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Spectroscopic and Thermal Studies of Some Palladium(II) Complexes with 2-amino-4-(4-subsistuted phenyl)thiazole Derivatives

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ABSTRACT

Six new complexes of palladium(II) with a general formula $[Pd(L)_2Cl_2]$, where L = 2-amino-4-(4-subsistuted phenyl)thiazole. The palladium complexes were prepared by the reaction of 2-amino-4-(4-subsistuted phenyl)thiazole ligands with with Bis(benzonitrile)palladium(II) dichloride in chloroform solvent at molar ratio Pd:L=1:2. The resulting complexes were characterized by the magnetic susceptibility, conductivity measurements, infrared, ^1H NMR and the thermo gravimetric analysis. Elemental analyses, spectroscopic and another physical studies of the prepared palladium (II) complexes allowed structures to be proposed. The thermal properties of the prepared complexes indicated the all-decomposition steps and gave an insight about the stability of palladium(II) complexes. The physical analysis indicated that prepared ligands behaved as mono dental, bounding Pd(II) through the nitrogen atoms from the thiazole ring.

1. Introduction

Palladium complexes with heterocyclic ligands were the subject on intensive studies due to their biological activity (Akpunar, et al., 2021; Mansour, et al., 2021). Many researches have been achieved on the palladium complexes with heterocyclic compounds containing nitrogen as a donor atom such as azines, pyridines and their derivatives. The resulting complexes have been stimulated by their magnetic coupling interactions, magnetic coupling interactions, catalytic, photocatalytic processes and electrochemical properties (Kantchev, et al., 2007; Gaw, et al., 2002).

The heterocyclic ligands that have nitrogen and / or sulphur atoms are of extensive use as building unit in coordination chemistry; where the sulphur being can give more biological activity for the ligands. These types of compounds are recognized as potent biological molecules with a wide range of activity, and textile dyes too (Das, et al., 2016; Singh, et al., 2002). 2-aminothiazole and its derivatives have been used as building blocks in the synthesis of numerous compounds which have biocides, dyes, fungicides, accelerators for chemical reaction, sulfur drugs. Furthermore, a huge number of 2-aminothiazoles derivatives have been used in pharmaceutical field and are similarly used in the preparation of numerous types of dyes which have been used as synthetic fibers, alongside their action as corrosion inhibitors for protection of mild steel (Mašković, et al., 2018; Khaled & Amin, 2009).

Coordination chemistry of Pd(II) , Pt(II) and Ru(II) have found a lot using as antitumor reagents (Alam & Huq, 2016; Alam, et al., 2020). Cis-platin derivatives of some benzimidazole molecules in addition to their corresponding palladium compounds have been characterized by different methods like X-ray structure analysis.

Many palladium complexes have got lots of attention due to the similarity between the coordination chemistry of palladium and platinum. Though the early studies indicated unpromising results obvious with larger toxicity and lower anti-cancer activity for Pd complexes than cis-platin, Lately, higher antitumor activity in Pd complexes together with low toxicity has been done by introduce of bulk substituted organic ligands (Alam & Huq, 2016; Alam, et al., 2020).

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Our interest in the coordination chemistry of heterocyclic ligands containing nitrogen atoms such as 2-hydroxybenzylidene-4-(4-substituted-phenyl)-2-aminothiazole (Aldelfy, et al., 2019) has encouraged us to investigate the reactions of Pd(II) with some selected 2-amino-4-(4-subsistuted phenyl)thiazole ligands (Scheme 1).

2. Materials and Methods

PdCl2,Acetophenone,4-Chloro-acetophenone,4-Methyl-acetophenone,4-Methoxy- acetophenone, 4-Bromo-acetophenone, 4-Nitro-acetophenone and thiourea were purchased from Fluka.

2.1. Instruments

The measurements of IR (KBr pellets) were achieved on a Shimadzu 8400S FT-IR spectrophotometer in the range of (4000-500) cm-1. 1HNMR measurements were carried out on a Bruker MHZ500. Samples were dissolved in deuterated DMSO-d6 solvent with TMS as internal reference. Thermogravimetric analyses (TG and DTG) have been carried out under inner atmosphere of nitrogen gas with a heating rate of 10 °C/min. by using a SDT Q600 V20.9 Build 20 thermal analyzer. The prepared Palladium complexes were characterized by using elemental analysis (Perkin-Elmer 2400 CHN instrument).

2.1.1. Preparation of 2-Amino 4-(4-substitutedphenyl) thiazole (general procedure)

2-Amino 4-(4-substitutedphenyl)thiazole compounds were prepared according to literature (Dodson & King, 1945), Iodine (15 mmol) dissolved in 10 ml ethanol was added to a mixture of thiourea (30 mmol) and acetophenone derivatives (15 mmol) dissolved in 20 ml ethanol, the resulting mixture was heated to reflux overnight. After that, it was diluted with water and then heated till the biggest amount of the solid has been dissolved. Then the resulting solution was cooled, filtered and it alkaline by using concentrated solution of NH4OH. The resulting precipitated of 2-amino-4-phenylthiazole was separated and recrystallized from ethanol to constant melting point.

2.1.2. Preparation of Bis (benzonitrile) palladium (II) Dichloride

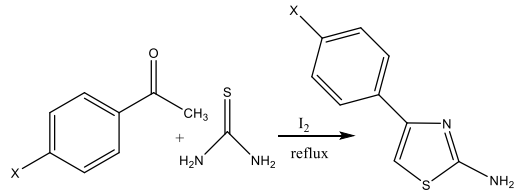
This complex PdCl2(PhCN)2, was prepared as described in the literature (Olmstead, et al., 2000). 0.4 gram of palladium(II) dichloride was dissolved in 2 mL of benzonitrile solvent . The resulting solution (dark orange) has been transferred after that to a 10 mL beaker and then heated for an hour at 100 °C. The resulting solution was partly evaporated and then cooled to give dark red crystals. The resulting crystals were collected by filtration and washed with ether.

2.1.3. Preparation of complexes of palladium with 2-Amino 4-(4-substitutedphenyl) thiazole

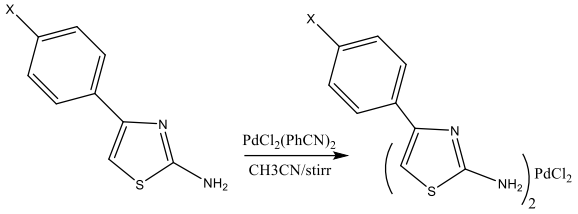
2-Amino 4-(4-substitutedphenyl) thiazole (2 mmol) dissolved in 25 ml of chloroform was added gradually with continuous stirring to solution of PdCl2(PhCN)2 (1 mmol) dissolved in 20 ml of chloroform. The resulting solution was left under reflux for four hours. The resulting mixture was cooled and the precipitate was collected by filtration and washed with ethanol.

3. Results & Discussion

Six thiazole ligands have been prepared by the reaction of thiourea and acetophenone derivatives, then the resulting ligands of 2-Amino 4-(4-substitutedphenyl)thiazole have been used to synthesized new palladium complexes by the reaction of these ligands with Bis(benzonitrile)palladium(II) Dichloride in chloroform solvent; see Scheme 1.



X= NO_2;L1, , OCH_3;L2, CH_3;L3, Cl;L4, H;L5, Br;L6



Scheme. 1. The synthetic route to complexes of palladium with 2-Amino 4-(4-substitutedphenyl) thiazole derivatives.

Table 1
Elemental analysis, color, yield. Magnetic susceptibility and conductivity data for the palladium complexes

Complex	Color	Yield (%)	Calcul (Found) C	H	N	m.p	μeff (B.M)	Λ m = ohm-1 cm² mol-1
[Pd(L1)2Cl2]	Dark yellow	51	34.80 (34.34)	2.26 (2.26)	13.57 (13.59)	296- 298	0.76	0.270
[Pd(L2)2Cl2]	Brown	48	40.74 (40.98)	3.39 (3.24)	9.50 (9.56)	270- 272	0.82	0.490
[Pd(L3)2Cl2]	Brown	50	43.64 (43.68)	3.60 (3.60)	10.44 (10.92)	Dec.> 300	0.79	0.168
[Pd(L4)2Cl2]	Brown	45	36.16 (36.22)	2.33 (2.27)	9.34 (9.27)	Dec. 200	0.83	3.927
[Pd(L5)2Cl2]	Brown	54	40.83 (40.97)	3.02 (3.25)	10.58 (10.59)	Dec.> 300	0.78	0.144
[Pd(L6)2Cl2]	Brown	52	31.44 (31.65)	2. 77 (2.90)	8.15 (8.43)	Dec.> 300	0.77	0.060

The physical and elemental analysis data of the prepared complexes are shown in Table 1. As shown in this table, there were a good agreement between theoretical and calculated results. Another data like color, yield and melting points of the prepared complexes are listed also in Table 1.

The magnetic susceptibility of the prepared palladium complexes was calculated at room temperature 298K, where the complexes showed diamagnetic properties. The observed magnetic moments of palladium complexes were less than one confirming the diamagnetic properties of the square planar complexes and hybridization dsp2, see Table 1. To investigate the behave of palladium complexes in solution, their conductivity was studied in DMSO solvent. The conductivity of the studied complexes indicate that are non-electrolyte, where the molar conductivity values range between (3.93-0.060 ohm-1cm2mol-1) at a concentration of (1x10-3M). Thus, the prepared palladium complexes have not a counter ion outside the coordination sphere, see Table 1.

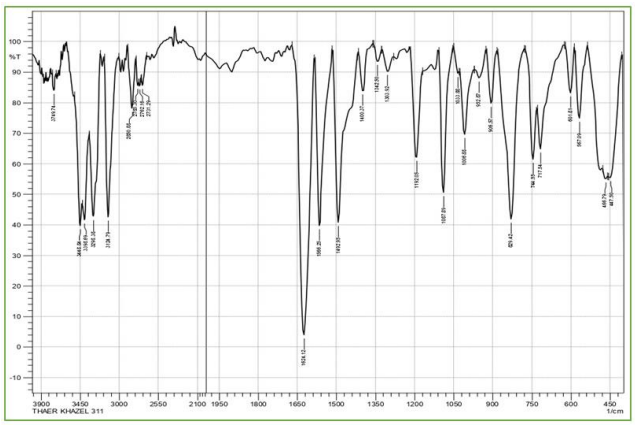


Fig. 1. IR spectrum of 2-Amino 4-(4-Chloro-phenyl)thiazole ligand

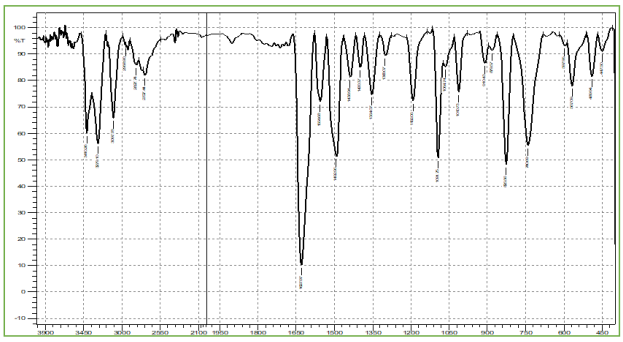


Fig. 2. IR spectrum of palladium complexes of 2-Amino 4-(4-Chloro-phenyl)thiazole

The infra-red spectra of the prepared complexes are presented in Table 2, see also Figure 1 and Figure 2. The IR spectra showed the characteristic bands of the ligands and complexes due to functional groups like NH, C=N, C=C and C-S with the suitable shifts, see Table 2. It can be seen clearly from the palladium complexes spectra that the bands characterizing the stretching vibration of NH2 group did not shift towards low frequencies. This means that there is not bound between NH2 group and Pd metal. On the other hand, the palladium complexes spectra indicated the stretching vibrations of the C=N group between 1600-1647 cm^{-1}, these bands were shifted towards lower frequencies with 39-20 cm^{-1}, in comparison with the free ligands, because of complex formation between the nitrogen atom of thiazole ring and the palladium metal. The stretching vibrations of C=N bond in free ligands indicated higher frequencies due to the redistribution of the electronic density as a result of the participation of the C=N group. Furthermore, new band in the IR spectra have been observed in the spectra of palladium complexes which can be assigned to ν(Pd-N) in the 474-582 cm^{-1} range.

The ^{1}H NMR spectra of the prepared palladium complexes are listed in Table 2, see also Figure 3 and Figure 4. The ^{1}HNMR spectra of complexes indicate signals due to the different proton nuclei in thiazole ligands. Generally, as shown in this table, the signals of the protons were significantly shifted down field, thus confirming the coordination of palladium through the nitrogen atom of thiazole ring. The signals shift of protons of methyl and methoxy group did not indicate noticeable change.

The thermo gravimetric analysis (TGA) and differential thermo gravimetric decomposition (DTG) for palladium complexes have been achieved. The data of thermo gravimetric analyses of palladium complexes are shown in Table 3, see also Figure 4 and Figure 5. Thermogravimetric analyses (TG and DTG) have been carried out under inner atmosphere of nitrogen gas with a heating rate of 10 °C/min.

The TGA curve of $[Pd(L_1)2Cl_2]$ indicate three phases of decomposition steps for complex. The first step inside the temperature range 99-340 °C (DTGmax=290 °C) is the moisture and a part of ligand (C8H4S2) which reflected mass losses of 26.52 % (cal. 26.55%).

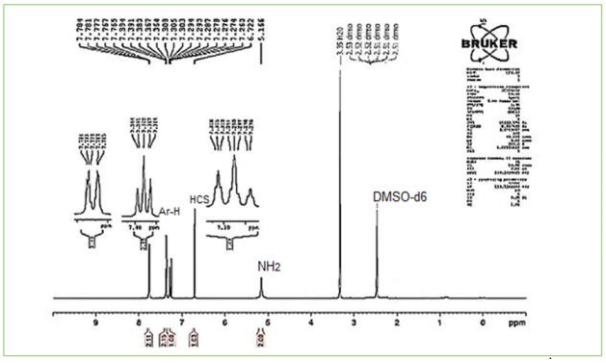


Fig. 3. ^{1}H NMR of spectrum of 2-Amino 4-(phenyl)thiazole ligand

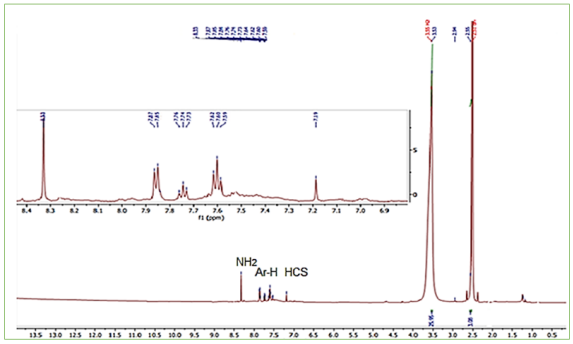


Fig. 4. ^{1}H NMR of spectrum of palladium complex of 2-Amino 4-(phenyl)thiazole

Table 2
Important IR and ^{1}HNMR data for2-Amino 4-(4-substitutedphenyl) thiazole derivatives ligands and their palladium complex

Comp.	IR data (cm^{-1})				^{1}H NMR DATA (ppm)
	ν(NH)	ν(C=N)	ν(C=C)	ν(C-S)	
L1	3402,3309 (m)	1639	1593	1107,1037	7.2 (s,2H,NH2) 7.4 (s,^{1}H, ring thiazole) 8.05-8.20 (m,4H,Ar-H)
[Pd(L$_1$)2Cl$_2$]	3422,3325	1600	1512	1111,1065	(8.04 - 8.26) (m,8H,Ar-H) (8.38 -8. 40)(s,4H,NH$_2$) 7.74-7.72 (s,2H, ring thiazole)
L2	3437,3271 (m)	1624	1531	1111,1033	7.01 (s ,2H,NH2) 7.4 (s,^{1}H, ring thiazole) 6.91-7.74 (m,4H,Ar-H) 3.7 (s, 3H, OCH$_3$)
[Pd(L$_2$)2Cl$_2$]	3421,3298	1604	1512	1180,1022	7.60 - 6.96 (m,8H,Ar-H) 7. 83 (s,4H,NH$_2$) , 6.86 -6.90 (s,2H,ring thiazole) 3.8(s,6H,OCH$_3$)
L3	3417,3302 (m)	1627	1519	1033,1130	8.3 (s,2H,NH2) 7.4 (s,^{1}H, ring thiazole) 7.6-7.9(m,4H,Ar-H) 2.3 (s,3H,CH3)
[Pd(L$_3$)2Cl$_2$]	3417,3286	1647	1519	1184,1045	7.6 -7.85 (m,8H,Ar-H) 7.76 (s,4H,NH$_2$) 7.25(s,2H,ring thiazole) 2.3(s,6H,CH3)
L4	3448,3298 (m)	1624	1566	1192,1087	4. 56 (s,2H,NH$_2$) 7.55 (s,^{1}H,ring thiazole) 7.4 - 7.7 (m,4H,Ar-H)
[Pd(L$_4$)2Cl$_2$]	3410,3279	1644	1554	1192,1091	7.49 -7.80 (m,8H,Ar-H) 7.86-7.88(s ,4H,NH$_2$) 7.18 (s,2H, ring thiazole)
L5	3437,3259 (m)	1600	1523	1072,1033	5.16(s,2H,NH$_2$) 6.72(s,^{1}H,ring thiazole) 7.26 -7.78(m,5H,Ar-H)
[Pd(L$_5$)2Cl$_2$]	3448,	1620	1519	1176,1030	7.59 -7. 87 (m,8H,Ar-H) 8.30 - 8.33 (s,4H,NH$_2$) 7.08 (s,^{2}H, ring thiazole)
L6	3441,3352 (m)	16027	1566	1037,1107	7.9(s,2H,NH$_2$) 7.24 (s,^{1}H,ring thiazole) 7.63-7.75 (m,4H,Ar-H)
[Pd(L$_6$)2Cl$_2$]	3421,3302	1608	1519	1176,1072	(7.86 - 7. 51) (m,8H,Ar-H) 7.88(S,4H,NH$_2$) (7.18)(S,^{2}H,ring thaizole)

The second decomposition step was within the 350-475 °C range (DTGmax=396 °C) agrees to the loss two Cl ion as two HCl molecules with percentage of 11.14% (cal. 11.44%). The last step of decomposition was within 475- 800 °C range, (DTGmax= 625 °C) is the loss of C4H5N4 fragment of ligand with mass losses of 17.73% (cal.17.60%). There was a remaining residue of palladium complexes as carbon and metal oxide due to decomposition.

The TGA curve of [Pd(L2)2Cl2] indicate two phases of decomposition steps for complex. The first step was at 30-310 °C range, (DTG max= 277 °C) with losing percentage of 18.92% (cal. 18.16%) due to losing of C7H7O fragment. The second step was at 310-800 °C range, (DTGmax= 475 °C) with losing percentage of 27.89% (cal. 27.84%) due to losing of the organic fragment of $C_8H_4S_2$.

The TGA curve of [Pd(L3)2Cl2] indicate three phases of decomposition steps for complex. The first step was at 25-380 °C range, (DTGmax= 284 °C) with losing percentage of 28.00% (28.02%) due to the losing of C8H4N4 fragment. On the other hand, the second step carried out at 380-580 °C range, (DTGmax= 457 °C) with losing percentage circa about 9.96 (cal. 9.86) due to losing of C4H7 fragment. The last third step was occurred at 580-800 °C range, (DTGmax= 710 °C) with losing percentage of 9.21% (cal.9.147) due to losing CH7S fragment.

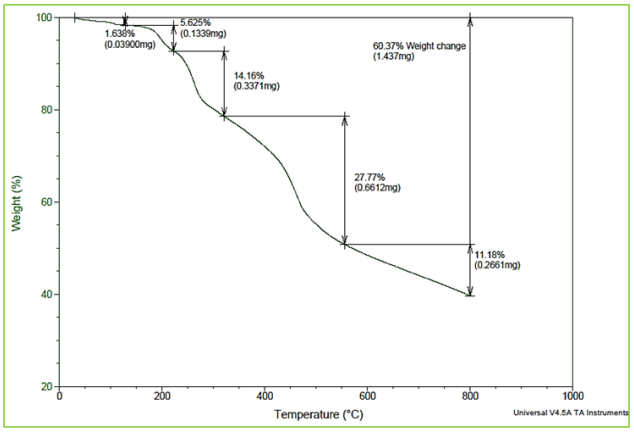


Fig. 5. TGA curve of palladium complexes of 2-Amino 4-(4-Chloro-phenyl)thiazole

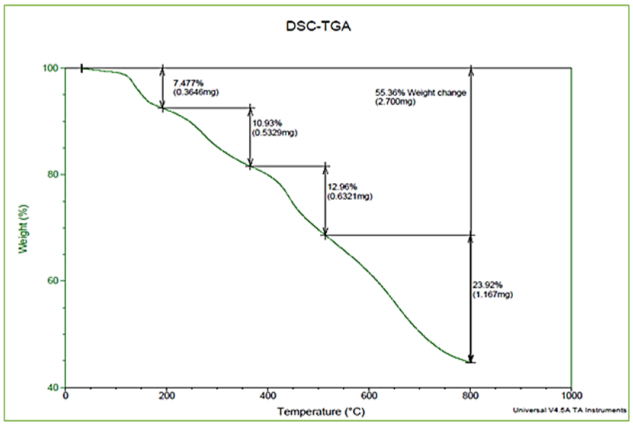


Fig. 6. TGA curve of palladium complex of 2-Amino 4-(phenyl) thiazole

The TGA curve of [Pd(L4)2Cl2] exhibited five phases of decomposition steps of complex. The first decomposition step occurred in the range 30-125 ºC, (DTGmax=103 ºC) with a net weight loss of 1.63% (cal. 1.66%), which corresponds to the elimination of five H2. The second step occurred in the 125-220 ºC range, (DTGmax= 197 ºC) with losing percentage of 5.62% (cal.6.01%) due to losing of two chloride ions as two HCl molecules. The third step carried out at 220-320 ºC range, (DTGmax= 260 ºC) with losing percentage of 14.16% (cal. 14.02%) due to losing of C4H4S fragment. The fourth step carried out at 320-550 ºC range, (DTGmax= 459 ºC) with losing percentage of 27.77% (cal. 27.87%) due to losing of C10HNS fragment. The final fifth step occurred at 550-800 ºC range, (DTGmax= 600 ºC) with losing percentage of 11.18 (cal.11.18%) due to losing C3H3N2 fragment.

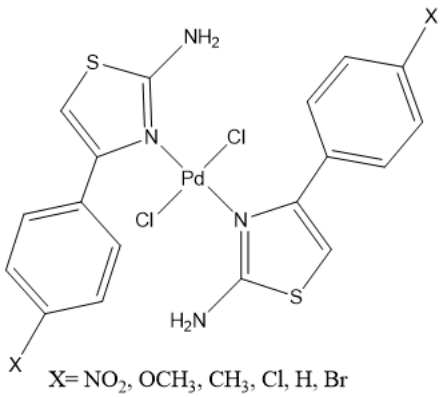
Table 3
Thermo analytical results (TG, DTG) of palladium complexes with with 2-Amino 4-(4-substitutedphenyl) thiazole derivatives

Assignment	% Mass loss		DTG max ^{0}C	TG Range ^{0}C	Stage	Complex
	Cal.	found				
C8H4S2	26.5	26.52	290	100-340	I	
2HCl	11.44	11.14	396	350-475	II	$[Pd(L1)_2Cl_2]$
C4H5N4	17.6	17.73	625	475-800	III	
C4H7N4	18.84	18.92	277	30-310	I	$[Pd(L_2)2Cl_2]$
C8H4S2	27.84	27.89	475	310-800	II	
C8H4N4	28.02	28	284	25-380	I	
C4H7	9.86	9.95	457	380-580	II	$[Pd(L_3)2Cl_2]$
CH7S	9.147	9.21	710	580-800	III	
5H2	1.66	1.63	103	30 -125	I	
HCl	6.01	5.62	197	125-220	II	
C4H4S	14.02	14.16	260	220-320	III	$[Pd(L_4)2Cl_2]$
C10HNS	27.87	27.77	459	320-550	IV	
C3H3N2	11.18	11.18	600	550-800	V	
2H2O	6.8	7.47	138	30-190	I	
C3H9N	11.15	10.93	271	190-360	II	$[Pd(L_5)2Cl_2]$
2HCl	13.23	12.96	442	360-510	III	
C4H3N3S	23.62	23.92	654	510-800	IV	
N2	4.07	4.246	136	30 -160	I	
HCl	5.16	5.429	237	175 -250	II	
C7N2	16.3	16.29	305	250 -400	III	$[Pd(L_6)2Cl_2]$
HBr	11.49	11.3	454	410 -510	IV	
C4H2S2	16.59	16.64	570	510 -800	V	

The TGA curve of [Pd(L5)2Cl2] exhibited four phases of decomposition steps of complex. The first decomposition step occurred in the range 30-190 ºC, (DTGmax=138 ºC) with a net weight loss of 7.48% (cal. 6.80%), which corresponds to the losing of two H2O molecules. The second step occurred in the 190-360 ºC range, (DTGmax= 271 ºC) with losing percentage of 10.93% (cal.11.15%) due to losing of C3H9N. The third step carried out at 360-510 ºC range, (DTGmax= 442 ºC) with losing percentage of 12.96% (cal. 13.23%) due to losing of two chloride ions as two HCl molecules. While, the fourth step carried out at 510-800 ºC range, (DTGmax= 654 ºC) with losing percentage of 23.92% (cal. 23.62%) due to losing of C4H3N3S fragment.

Finally, the TGA curve of [Pd(L6)2Cl2] complex showed fifth phases of decomposition steps of complex. The first decomposition step occurred in the range 30-160 ºC, (DTGmax=136 ºC) with a net weight loss of 4.25% (cal. 4.07%), which corresponds to the losing of nitrogen molecule. The second step occurred in the 175-250 ºC range, (DTGmax= 237 ºC) with losing percentage of 5.43% (cal.5.16%) due to losing of chloride ion as HCl molecule. The third step carried out at 250-400 ºC range, (DTGmax= 305 ºC) with losing percentage of 16.29% (cal. 16.30%) due to losing ofC7N2 fragment. The fourth step carried out at 410-510 ºC range, (DTGmax= 454 ºC) with losing percentage of 11.30% (cal. 11.49%) due to losing of bromide ion as HBr molecules. The final fifth step occurred at 510-800 ºC range, (DTGmax= 570 ºC) with losing percentage of 16.64% (cal.16.59%) due to losing C4H2S2 fragment.

All in all, based on the previous analysis, the magnetic susceptibility, conductivity measurements, infrared, proton NMR and the thermo gravimetric analysis, the suggested geometry of the prepared palladium complexes is square planar as shown in Scheme 2.



Scheme. 2. The suggested structure of palladium complexes with 2-Amino 4-(4-substitutedphenyl) thiazole derivatives.

4. Conclusions

2-amino-4-(4-subsistuted phenyl)thiazole derivatives were prepared and the analog palladium(II) complexes were prepared by reaction of two mole of ligand and one mole of palladium dichloride. The resulting palladium(II) complexes were characterized by different methods like elemental analyses magnetic susceptibility, conductivity measurements, infrared, ^{1}H NMR and the thermo gravimetric analysis. The previous analysis indicated that prepared ligands behaved as mono dental, bounding Pd(II) through the nitrogen atoms from the thiazole ring. The thermal properties of the prepared complexes indicated the all-decomposition steps and gave an insight about the stability of palladium(II) complexes.

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Competing Interests

The authors have declared that no competing interests exist.

References

Akpunar, C., Özdemir, N., Karataş, M. O., Alıcı, B., & Özdemir, İ. (2021). Synthesis, crystal structures and catalytic activities of palladium complexes with coumarin-functionalised N-heterocyclic carbene ligands. Inorganic Chemistry Communications, 131, 108755. https://doi.org/10.1016/j.inoche.2021.108755

Alam, M. N., & Huq, F. (2016). Comprehensive review on tumour active palladium compounds and structure–activity relationships. Coordination Chemistry Reviews, 316, 36-67. https://doi.org/10.1016/j.ccr.2016.02.001

Alam, M. N., Yu, J. Q., Beale, P., Turner, P., Proschogo, N., & Huq, F. (2020). Crystal Structure, Antitumour and Antibacterial Activity of Imidazo [1, 2-α] pyridine Ligand Containing Palladium Complexes. ChemistrySelect, 5(2), 668-673. https://doi.org/10.1002/slct.201902438

Aldelfy, Z., Alshamkhani, Z., & Al-Assadi, M. (2019). 2-Hydroxybenzylidene-4-(4-SubstitutedPhenyl)-2-amino thiazole and their Pt (II) complexes: synthesis, characterization and biological study. Egyptian Journal of Chemistry, 62(10), 1851-1867. https://dx.doi.org/10.21608/ejchem.2019.10039.1661

Das, D., Sikdar, P., & Bairagi, M. (2016). Recent developments of 2-aminothiazoles in medicinal chemistry. European Journal of Medicinal Chemistry, 109, 89-98. https://doi.org/10.1016/j.ejmech.2015.12.022

Dodson, R. M., & King, L. C. (1945). The reaction of ketones with halogens and thiourea1. Journal of the American Chemical society, 67(12), 2242-2243. https://doi.org/10.1021/ja01228a059

Gaw, K. G., Smith, M. B., & Steed, J. W. (2002). Facile syntheses of new multidentate (phosphino) amines: X-ray structure of 1, 4-{(OC) 4Mo (Ph2P) 2NCH2} 2C6H4. Journal of organometallic chemistry, 664(1-2), 294-297. https://doi.org/10.1016/S0022-328X(02)02025-9

Kantchev, E. A. B., O'Brien, C. J., & Organ, M. G. (2007). Palladium complexes of N-heterocyclic carbenes as catalysts for cross-coupling reactions—A synthetic chemist's perspective. Angewandte Chemie International Edition, 46(16), 2768-2813. https://doi.org/10.1002/anie.200601663

Khaled, K. F., & Amin, M. A. (2009). Corrosion monitoring of mild steel in sulphuric acid solutions in presence of some thiazole derivatives–molecular dynamics, chemical and electrochemical studies. Corrosion Science, 51(9), 1964-1975. https://doi.org/10.1016/j.corsci.2009.05.023

Mansour, W., Suleiman, R., Iali, W., Fettouhi, M., & El Ali, B. (2021). Synthesis, crystal structure, and catalytic activity of bridged-bis (N-heterocyclic carbene) palladium (II) complexes in selective Mizoroki-Heck cross-coupling reactions. Polyhedron, 207, 115371. https://doi.org/10.1016/j.poly.2021.115371

Mašković, J. M., Hatzidimitriou, A., Damjanović, A., Stanojković, T. P., Trifunović, S. R., Geronikaki, A. A., & Papagiannopoulou, D. (2018). Synthesis, characterization and biological evaluation of Pd (ii), Cu (ii), Re (i) and 99m Tc (i) thiazole-based complexes. MedChemComm, 9(5), 831-842. https://doi.org/10.1039/C8MD00067K

Olmstead, M. M., Wei, P. P., Ginwalla, A. S., & Balch, A. L. (2000). Bis (benzonitrile) palladium (II) Dihalides: Structures and Cocrystallization of the Cubic Cluster Pd6Cl12 with (E)-Stilbene and with Bis (benzonitrile) palladium (II) Dichloride. Inorganic Chemistry, 39(20), 4555-4559. https://doi.org/10.1021/ic0000597

Singh, M. S., Singh, A. K., & Tawade, K. (2002). N-benzoin-o-mercaptoaniline as an efficient synthon for organotin (IV) compounds. Synthesis and reactivity in inorganic and metal-organic chemistry, 32(4), 639-648. https://doi.org/10.1081/SIM-120004437