-spiro[indoline-3,5'-pyrrolo[1,2-c]thiazole]-6'-carboxylate. After the completion of reaction as indicated by TLC, solvent was evaporated under reduced pressure. The crude product was purified by column

chromatography using hexane: EtOAc (3:2) as eluent. Block-shaped single crystals of the title compound suitable for X-ray diffraction analysis were obtained from a solution of hexane/ethyl acetate (3:2) by slow evaporation at room temperature.

Synthesis of compound 2: ((6'R)-7'-((3aS,6R,6aS)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro [3,2-d][1,3]dioxol-5-yl)-6'-(4-chlorobenzoyl)-3',6',7',7a'-tetrahydro-1'H-spiro[indene-2,5'-pyrrolo[1,2c]thiazole]-1,3-dione):A mixture of (*E*)-3-((3aS,6R,6aS)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[3,2-d][1,3]dioxol-5-yl)-1-(4-chlorophenyl)prop-2-en-1-one(300mg, 0.724 mmol), ninhydrine (115mg, 0.724 mmol) and thiazolidine-4-carboxylic acid (96mg, 0.724 mmol) was refluxed at 120 °C in toluene for about 6 hrs under Dean stark reaction condition to give (6'R)-7'-((3aS,6R,6aS)-6-(benzyloxy)-2,2-dimethyltetrahydrofuro[3,2-d][1,3]dioxol-5-yl)-6'-(4-chlorobenzoyl)-3',6',7',7a'-tetrahydro-1'H-spiro[indene-2,5'-pyrrolo[1,2-c]thiazole]-1,3-dione. After the completion of reaction as indicated by TLC, solvent was evaporated under reduced pressure. The crude product was purified by column chromatography using hexane: EtOAc (3:2) as eluent. Block-shaped single crystals of the title compound suitable for X-ray diffraction analysis were obtained from a solution of hexane/ethyl acetate (3:2) by slow evaporation at room temperature.

Synthesis of compound 3: (3'-(4-chlorobenzoyl)-1'-methyl-4'-((3aR,5R,5aS,8aS,8bR)-2,2,7,7-tetramethyltetrahydro-3aH-bis[1,3]dioxolo[4,5-b:4',5'-d]pyran-5-yl)-2H-spiro[acenaphthylene-1,2'-pyrrolidin]-2-one):A mixture of (*E*)-1-(4-chlorophenyl)-3-((3aR,5R,5aS,8aS,8bR)-2,2,7,7-tetramethyltetrahydro-3aH-bis[1,3] dioxolo [4,5-b:4',5'-d]pyran-5-yl)prop-2-en-1-one (300mg, 0.761 mmol), acenaphthenequinone (138mg, 0.761 mmol) and sarcosine (80mg, 0.913 mmol) was refluxed at 120 °C in toluene for about 6 hrs under Dean stark reaction condition to give 3'-(4-chlorobenzoyl)-1'-methyl-4'-((3aR,5R,5aS,8aS,8bR)-2,2,7,7-tetramethyltetrahydro-3aH-bis[1,3]dioxolo[4,5-b:4',5'-d]pyran-5-yl)-2H-spiro[acenaphthylene-1,2'-pyrrolidin]-2-one. After the completion of reaction as indicated by TLC, solvent was evaporated under reduced pressure. The crude product was purified by column chromatography using hexane: EtOAc (4:1) as eluent. Block-shaped single crystals of the title compound suitable for X-ray diffraction analysis were obtained from a solution of hexane/ethyl acetate (4:1) by slow evaporation at room temperature.

Results and Discussion

For compound 1:

The thiazolidine ring (S1/N2/C11/C12/C13) adopts a *twisted* conformation; the furan ring (O4/C17/C18/C19/C20) adopts a *twisted* conformation, the dioxolane ring (O5/O6/C19/C20/C21) adopts an *envelope* conformation and the pyrrolidine ring (N2/C7/C9/C10/C11) adopts an *envelope* conformation. The thiazolidine ring makes a dihedral angle of 73.76(2)° with the furan ring, a dihedral angle of 59.72(2)° with the dioxolane ring and a dihedral angles of 53.56(1)° and 60.28(1)° with the two pyrrolidine ring systems, respectively. The furan ring makes a dihedral angle of 67.49(1)° with the dioxolane ring and dihedral angles of 67.28(1)° and 37.32(1)° with the two pyrrolidine ring systems, respectively. The dioxolane ring makes a dihedral angle of 70.02(1)° and 76.41(2)° with the two pyrrolidine ring systems, respectively. The dihedral angle between the two pyrrolidine rings are 87.79(1)° which shows they are almost orthogonal to each other. The methyl carbon atoms C22 and C23 attached with the dioxolane ring deviate by -1.0777(5) Å and 1.3855(5) Å, respectively. The crystal structure and packing diagram of compound 1 are shown in Figs. 1 and 2. The packing of the crystal is stabilized by intermolecular N—H…O, C—H…O and intramolecular C—H…O hydrogen bonds. The hydrogen bond geometry for compound 1 is given in Table 2. The selected bond lengths and bond angles are given in tables 3 and 4, respectively.

Table 2 Hydrogen-bond geometry [Å] for compound 1

D—H…A	D—H	H…A	D…A	D—H…A
N1--H1...N2^{i}	0.86	2.53	3.309(3)	151
C2--H2...O1^{i}	0.93	2.49	3.288(3)	144
C13--H13B...O5^{i}	0.97	2.53	3.232(3)	129
C11--H11...O4	0.98	2.46	2.899(3)	107
C10--H10...O2	0.98	2.44	2.876(3)	106

Symmetry code: i)**-1/2+x,-1/2-y,-z**

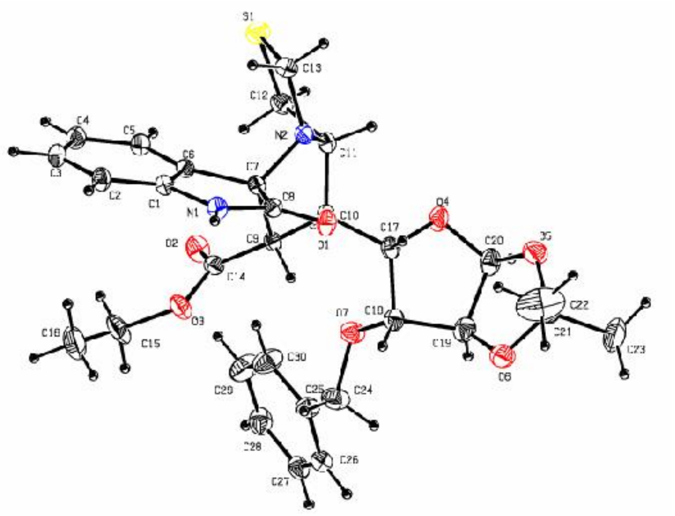

Fig. 1. The molecular structure of the compound 1, with atom labeling. Displacement ellipsoids are drawn at the 30% probability level.

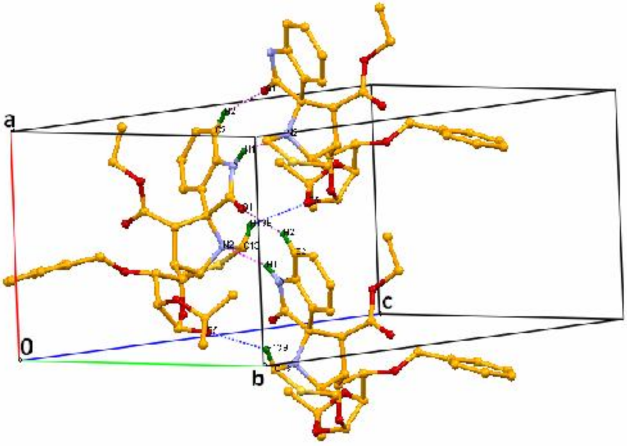

Fig. 2. The crystal packing of the compound 1 viewed along the *b* axis. The hydrogen bonds are shown as dashed lines (see Table 2 for details; H-atoms not involved in H-bonds have been excluded for clarity).

Table 3: Selected bond lengths [Å] for compound 1

Selected bonds	Bond lengths (Å)	Selected bonds	Bond lengths (Å)
C(16)-C(15)	1.462(5)	C(13)-S(1)	1.853(3)
C(22)-C(21)	1.491(5)	C(14)-O(2)	1.191(3)
C(1)-C(2)	1.371(3)	C(14)-O(3)	1.341(3)
C(1)-C(6)	1.397(3)	C(15)-O(3)	1.466(3)
C(1)-N(1)	1.406(3)	C(17)-O(4)	1.434(3)
C(2)-C(3)	1.386(3)	C(17)-C(18)	1.521(4)
C(3)-C(4)	1.383(4)	C(18)-O(7)	1.423(3)
C(4)-C(5)	1.390(3)	C(18)-C(19)	1.523(4)
C(5)-C(6)	1.380(3)	C(19)-O(6)	1.398(3)
C(6)-C(7)	1.517(3)	C(19)-C(20)	1.511(4)
C(7)-N(2)	1.471(3)	C(20)-O(4)	1.391(3)
C(7)-C(8)	1.558(3)	C(20)-O(5)	1.399(3)
C(7)-C(9)	1.577(3)	C(21)-O(6)	1.386(3)
C(8)-O(1)	1.212(3)	C(21)-O(5)	1.422(3)
C(8)-N(1)	1.350(3)	C(21)-C(23)	1.480(5)
C(9)-C(14)	1.507(3)	C(24)-O(7)	1.417(3)
C(9)-C(10)	1.544(3)	C(24)-C(25)	1.499(4)
C(10)-C(11)	1.514(3)	C(25)-C(26)	1.366(4)
C(10)-C(17)	1.523(3)	C(25)-C(30)	1.374(4)

C(11)-N(2)	1.456(3)	C(26)-C(27)	1.376(4)
C(11)-C(12)	1.545(3)	C(27)-C(28)	1.352(4)
C(12)-S(1)	1.800(3)	C(28)-C(29)	1.367(4)
C(13)-N(2)	1.448(3)	C(29)-C(30)	1.374(4)

Table 4: Selected bond angles (deg.) for compound 1

Selected bond angles	Angles (deg.)	Selected bond angles	Angles (deg.)
C(2)-C(1)-C(6)	123.1(2)	C(18)-C(17)-C(10)	115.8(2)
C(2)-C(1)-N(1)	127.4(2)	O(7)-C(18)-C(17)	108.5(2)
C(6)-C(1)-N(1)	109.5(2)	O(7)-C(18)-C(19)	110.3(2)
C(1)-C(2)-C(3)	117.3(3)	C(17)-C(18)-C(19)	103.4(2)
C(4)-C(3)-C(2)	121.3(3)	O(6)-C(19)-C(20)	105.7(2)
C(3)-C(4)-C(5)	120.2(2)	O(6)-C(19)-C(18)	113.2(3)
C(6)-C(5)-C(4)	119.6(3)	C(20)-C(19)-C(18)	104.2(2)
C(5)-C(6)-C(1)	118.5(2)	O(4)-C(20)-O(5)	111.5(2)
C(5)-C(6)-C(7)	132.6(2)	O(4)-C(20)-C(19)	108.5(2)
C(1)-C(6)-C(7)	108.84(19)	O(5)-C(20)-C(19)	104.6(2)
N(2)-C(7)-C(6)	120.6(2)	O(6)-C(21)-O(5)	106.3(2)
N(2)-C(7)-C(8)	106.78(19)	O(6)-C(21)-C(23)	110.2(3)
C(6)-C(7)-C(8)	101.30(18)	O(5)-C(21)-C(23)	109.9(3)
N(2)-C(7)-C(9)	103.34(18)	O(6)-C(21)-C(22)	107.4(3)
C(6)-C(7)-C(9)	115.23(19)	O(5)-C(21)-C(22)	109.5(3)
C(8)-C(7)-C(9)	109.07(19)	C(23)-C(21)-C(22)	113.2(3)
O(1)-C(8)-N(1)	126.8(2)	O(7)-C(24)-C(25)	108.3(2)
O(1)-C(8)-C(7)	125.0(2)	C(26)-C(25)-C(30)	118.6(3)
N(1)-C(8)-C(7)	108.2(2)	C(26)-C(25)-C(24)	120.9(3)
C(14)-C(9)-C(10)	112.6(2)	C(30)-C(25)-C(24)	120.6(3)
C(14)-C(9)-C(7)	112.93(19)	C(25)-C(26)-C(27)	120.7(3)
C(10)-C(9)-C(7)	106.26(19)	C(28)-C(27)-C(26)	120.6(3)
C(11)-C(10)-C(17)	113.5(2)	C(27)-C(28)-C(29)	119.4(3)
C(11)-C(10)-C(9)	105.18(19)	C(28)-C(29)-C(30)	120.4(3)
C(17)-C(10)-C(9)	110.44(19)	C(25)-C(30)-C(29)	120.4(3)
N(2)-C(11)-C(10)	104.76(19)	C(8)-N(1)-C(1)	112.0(2)
N(2)-C(11)-C(12)	108.2(2)	C(13)-N(2)-C(11)	109.90(19)
C(10)-C(11)-C(12)	114.6(2)	C(13)-N(2)-C(7)	118.0(2)
C(11)-C(12)-S(1)	106.15(17)	C(11)-N(2)-C(7)	110.79(18)
N(2)-C(13)-S(1)	108.24(17)	C(14)-O(3)-C(15)	115.8(2)
O(2)-C(14)-O(3)	124.1(2)	C(20)-O(4)-C(17)	107.5(2)
O(2)-C(14)-C(9)	125.9(2)	C(20)-O(5)-C(21)	110.5(2)
O(3)-C(14)-C(9)	110.0(2)	C(21)-O(6)-C(19)	111.4(2)
C(16)-C(15)-O(3)	108.5(3)	C(24)-O(7)-C(18)	114.3(2)
O(4)-C(17)-C(18)	104.6(2)	C(12)-S(1)-C(13)	92.51(12)
O(4)-C(17)-C(10)	107.8(2)		

For compound 2:

The thiazolidine ring (S1/N1/C12/C13/C14) adopts an *envelope* conformation, the furan ring (04/C22/C23/C24/C25/C26) adopts a *twisted* conformation, the dioxolane ring (05/06/C24/C25/C26) adopts an *envelope* conformation, the pyrrolidine ring (N1/C8/C10/C11/C12) adopts a *twisted* conformation and the cyclopentane ring (C1/C6/C7/C8/C9) adopts an *envelope* conformation. The thiazolidine ring makes a dihedral angle of 40.28(1)° with the furan ring, it makes a dihedral angle of 89.64(1)° with the dioxolane ring which shows it is almost perpendicular to each other; it makes a dihedral angle of 30.04(1)° with the pyrrolidine ring systems; and a dihedral angle of 79.84(1)° with the cyclopentane ring .The furan ring makes a dihedral angle of 72.75(1)° with the dioxolane ring; it makes dihedral angle of 13.69(1)° with the pyrrolidine ring and a dihedral angle of 86.54(1)° with the cyclopentane ring. The dioxolane ring makes a dihedral angle of 84.42(1)° with the pyrrolidine ring and a dihedral angle of 46.58(1)° with the cyclopentane ring. The dihedral angle between the pyrrolidine ring and the cyclopentane ring is 83.04(1)°. The methyl carbon atoms C27 and C28 attached with the dioxolane ring deviate by -1.1240(5) Å and 1.3553(4) Å, respectively. The chlorine atom Cl1 attached with the phenyl ring (C16-C21) deviates by 0.0533(1) Å. The crystal structure and packing diagram of compound 2 are shown in Figs. 3 and 4. The packing of the crystal is stabilized by intermolecular and intramolecular C H…O hydrogen bonds. The hydrogen bond geometry for compound 2 is given in Table 5. The selected bond lengths and bond angles are given in tables 6 and 7, respectively.

Table 5 Hydrogen-bond geometry [Å] for compound 2

D—H…A	D—H	H…A	D…A	D—H…A
C20 --H20 ...O1^{i}	0.93	2.41	3.232(3)	147
C11--H11...O7	0.98	2.41	2.832(3)	105
C31--H31…O3	0.93	2.48	3.339(4)	154

Symmetry code: i)**-1/2+x,-1/2-y,-z**

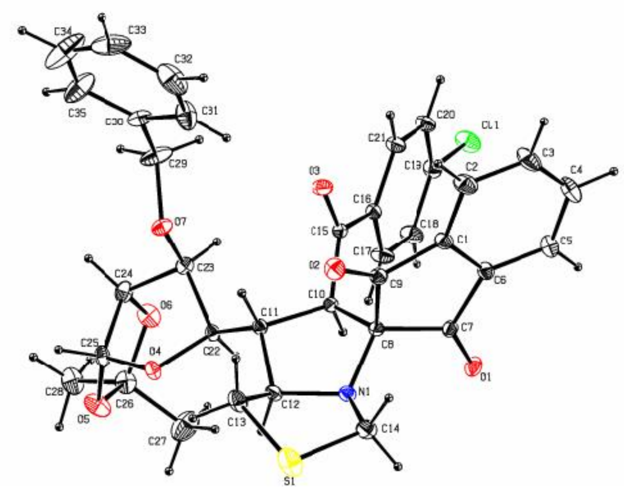

Fig. 3. The molecular structure of the compound 2, with atom labeling. Displacement ellipsoids are drawn at the 30% probability level

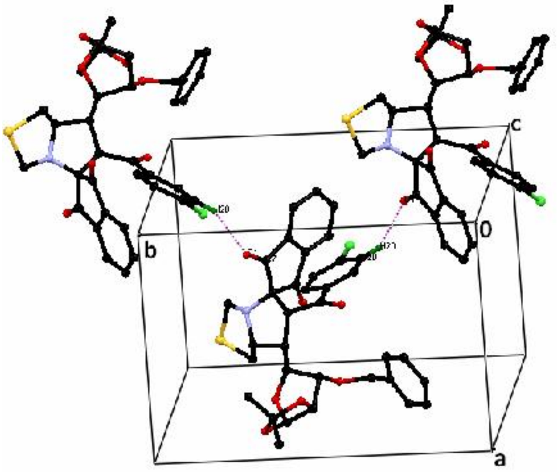

Fig. 4. The crystal packing of the compound 2 viewed along the *c* axis. The hydrogen bonds are shown as dashed lines (see Table 5 for details; H-atoms not involved in H-bonds have been excluded for clarity).

Table 6: Selected bond lengths [Å] for compound 2

Selected bonds	Bond lengths (Å)	Selected bonds	Bond lengths (Å)
C(1)-C(6)	1.383(3)	C(16)-C(21)	1.385(3)
C(1)-C(2)	1.388(3)	C(17)-C(18)	1.382(4)
C(1)-C(9)	1.481(3)	C(18)-C(19)	1.363(4)
C(2)-C(3)	1.371(5)	C(19)-C(20)	1.368(4)
C(3)-C(4)	1.385(5)	C(19)-Cl(1)	1.739(2)
C(4)-C(5)	1.379(5)	C(20)-C(21)	1.374(3)
C(5)-C(6)	1.387(3)	C(22)-O(4)	1.436(2)
C(6)-C(7)	1.469(3)	C(22)-C(23)	1.525(3)
C(7)-O(1)	1.202(3)	C(23)-O(7)	1.415(3)
C(7)-C(8)	1.547(3)	C(23)-C(24)	1.527(3)
C(8)-N(1)	1.436(3)	C(24)-O(6)	1.413(3)
C(8)-C(10)	1.549(3)	C(24)-C(25)	1.520(4)
C(8)-C(9)	1.550(3)	C(25)-O(5)	1.389(3)
C(9)-O(2)	1.199(3)	C(25)-O(4)	1.417(3)
C(10)-C(15)	1.517(3)	C(26)-O(6)	1.420(4)
C(10)-C(11)	1.543(3)	C(26)-O(5)	1.433(3)
C(11)-C(22)	1.513(3)	C(26)-C(27)	1.491(5)
C(11)-C(12)	1.526(3)	C(26)-C(28)	1.509(4)
C(12)-N(1)	1.484(3)	C(29)-O(7)	1.421(4)
C(12)-C(13)	1.518(3)	C(29)-C(30)	1.491(4)
C(13)-S(1)	1.803(3)	C(30)-C(35)	1.352(5)
C(14)-N(1)	1.466(3)	C(30)-C(31)	1.369(4)
C(14)-S(1)	1.797(3)	C(31)-C(32)	1.371(6)
C(15)-O(3)	1.208(3)	C(32)-C(33)	1.384(8)
C(15)-C(16)	1.489(3)	C(33)-C(34)	1.343(9)
C(16)-C(17)	1.385(3)	C(34)-C(35)	1.353(7)

Table 7: Selected bond angles (deg.) for compound 2

Selected bond angles	Angles (deg.)	Selected bond angles	Angles (deg.)
C(6)-C(1)-C(2)	121.1(2)	C(18)-C(19)-C(20)	121.8(2)
C(6)-C(1)-C(9)	110.40(19)	C(18)-C(19)-Cl(1)	118.6(2)
C(2)-C(1)-C(9)	128.5(2)	C(20)-C(19)-Cl(1)	119.61(19)
C(3)-C(2)-C(1)	117.1(3)	C(19)-C(20)-C(21)	119.0(2)
C(2)-C(3)-C(4)	122.2(3)	C(20)-C(21)-C(16)	121.0(2)
C(5)-C(4)-C(3)	120.8(3)	O(4)-C(22)-C(11)	111.20(16)
C(4)-C(5)-C(6)	117.4(3)	O(4)-C(22)-C(23)	103.32(16)
C(1)-C(6)-C(5)	121.4(2)	C(11)-C(22)-C(23)	116.02(17)
C(1)-C(6)-C(7)	110.39(19)	O(7)-C(23)-C(22)	108.05(16)
C(5)-C(6)-C(7)	128.2(2)	O(7)-C(23)-C(24)	110.81(19)
O(1)-C(7)-C(6)	126.8(2)	C(22)-C(23)-C(24)	100.65(19)
O(1)-C(7)-C(8)	125.07(19)	O(6)-C(24)-C(25)	104.4(2)
C(6)-C(7)-C(8)	108.03(18)	O(6)-C(24)-C(23)	108.2(2)
N(1)-C(8)-C(7)	115.57(17)	C(25)-C(24)-C(23)	104.19(18)
N(1)-C(8)-C(10)	100.77(14)	O(5)-C(25)-O(4)	113.2(2)
C(7)-C(8)-C(10)	107.38(16)	O(5)-C(25)-C(24)	105.22(19)
N(1)-C(8)-C(9)	117.93(18)	O(4)-C(25)-C(24)	106.95(17)
C(7)-C(8)-C(9)	102.31(15)	O(6)-C(26)-O(5)	105.5(2)
C(10)-C(8)-C(9)	112.84(17)	O(6)-C(26)-C(27)	109.4(3)
O(2)-C(9)-C(1)	127.3(2)	O(5)-C(26)-C(27)	110.1(3)
O(2)-C(9)-C(8)	125.3(2)	O(6)-C(26)-C(28)	109.5(3)
C(1)-C(9)-C(8)	107.36(18)	O(5)-C(26)-C(28)	110.1(2)
C(15)-C(10)-C(11)	116.38(17)	C(27)-C(26)-C(28)	112.0(3)

C(15)-C(10)-C(8)	113.45(16)	O(7)-C(29)-C(30)	109.5(2)
C(11)-C(10)-C(8)	102.04(15)	C(35)-C(30)-C(31)	119.0(3)
C(22)-C(11)-C(12)	114.50(17)	C(35)-C(30)-C(29)	121.0(3)
C(22)-C(11)-C(10)	110.31(16)	C(31)-C(30)-C(29)	120.0(3)
C(12)-C(11)-C(10)	102.90(16)	C(32)-C(31)-C(30)	120.5(4)
N(1)-C(12)-C(13)	107.82(18)	C(31)-C(32)-C(33)	118.8(4)
N(1)-C(12)-C(11)	105.31(16)	C(34)-C(33)-C(32)	119.9(4)
C(13)-C(12)-C(11)	115.3(2)	C(33)-C(34)-C(35)	120.5(5)
C(12)-C(13)-S(1)	103.7(2)	C(30)-C(35)-C(34)	121.1(5)
N(1)-C(14)-S(1)	107.33(16)	C(8)-N(1)-C(14)	118.78(17)
O(3)-C(15)-C(16)	120.8(2)	C(8)-N(1)-C(12)	110.21(16)
O(3)-C(15)-C(10)	119.83(19)	C(14)-N(1)-C(12)	113.47(18)
C(16)-C(15)-C(10)	119.36(18)	C(25)-O(4)-C(22)	108.30(16)
C(17)-C(16)-C(21)	118.6(2)	C(25)-O(5)-C(26)	111.3(2)
C(17)-C(16)-C(15)	123.6(2)	C(24)-O(6)-C(26)	110.4(2)
C(21)-C(16)-C(15)	117.8(2)	C(23)-O(7)-C(29)	113.3(2)
C(18)-C(17)-C(16)	120.6(2)	C(14)-S(1)-C(13)	92.52(12)
C(19)-C(18)-C(17)	119.1(3)		

For compound 3:

The dioxolane ring (O3/04/C25/C26/C27) adopts an *envelope* conformation; the dioxolane ring (06/07/C20/C31/C32) adopts an *envelope* conformation; the pyrrolidine ring (N1/C12/C13/C14/C15) adopts a twisted conformation. The dihedral angle between the dioxolane rings is 78.41(2)°. The dioxolane ring makes a dihedral angle of 44.82(2)° with the pyrrolidine ring; it makes a dihedral angle of 84.1(2)° with the cyclopentane ring (C5/C6/C7/C11/C12) and a dihedral angle of 76.56(2)° with the furan ring. The dioxolane ring makes a dihedral angle of 39.24(2)° with the pyrrolidine ring; it makes a dihedral angle of 58.7(2)° with the cyclopentane ring and a dihedral angle of 77.44(2)° with the furan ring. The pyrrolidine ring makes a dihedral angle of 87.3(2)° with the cyclopentane ring which shows they are almost orthogonal to each other; it makes a dihedral angle of 56.69(2)° with the furan ring. The dihedral angle between the cyclopentane ring and the furan ring is 44.0(2)°. The methyl carbon atoms C28 and C29 attached with the dioxolane ring deviate by 0.0483(3) Å and -1.7189(5) Å, respectively. The methyl carbon atoms C33 and C34 attached with the dioxolane ring deviates by -0.6785(5) Å and 1.7104(4) Å, respectively. The chlorine atom Cl1 attached with the phenyl ring (C18-C23) deviates by -0.0350(1) Å. The crystal structure and packing diagram of compound 3 are shown in Figs. 5 and 6. The packing of the crystal is stabilized by intermolecular and intramolecular C—H…O hydrogen bonds. The hydrogen bond geometry for compound 3 is given in Table 8. The selected bond lengths and bond angles are given in tables 9 and 10 respectively.

Table 8 Hydrogen-bond geometry [Å] for compound 3

D—H…A	D—H	H…A	D…A	D—H…A
C13--H13...O1	0.98	2.60	3.044(4)	108
C13 --H13...O5	0.98	2.42	2.872(3)	107
C15--H15B...O3	0.97	2.54	2.960(4)	106
C26 --H26…O1^{i}	0.98	2.54	3.474(4)	159

Symmetry code: i) **x, 1+y, z**

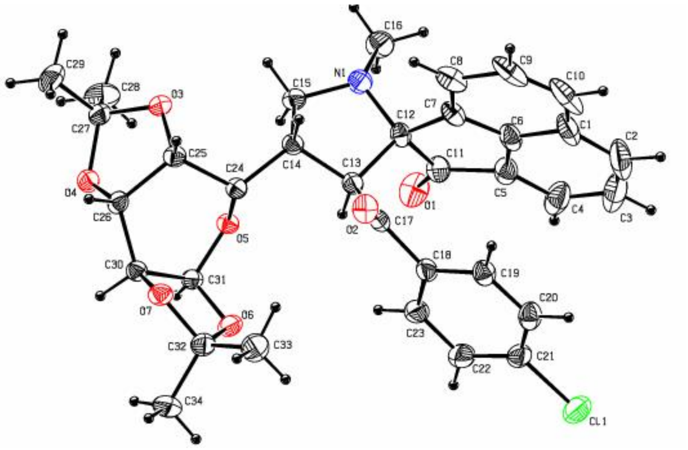

Fig. 5. The molecular structure of the compound 3, with atom labeling. Displacement ellipsoids are drawn at the 30% probability level.

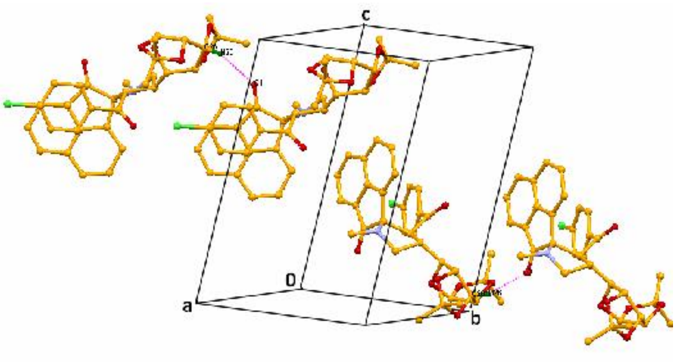

Fig. 6. The crystal packing of the compound 3 viewed along the *a* axis. The hydrogen bonds are sown as dashed lines (see Table 8 for details; H-atoms not involved in H-bonds have been excluded for clarity).

Table 9: Selected bond lengths [Å] for compound 3

Selected bonds	Bond lengths (Å)	Selected bonds	Bond lengths (Å)
C(1)-C(10)	1.393(10)	C(18)-C(23)	1.362(6)
C(1)-C(6)	1.411(6)	C(18)-C(19)	1.399(4)
C(1)-C(2)	1.424(12)	C(19)-C(20)	1.385(6)
C(2)-C(3)	1.369(12)	C(20)-C(21)	1.351(6)
C(3)-C(4)	1.387(9)	C(21)-C(22)	1.386(6)
C(4)-C(5)	1.355(6)	C(21)-Cl(1)	1.737(4)
C(5)-C(6)	1.406(6)	C(22)-C(23)	1.387(6)
C(5)-C(11)	1.480(6)	C(24)-O(5)	1.440(4)
C(6)-C(7)	1.388(6)	C(24)-C(25)	1.511(4)
C(7)-C(8)	1.379(6)	C(25)-O(3)	1.422(4)
C(7)-C(12)	1.511(5)	C(25)-C(26)	1.552(5)
C(8)-C(9)	1.432(7)	C(26)-O(4)	1.424(4)
C(9)-C(10)	1.374(11)	C(26)-C(30)	1.517(5)
C(11)-O(1)	1.199(4)	C(27)-O(3)	1.404(4)
C(11)-C(12)	1.569(5)	C(27)-O(4)	1.427(4)
C(12)-N(1)	1.468(5)	C(27)-C(28)	1.499(6)
C(12)-C(13)	1.565(5)	C(27)-C(29)	1.502(6)
C(13)-C(17)	1.512(4)	C(30)-O(7)	1.419(4)
C(13)-C(14)	1.528(5)	C(30)-C(31)	1.525(5)
C(14)-C(24)	1.524(5)	C(31)-O(6)	1.402(4)
C(14)-C(15)	1.525(5)	C(31)-O(5)	1.412(4)

C(15)-N(1)	1.440(5)	C(32)-O(6)	1.422(5)
C(16)-N(1)	1.426(5)	C(32)-O(7)	1.429(5)
C(17)-O(2)	1.211(4)	C(32)-C(33)	1.515(5)
C(17)-C(18)	1.492(5)	C(32)-C(34)	1.518(6)

Table 10: Selected bond angles (deg.) for compound 3

Selected bond angles	Angles (deg.)	Selected bond angles	Angles (deg.)
C(10)-C(1)-C(6)	117.0(6)	C(21)-C(20)-C(19)	120.4(3)
C(10)-C(1)-C(2)	129.1(6)	C(20)-C(21)-C(22)	121.0(4)
C(6)-C(1)-C(2)	113.8(7)	C(20)-C(21)-Cl(1)	120.3(3)
C(3)-C(2)-C(1)	122.3(6)	C(22)-C(21)-Cl(1)	118.6(3)
C(2)-C(3)-C(4)	122.3(6)	C(21)-C(22)-C(23)	118.2(4)
C(5)-C(4)-C(3)	117.6(6)	C(18)-C(23)-C(22)	121.8(3)
C(4)-C(5)-C(6)	121.3(4)	O(5)-C(24)-C(25)	109.1(2)
C(4)-C(5)-C(11)	132.3(5)	O(5)-C(24)-C(14)	108.0(2)
C(6)-C(5)-C(11)	106.4(3)	C(25)-C(24)-C(14)	115.7(3)
C(7)-C(6)-C(5)	114.2(3)	O(3)-C(25)-C(24)	111.9(3)
C(7)-C(6)-C(1)	123.1(5)	O(3)-C(25)-C(26)	103.6(2)
C(5)-C(6)-C(1)	122.6(5)	C(24)-C(25)-C(26)	111.0(3)
C(8)-C(7)-C(6)	119.9(4)	O(4)-C(26)-C(30)	107.2(3)
C(8)-C(7)-C(12)	130.9(4)	O(4)-C(26)-C(25)	103.7(2)
C(6)-C(7)-C(12)	109.1(3)	C(30)-C(26)-C(25)	114.4(2)
C(7)-C(8)-C(9)	117.0(5)	O(3)-C(27)-O(4)	105.5(2)
C(10)-C(9)-C(8)	122.8(6)	O(3)-C(27)-C(28)	108.7(4)
C(9)-C(10)-C(1)	120.0(5)	O(4)-C(27)-C(28)	107.6(3)
O(1)-C(11)-C(5)	128.3(4)	O(3)-C(27)-C(29)	109.8(4)
O(1)-C(11)-C(12)	123.9(3)	O(4)-C(27)-C(29)	110.9(3)
C(5)-C(11)-C(12)	107.8(3)	C(28)-C(27)-C(29)	114.0(4)
N(1)-C(12)-C(7)	111.8(3)	O(7)-C(30)-C(26)	107.4(2)
N(1)-C(12)-C(13)	103.1(2)	O(7)-C(30)-C(31)	103.7(2)
C(7)-C(12)-C(13)	115.4(3)	C(26)-C(30)-C(31)	113.9(3)
N(1)-C(12)-C(11)	116.7(3)	O(6)-C(31)-O(5)	110.1(2)
C(7)-C(12)-C(11)	102.2(3)	O(6)-C(31)-C(30)	104.2(3)
C(13)-C(12)-C(11)	108.1(3)	O(5)-C(31)-C(30)	114.1(3)
C(17)-C(13)-C(14)	117.0(3)	O(6)-C(32)-O(7)	105.0(3)
C(17)-C(13)-C(12)	113.5(3)	O(6)-C(32)-C(33)	109.0(3)
C(14)-C(13)-C(12)	104.4(3)	O(7)-C(32)-C(33)	108.6(4)
C(24)-C(14)-C(15)	119.4(3)	O(6)-C(32)-C(34)	110.4(3)
C(24)-C(14)-C(13)	109.8(3)	O(7)-C(32)-C(34)	110.2(3)
C(15)-C(14)-C(13)	100.8(3)	C(33)-C(32)-C(34)	113.3(4)
N(1)-C(15)-C(14)	102.8(3)	C(27)-O(3)-C(25)	110.0(3)
O(2)-C(17)-C(18)	122.4(3)	C(26)-O(4)-C(27)	106.2(3)
O(2)-C(17)-C(13)	122.3(3)	C(31)-O(5)-C(24)	111.7(2)
C(18)-C(17)-C(13)	115.3(3)	C(31)-O(6)-C(32)	110.1(3)
C(23)-C(18)-C(19)	118.8(4)	C(30)-O(7)-C(32)	105.7(2)
C(23)-C(18)-C(17)	121.7(3)	C(16)-N(1)-C(15)	118.1(3)
C(19)-C(18)-C(17)	119.4(3)	C(16)-N(1)-C(12)	117.5(3)
C(20)-C(19)-C(18)	119.6(4)	C(15)-N(1)-C(12)	110.6(3)

Conclusion

The crystal structure analysis of the three novel Spiro pyrrolidine derivatives was studied using x-ray diffraction method. In all the three compounds the packing of the crystal structure is stabilized by intermolecular and intramolecular C—H…O hydrogen bonds.

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