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Research Article

SYNTHESIS AND CHARACTERIZATION OF SOME TRANSITION METAL COMPLEXES WITH A NEW MONODENTATE PHOSPHORUS YIELD AND THEIR ANTIBACTERIAL ACTIVITIES

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Abstract

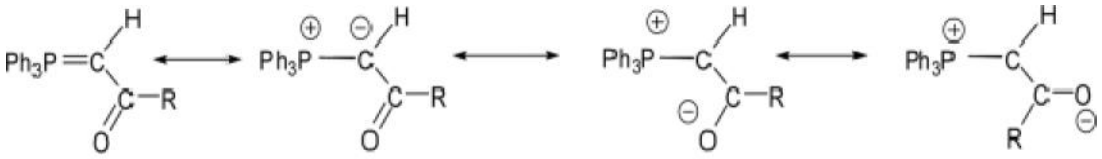
A new monodentate phosphorus yield $Ph_3P{=}CHC(O)C_6H_4$-m-Br (**L**),was synthesized and characterized with elemental analysis as well as various spectroscopic techniques. The reactions of the title ylide with mercury(II) halides in equimolar ratios using dry methanol as solvent have yielded $[\mathbf{L}.HgX_2]_2$ (X= Cl (**1**), Br (**2**), I (**3**)). The reaction of 1 equiv. this ylide with $Cd(NO_3)_2.4H_2O$ in the same solvent give a polynuclear complex [Cd (**L**)$(NO_3)(\mu\text{-}NO_3)$]n (**4**), followed by treatment with 2 equiv. $AgNO_3$ and AgOTf led to monomeric chelate complexes **5** and **6,** respectively. Characterization of the obtained compounds was also performed by elemental analysis, IR, ^1H, ^{31}P and ^{13}C NMR. All DMSO-solved synthesized compounds were subjected to biological evaluation for their antibacterial against 6 Gram positive and negative bacteria effects by disc diffusion method. Results showed antibacterial activity for studied metal complexes and suggested their possible application as antibacterial agents.

Keywords: Phosphorus yields, mercury(II) complexes, silver(I) complexes, cadmium(II) complexes, antibacterial activity.

Introduction

The utility of metalated phosphorus ylides in synthetic chemistry has been well documented (Christau, 1994; Kolodiazhnyi, 1996). The keto group in the a-keto stabilized phosphorus ylides cause resonance delocalization and provide additional stabilization to the ylide species (Scheme 1). The synthesis of complexes derived from ylides and Ag(I) began in 1975 by Yamamoto et al. (Yamamoto and Schmidbaur, 1975). Other types of ylide complexes of silver(I) have been reported (Schmidbaur et al., 1973; Schmidbaur et al., 1974; Schmidbaur and Richer, 1975; Yamamoto and Schmidbaur, 1975; Schmidbaur and Scherm, 1977;). In 1987 and 1983, Vicente et al. (Vicente et al., 1987; Vicente et al., 1993) reported the crystal structures of Ag(I) complexes of phosphorus ylides. The synthesis of complexes derived from phosphorus ylides and Hg(II) salts was limited to Hg(II) halides and was started in 1965 by Nesmeyanov et al. (Nesmeyanov et al., 1965). Weleski et al. (Weleski et al., 1975) in 1975 proposed a symmetric halide-bridged dimeric structure for Hg(II) halide complexes, while Kalyanasundari et al. (Kalyanasundari et al., 1995) in 1995 reported an asymmetric halide bridged structure. Antimicrobial resistance is fast becoming a global concern with rapid promotion in multidrug resistant bacteria (Bennett, 2008). Development of metal complexes are able to inhibit bacterial growth has been of great interest in recent years due to their potential use in paints, kitchenware, school and hospital utensils, etc. Metal complexes play important roles in many biological systems (Kamalakannan, and Venkappayya, 2002; Islam et al., 2002; Agwara et al., 2011). This revival interest was generated by the discovery of antibacterial activity of several metal complexes (Saha et al., 2009; Sabounchei et al., 2013). Although some Hg(II) complexes are among the most widely used antibacterial agents, it seem that the assessment of antibacterial activity of new metal complexes with ligands system is

very necessary. In this study, we describe the preparation, spectroscopic characterization and antibacterial activities of Hg(II), Cd(II) and Ag(I)complexes with the title ylide.



Scheme 1. Resonance forms for a ketostabilized phosphorus ylide

Materials and Methods

2.1. Chemicals and Instrumentation

All reactions were performed in air. All other chemicals were reagent grade and were used without further purification. Elemental analysis for C, H and N were performed using a Perkin-Elmer 2400 series analyzer. IR spectra were recorded on a Shimadzu 435-U-04 spectrophotometer in a region 4000-550 cm^{-1} and the measurements were made by the KBr disk method. Melting points were measured on a SMP3 apparatus. Solution-state ^{1}H, ^{31}P and ^{13}C NMR spectra were recorded on 400 MHz Bruker and 90 MHz Jeol spectrometer in $CDCl_3$ as solvent at 25 ºC. Chemical shifts (ppm) are reported according to internal TMS and external 85% phosphoric acid.

2.2. Synthesis and Characterization

2.2.1. Synthesis of monophosphonium salt [$Ph_3PCH_2C(O)C_6H_4$-m-Br]Br (S)

Triphenylphosphine (0.262 g, 1 mmol) was dissolved in 5 ml of acetone and then a solution of 2,3-di bromoacetophenone (0.277 g, 1 mmol) in the same solvent (5 ml) was added dropwise to the above solution. The resulting yellow solution was stirred for 4 h. The solution was concentrated under reduced pressure to 2 ml, and diethyl ether (20 ml) was added. The white solid formed was filtered off, washed with diethyl ether (2×10 ml) and dried under reduced pressure. White solid, 0.269 g (50 %), m.p. 82–85 ^{0}C. Anal. Calc. for $C_{26}H_{21}Br_2OP$: C: 57.81; H: 3.92; Found: C: 57.98; H: 3.96.; IR (KBr disk) ν: 1676.34(CO) and 859.37 (P^{+}-C^{-}) cm^{-1}. $^{1}HNMR$ ($CDCl_3$) δ: 6.34 (d, $^{2}J_{PH}$ =12.18 Hz, 2H, CH_2) and 7.26 – 8.58 ppm (m, 19H, arom.).

2.2.2. Synthesis of monodentate phosphorus ylide [Ph_3P=CHC(O)C_6H_4-m-Br] (L)

The phosphonium salt (**S**) (0.533 gr, 1 mmol) was transferred to an aqueous NaOH (5 %) and stirred at 40°C for 24 h. The white product was obtained, washed with distilled water and air dried. White solid, 0.920 g (91 %), m.p. 133–136 ^{0}C. Anal. Calc. for $C_{26}H_{20}BrOP$: C: 67.99; H: 4.39; Found: C: 68.15; H: 4.42. IR (KBr disk): ν 1520.82 (CO) and 876.50 (P^{+}-C^{-}) cm^{-1}. $^{1}HNMR$ ($CDCl_3$) δ= 4.39 (d, ^{2}JPH =23.38 Hz, 1H, CH) and 7.27-8.09 ppm (m, 19H, arom.). ^{31}P NMR ($CDCl_3$) δ :13.22 ppm (s). ^{13}C NMR ($CDCl_3$) δ : 53.25 ppm (s,1C , CH), 125.13-135.41 ppm (m, C_6H_5), and 195.25 ppm (s, CO).

2.2.3. Synthesis of Hg(II) halide complexes (1-3)

General procedure. To a methanolic solution (15 ml) of HgX_2 (1 mmol) was added a methanolic solution (10 ml) of **L** (0.459 g, 1 mmol). The mixture was stirred for 4 h. The separated solid was filtered and washed with diethyl ether.

Data for [L.$HgCl_2$]$_2$ (**1**): white solid, 86 %, m.p. 160–163 ^{0}C. Anal. Calc. for $C_{52}H_{40}Br_2O_2P_2Hg_2Cl_2$: C: 44.91; H: 2.90. Found: C: 45.13; H: 2.94. IR (KBr disk) ν: 1625.88(CO) and 829.79 (P^{+}-C^{-}) cm^{-1}. $^{1}HNMR$ ($CDCl_3$) δ: 5.27 (s, 1H, CH) and 7.26-8.11 ppm (m, 19H, arom.). ^{31}P NMR ($CDCl_3$) δ: 22.60 ppm (s). ^{13}C NMR ($CDCl_3$) δ : 28.40 ppm (s, 1C, CH), 122.43-136.47 ppm (m, 24C,arom), and 187.89 ppm (s, CO).

Data for [L.$HgBr_2$]$_2$ (**2**): white solid, Salt: 95 %, m.p. 153–157^{0}C. Anal. Calc. for $C_{52}H_{40}Br_6O_2P_2Hg_2$: C: 38.10; H: 2.46. Found: C: 39.05; H: 2.49. IR (KBr disk) ν: 1624.14 (CO) and 824.87 (P^{+}-C^{-}) cm^{-1}. $^{1}HNMR$ ($CDCl_3$) δ: 5.72 (s, 1H, CH) and 7.27-8.15 ppm (m, 19H, arom.). ^{31}P NMR ($CDCl_3$) δ: 22.32 ppm(s). ^{13}C NMR ($CDCl_3$) δ : 29.4 ppm (s, CH), 122.43-136.45 ppm (m, 24C, arom), and 188.86 ppm (s, CO).

Data for [L.HgI_2]$_2$ (3): yellow solid, Salt: 54 %, m.p. 170–174 ^{0}C. Anal. Calc. for $C_{52}H_{40}Br_2O_2P_2Hg_2I_4$: C: 34.18; H: 2.21. Found: C: 34.82; H: 2.27. IR (KBr disk) ν: 1634.50 (CO) and 824.39 (P^{+}-C^{-}) cm^{-1}. $^{1}HNMR$ ($CDCl_3$) δ: 5.59 (s, 1H, CH) and 7.26-8.14 ppm (m, 19H, arom.). ^{31}P NMR ($CDCl_3$) δ: 18.32 ppm(s). ^{13}C NMR ($CDCl_3$) δ : 24.6 ppm (s, 1C , CH), 127.09-136.49 ppm (m, 24C,arom), and 187.01 ppm (s, CO).

2.2.4. Synthesis of Cd(II) nitrate complexe (4)

A solution (1 mmol) of $Cd(NO_3)_2.4H_2O$ (0.312 g, 1 mmol) in dry methanol (5 mL) was added to a solution (0.459 g , 1 mmol) of **L** in dry methanol and stirred for 30 min at room temperature. The white solution was concentrated to 2mL and diethyl ether (15 mL) was added to precipitate the dinuclear complex which was recrystallized from chloroform–diethyl ether and dried in vacuum. White solid, 0.695 g (85%), m.p. 160.3 – 162.7 ^{0}C. Anal. Calc. for $C_{26}H_{20}BrPN_2O_7Cd$: C: 44.88; H: 2.90; N: 4.03. Found: C: 45.23; H: 2.96; N: 3.92. IR (KBr disk) ν: 1681.93 (CO) and 825.35 (P^+-C^-) cm^{-1}. ^{1}HNMR ($CDCl_3$) δ: 5.67 (d, ^{2}JPH =12.45 Hz, 1H, CH) and 7.26 - 8.22 ppm (m, 19H, arom.). ^{31}P NMR ($CDCl_3$) δ: 17.48 ppm (s).

2.2.5. Synthesis of the Ag(I) complexes (5 and 6)

General procedure. To $AgNO_3$ (0.169 g, 1 mmol) and AgOTF (0.256 g, 1mmol) dissolved in 5 mL of dried methanol was added the **L** (0.450 g, 1 mmol). The mixture was stirred for 4 h, during which time it was protected from light. The white solid product was filtered, washed with Et_2O and dried under reduced pressure.

Data for $[Ag.(L)_2]NO_3$ (5). white solid, 0581 g (92 %), m.p. 170.2 – 174.5 ^{0}C. Anal. Calc. for $C_{52}H_{40}Br_2P_2NO_5Ag$: C: 57.38; H: 3.70; N: 1.29. Found: C: 57.89; H: 3.81; N: 1.21. IR (KBr disk) ν: 1678.14 (CO) and 856.26 (P^+-C^-) cm^{-1}. ^{1}HNMR ($CDCl_3$) δ: 5.98 (d, ^{2}JPH =12.18 Hz , 1H, CH) and 7.49 – 8.11 ppm (m, 19H, arom.). ^{31}P NMR ($CDCl_3$) δ: 22.97 ppm (s). ^{13}C NMR ($CDCl_3$) δ: 29.12 ppm (s, 1C, CH), 127.87- 136.6 ppm (m, 24C, arom.), and 187.96 ppm (s, CO).

Data for $[Ag.(L)_2]OTF$ (6). white solid, 0.642 g (89%), m.p. 109.2 -112.7 ^{0}C. Anal. Calc. for $CF_3SO_5C_{52}H_{40}Br_2P_2Ag$: C: 54.15; H: 3.43. Found: C: 54.67; H: 3.55. IR (KBr disk) ν: 1683.94 (CO) and 845.63 (P^+-C^-) cm^{-1}. ^{1}HNMR ($CDCl_3$) δ: 5.62 (d, ^{2}JPH =13.08 Hz, 1H, CH) and 7.25-8.28 ppm (m, 19H, arom.). ^{31}P NMR ($CDCl_3$) δ: 22.85 ppm (s). ^{13}C NMR ($CDCl_3$) δ : 24.6 ppm (s, 1C , CH), 127.09-136.33 ppm (m, 24C, arom.), and 187.02 ppm (s, CO).

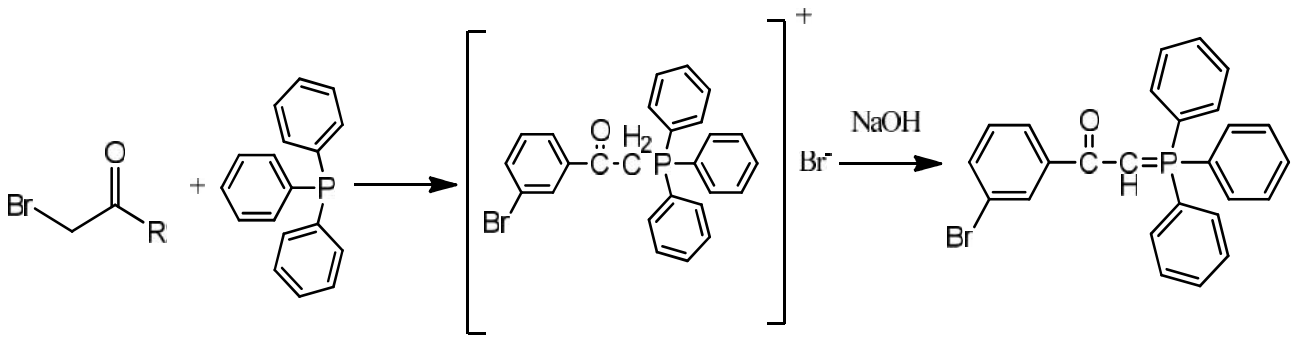
2.3. Antibacterial activity

The potential antibacterial effects of the metal complexes were investigated against three Gram positive bacteria, namely *Bacillus cereus* (PTCC 1247), *Staphylococcus aureus* (Wild) and *Bacillus megaterium* (PTCC 1017), and three Gram negative bacteria, namely *Escherichia coli* (Wild), *Proteus vulgaris* (PTCC 1079), and *Serratiamarcescens* (PTCC 1111) by disc diffusion method (Awoyinka et al., 2007). The complexes were dissolved in DMSO to a final concentration of 1 mg ml^{-1} and then sterilized by filtration using 0.45 µm millipore. All tests were carried using 10 ml of suspension containing 1.5×10^8 bacteria/ml and spread on nutrient agar medium. Negative controls were prepared by using DMSO. Gentamycin, penicillin and neomycin were used as positive reference standards. The diameter of inhibition zones generated by the complexes was measured.

Results and Discussion

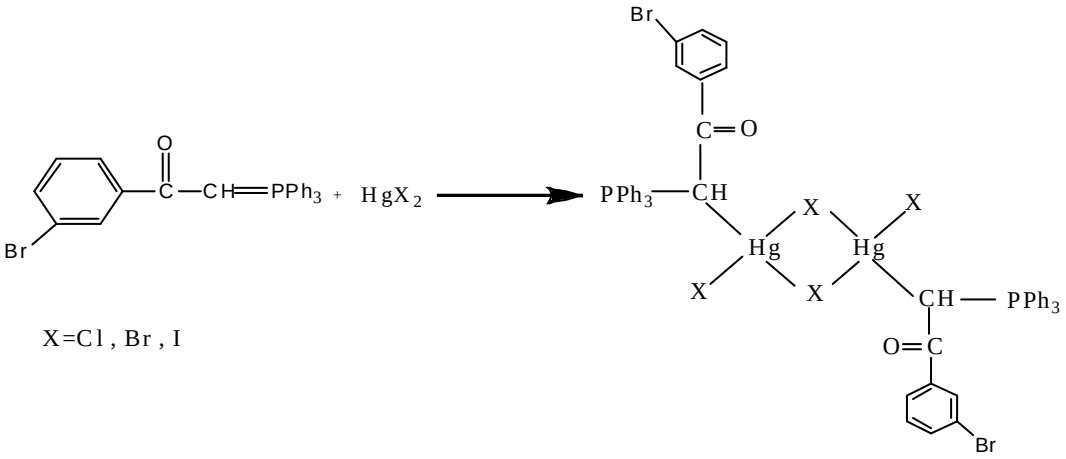
3.1. Synthesis

The ligand (**L**) was synthesized by treating 2, 3′-dibromoacetophenone with triphenylphosphine and removal of the proton from the phosphonium salt (See Scheme **2**).



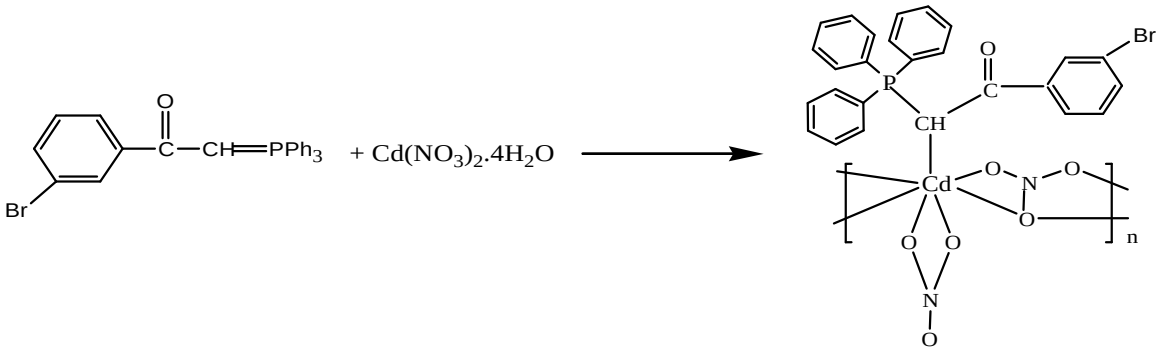
Scheme 2. The synthesis route for preparation of phosphonium salt (**S**) and related ylide (**L**)

Reaction of the ligand with HgX_2 (X = Cl, Br and I) (1:1) yielded the binuclear complexes (see Scheme **3**).



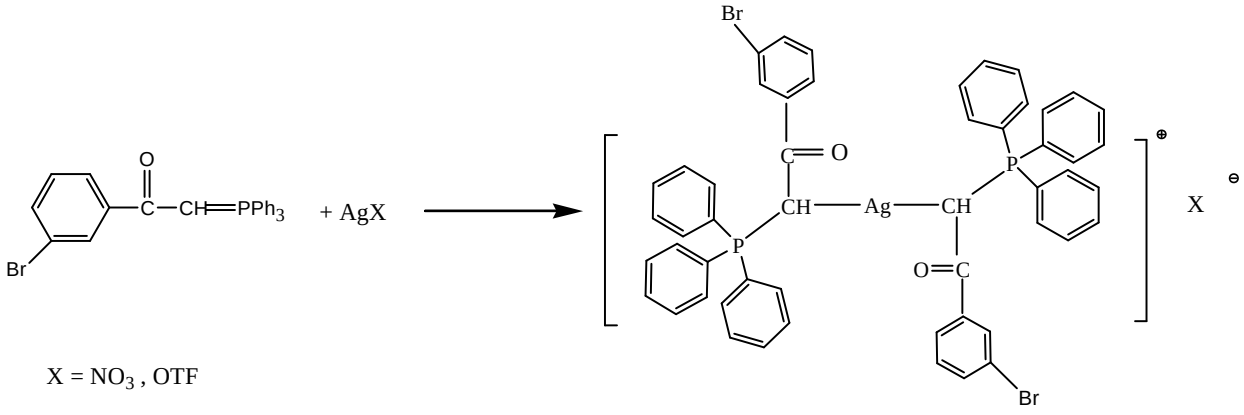
Scheme 3. Synthetic route for preparation of Hg(II) complexes

The compounds derived from phosphorus ylide with $Cd(NO_3)_2.4H_2O$ form polynuclear structures with nitrate anions in the bridges (Scheme **4**).



Scheme 4. Synthetic route for preparation of Cd(II) complex

The reaction of ylide with AgX (X = NO_3, OTF) in a 2:1 molar ratio in dichloromethane as solvent gave mononuclear complexes (see Scheme **5**).



Scheme 5. Synthetic route for preparation of Ag complexes

3.2. Spectroscopy

The shift to higher energy of ν(CO) in complexes relative to the free ylide (Table 1) suggests coordination of the ylide through the carbon atom. Coordination through the carbon atom causes an increase in ν(CO), while O-coordination gives a lowering of ν(CO). The infrared spectra of complexes in the solid state show ν(CO) from 1624–1681 cm^{-1}, which is at higher frequencies with respect to the free ylide. The $\nu(P^{+}–C^{-})$ frequency, which is also diagnostic of coordination, occurs at 876 cm^{-1} for the ylide. In the present study the $\nu(P^{+}–C^{-})$ values for all the complexes were shifted to lower frequencies; i.e., observed from 824–859 cm^{-1}. This suggests some removal of electron density from the P–C bond (Onishi et al., 1982; Sabounchei et al., 2007). In the ^{1}H NMR spectra, methinic protons exhibit a broad or broad doublet signals. Similar behavior was observed earlier in the case of ylide complexes of platinum(II) chloride (Teagle and Burmeister, 1986). The $^{31}P\{^{1}H\}$ NMR spectra of these complexes show only one sharp singlet between 17.48 ppm and 22.97 ppm. The ^{31}P chemical shift values for the complexes appear at higher frequency by about 4–10 ppm relative to the parent ylides (δ = 13.22 ppm for **L**), which indicates that coordination of the ylide occurred (Table 1). The appearance of one set of signals for the PCH group in both the ^{31}P and ^{1}H NMR spectra indicates the presence of only one molecule for all complexes (Kalyanasundari et al., 1995). The most interesting aspect of the ^{13}C NMR spectra of the complexes is the upfield shift of the signals due to the ylidic carbon atoms. Such an upfield shift is due to the change in hybridization of the ylidic carbon atom on coordination. Similar up field shifts of 2–3 ppm with reference to the parent ylide were also observed in the case of $[(C_6H_5)_3PC_5H4HgI_2]_2$ (Holy et al., 1976). The downfield shifts of the carbonyl C atom in the complexes compared to the same carbon atom in the parent ylide, indicate a much lower shielding of the CO group in these complexes.

Table 1. Selected ^{1}H and ^{31}P NMR [*δ* (ppm), *J* (Hz)] and IR(cm^{-1}) data for the salt (**S**), ligand (**L**) and corresponding complexes (**1**-**6**)

Compound	C(CO)	δ CH_2	δ PCH_2	δ CH ($^{2}J_{P–H}$)	υ(CO)	υ(PC)
S	190.56	37.75(d)	18.39(s)	6.34(d)	1676	859.37
L	195.25	53.25(br)	13.22(s)	4.39(d)	1520	876.50
$HgCl_2$ (1)	187.89	28.40(br)	22.60(s)	5.27(br)	1625	829.79
$HgBr_2$ (2)	188.86	29.4(br)	22.32(s)	5.72(br)	1624	824.87
HgI_2 (3)	187.01	24.6(br)	18.32(s)	5.59(br)	1634	824.39
$Cd(NO_3)_2$ (4)	-	-	17.48(s)	5.67(d)	1681	825.35
$AgNO_3$ (5)	187.96	29.12(br)	22.97(s)	5.98(d)	1678	856.26
AgOTF (6)	187.02	24.6(br)	22.85(s)	5.62(d)	1683	845.63

S (singlet), br (broad), d (doublet)

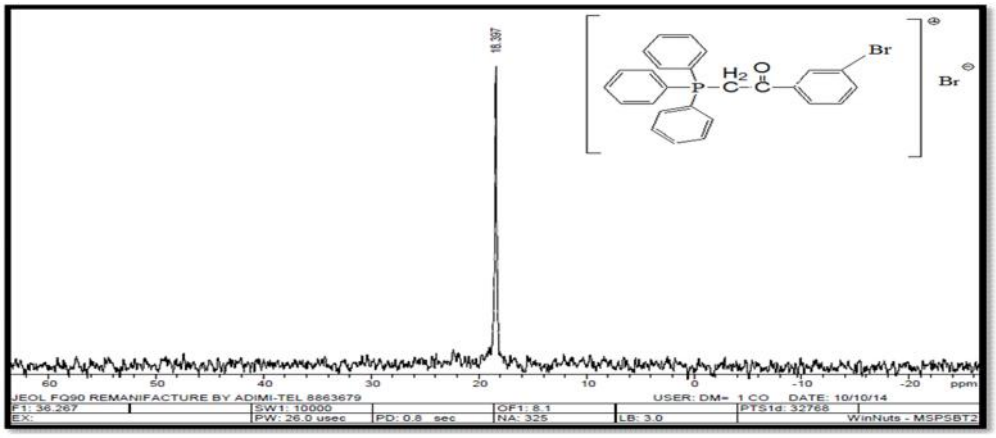


Figure S1. ^{31}P NMR Spectrum of compound **S**

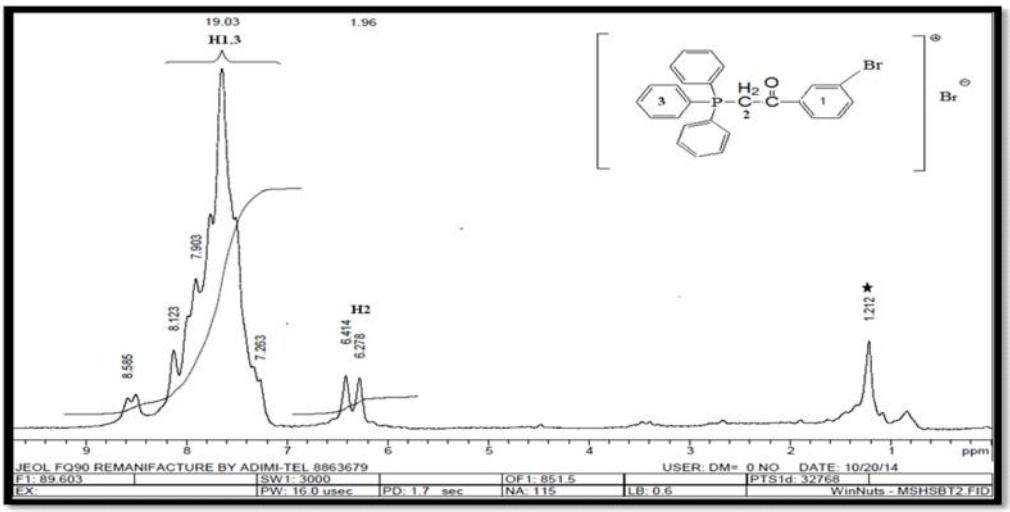


Figure S2. ^{1}H NMR Spectrum of compound **S**

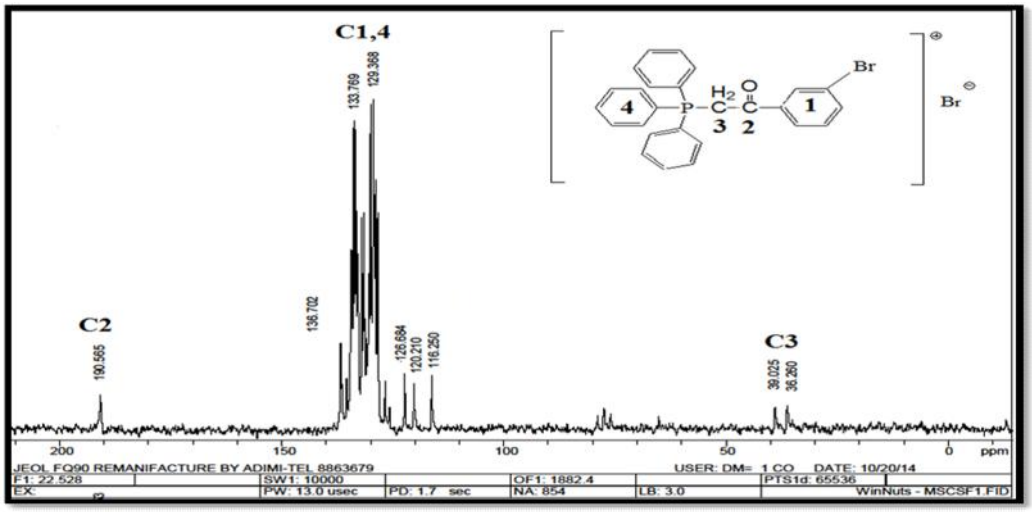


Figure S3. ^{13}C NMR Spectrum of compound **S**

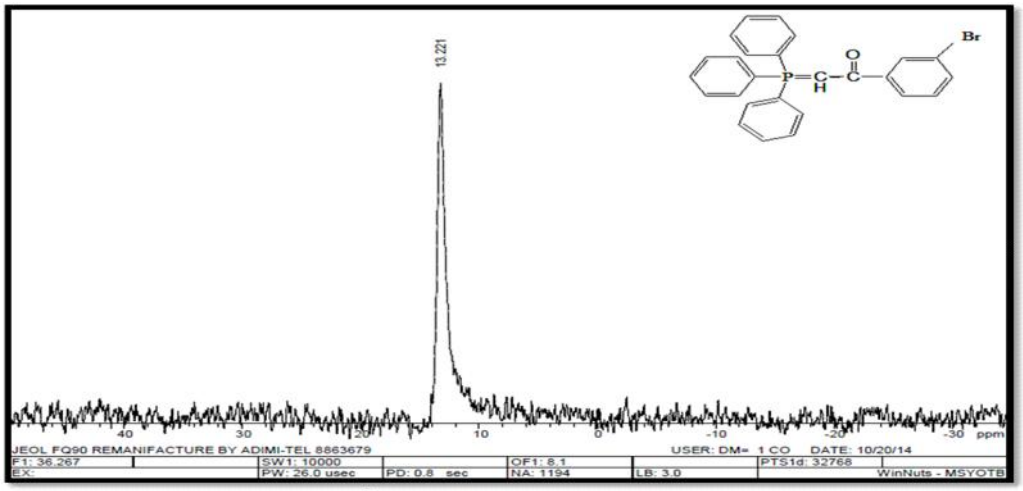


Figure S4. ^{31}P NMR Spectrum of compound **L**

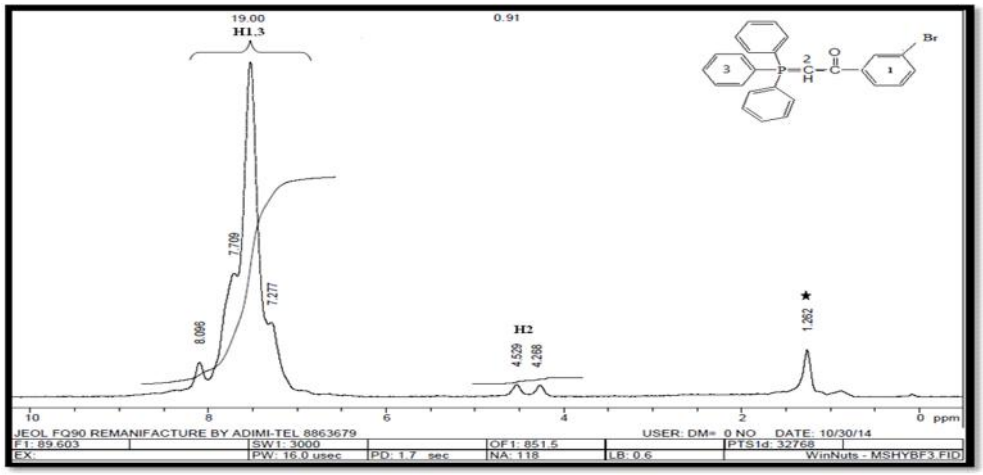


Figure S5. ^{1}H NMR Spectrum of compound **L**

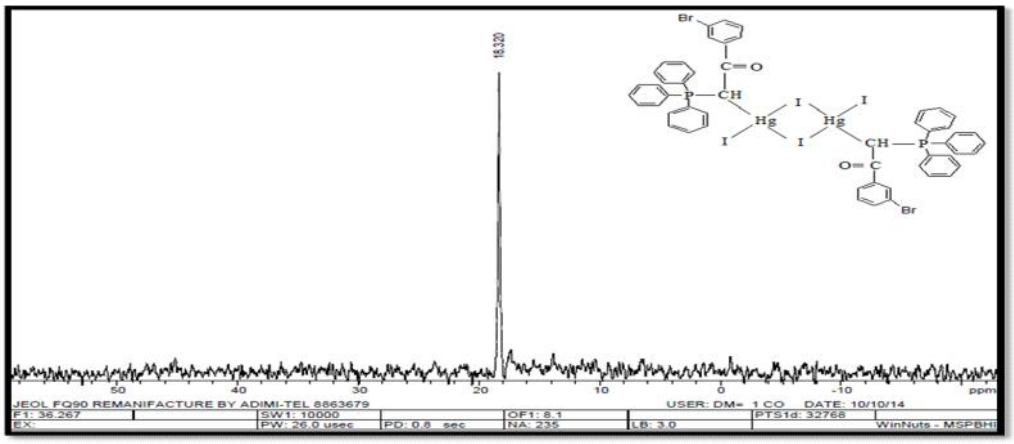


Figure S6. ^{31}P NMR Spectrum of compound **3**

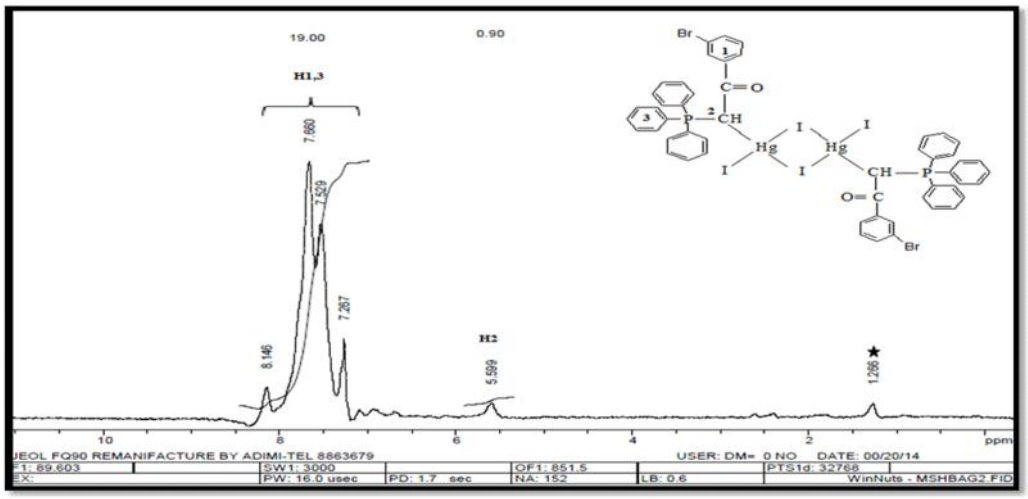


Figure S7. ^{1}H NMR Spectrum of compound **3**

3.3. Antibacterial activity

Our results demonstrated that all studied complexes display antibacterial activity against the bacteria tested especially Gram positive ones. With comparing antibacterial activity of the complexes with those of reference antibiotics, it seems that they have remarkable inhibitory potency against bacteria.Results from antibacterial assessment of the samples and from positive and negative controls are in Tables 2 and 3. The test compounds were dissolved in DMSO at concentrations of 1, 0.1 and 0.01 $mgml^{-1}$. DMSO which was used as a solvent was also screened against all bacteria. It has no activity against the bacteria. Generally the antibacterial activity of compounds is attributed mainly to its major components. However, today it is known that the synergistic or antagonistic effect of one compound, even when it is a minor component of mixture has to be considered (Burt, 2004). The complexes reported here showed more activity against some bacteria, than othersat the same identical experimental conditions. This would suggest that the structure of complexes may reduce the polarity of the metal ion mainly. Perhaps a neutral coordination complex may also transport easily from the lipid phase of the bacterial cell membrane and then affected growth and development (Fahmi et al., 1998; Tumer et al., 2007). Composition of the coordination site and the geometry of the tested complexes seemed to be the principal factors that influence antibacterial activity. However, the complexes studied here may be used in treatment of the diseases caused by tested bacteria.

Table 2. Antibacterial activity ligand (**L**) and corresponding complexes (**1-6**).

Compound	Concentration	Inhibition zone (mm)					
		***P. v* (-)**	***E. c* (-)**	***B. c* (+)**	***S. a* (+)**	***B. m*(+)**	***S. m* (-)**
L	1 (mg/ml)	15 ± 0.32[a]	10 ± 0.28[a]	7 ± 0.00	10 ± 0.11[a]	11 ± 0.13[a]	14 ± 0.54[a]
	0.1(mg/ml)	12 ± 0.14[b]	9 ± 0.35[b]	Na	7 ± 0.18[b]	8 ± 0.28[b]	11 ± 0.22[b]
	0.01(mg/ml)	7 ± 0.00[c]	7 ± 0.00[c]	Na	Na	8 ± 0.54[b]	8 ± 0.18[c]
1	1(mg/ml)	16± 0.33[a]	18 ± 0.16[a]	20 ± 0.14[a]	21 ± 0.14[a]	25 ± 0.12[a]	10 ± 0.66[a]
	0.1(mg/ml)	12 ± 0.35[b]	11 ± 0.15[b]	17 ± 0.33[b]	16 ± 0.34[b]	15 ± 0.25[b]	8 ± 0.27[b]
	0.01(mg/ml)	8 ± 0.24c	7 ± 0.00[c]	10 ± 0.18[c]	10 ± 0.26[c]	11 ± 0.35c	Na
2	1(mg/ml)	16 ± 0.43[a]	30 ± 0.25[a]	19 ± 0.26[a]	17 ± 0.25[a]	16 ± 0.14a	11 ± 0.46[a]
	0.01(mg/ml)	11 ± 0.24[b]	22 ± 0.23[b]	13 ± 0.20[b]	13 ± 0.25[b]	12 ± 0.18[b]	8 ± 0.11[b]
	0.01(mg/ml)	8 ± 0.10[c]	14 ± 0.18[c]	Na	Na	Na	Na
3	1(mg/ml)	16 ± 0.26[a]	15 ± 0.26[a]	21 ± 0.38[a]	17 ± 0.24[a]	14 ± 0.10[a]	14 ± 0.26[a]
	0.1(mg/ml)	11 ± 0.18[b]	10 ± 0.18[b]	14 ± 0.15[b]	14 ± 0.00[b]	11 ± 0.15[b]	8 ± 0.27[b]
	0.01(mg/ml)	8 ± 0.24[c]	7 ± 0.24[c]	10 ± 0.24[c]	11 ± 0.34[c]	8 ± 0.18[c]	7 ± 0.00[c]
4	1(mg/ml)	14 ± 0.13[a]	13 ± 0.14[a]	11 ± 0.16[a]	16± 0.13[a]	12 ± 0.16[a]	14 ± 0.34[a]
	0.1(mg/ml)	11 ± 0.24[b]	9 ± 0.21[b]	8 ± 0.15[b]	11 ± 0.33[b]	8 ± 0.23[b]	10 ± 0.21[b]
	0.01(mg/ml)	8 ± 0.15[c]	9 ± 0.18[b]	7 ± 0.11[c]	10 ± 0.11[c]	8 ± 0.15[b]	8 ± 0.00[c]
5	1(mg/ml)	14 ± 0.16[a]	15 ± 0.33[a]	13 ± 0.16[a]	18 ± 0.25[a]	11 ± 0.14[a]	14 ± 0.33[a]
	0.1(mg/ml)	10 ± 0.24[b]	14 ± 0.15[b]	10 ± 0.45[b]	13 ± 0.10[b]	8 ± 0.26[b]	10 ± 0.11[b]
	0.01(mg/ml)	8 ± 0.21[c]	10 ± 0.00[c]	8 ± 0.14[c]	8 ± 0.14[c]	Na	8 ± 0.15[c]
6	1(mg/ml)	16 ± 0.12[a]	14 ± 0.38[a]	14 ± 0.17[a]	17 ± 0.34[a]	12 ± 0.23[a]	13 ± 0.18[a]
	0.1(mg/ml)	12 ± 0.14[b]	11 ± 0.35[b]	9 ± 0.15[b]	15 ± 0.11[b]	8 ± 0.16[b]	9 ± 0.73[b]
	0.01(mg/ml)	10 ± 0.45[c]	10 ± 0.25[c]	8 ± 0.13[c]	10 ± 0.11[c]	7 ± 0.27[c]	7 ± 0.25[c]

Experiment was performed in triplicate and expressed as mean ± SD. Values with different superscripts within each column (for any bacteria in different concentrations) are significantly different ($P < 0.05$).
Na: no active.

Table 3. Antibacterial activity of antibiotics as positive controls and DMSO as negative control.

Microorganism	Inhibition zone (mm)				
	Gentamicin	**Penicillin**	**Nitrofurantion**	**Neomycin**	**DMSO**
Proteus vulgaris (−)	28 ± 0.64	NA	18 ± 0.23	21 ± 0.45	NA
Escherichia coli (−)	NA	NA	23 ± 0.33	24 ± 0.16	NA
Bacillus cereus (+)	22 ± 0.57	NA	12 ± 0.28	18 ± 0.17	NA
Staphylococcus aureus(+)	37 ± 0.21	NA	30 ± 0.22	24 ± 0.28	NA
Bacillus megaterium(+)	25 ± 0.44	NA	23 ± 0.46	18 ± 0.26	NA
Serratiamarcescens(−)	22 ± 0. 22	NA	18 ± 0.44	25 ± 0.33	NA

Experiment was performed in triplicate and expressed as mean ± SD. Values with different superscripts within each column (for any bacteria in different concentrations) aresignificantly different ($P < 0.05$).
Na: no active

Conclusions

The present study describes the synthesis and characterization of a new series of Hg(II), Cd(II) and Ag(I) complexes of a monodentate phosphorus ylide. On the basis of the physical–chemical and spectroscopic data we propose that the ligands described herein exhibit monodentate C-coordination to the metal center. In addition, the metal complexes represent significant antibacterial activity, which may help us to design of improved antibacterial agents.

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