A B-Keto ester as a novel, efficient, and versatile ligand for copper (II)-catalyzed C-C coupling reactions and evaluation anti-bacterial activity

Madhukar P Shinde, Raghunath B Toche, Pankaj B Aware and Pawan J Tambde

DOI: https://doi.org/10.22271/chemi.2020.v8.i2ak.9115

Abstract
Employing α-acetyl-γ-butyrolactone as a novel, efficient, and versatile ligand, the copper catalyzed Sonogashira and Suzuki coupling reactions with nucleophilic reagents with aryl halides and boronic acid could be successfully carried out under mild conditions. Synthesis. Present communication describes Synthesis, Characterization and IR spectrum, elemental analysis, mass spectrum, molar conductance, TGA and DTA analysis, catalytic activity, crystal structure with the help of single XRD and antimicrobial activity of Cu(II) complex.

Keywords: α-acetyl-γ-butyrolactone, copper acetate monohydrate, structural analysis, biological activity

Introduction
The 1,3-dicarbonyl compounds are important class of organic compound used as intermediate for the synthesis of core heterocycles such as pyrazole [1-3], isoxazole [4-6] and triazole [7]. They find extensive applications in CVD (Chemical vapour deposition), processes which are used in wide range of industrial components and various items of chemical plant [8]. They are also used as chelating ligands for various lanthanide and transition metals in material chemistry [9,10]. Owing to such an enormous applications, the synthesis of 1, 3-diketones has gained considerable interest in recent years. The applications of 1,3-dicarbonyl compounds as ligand is well explored and are found to show great catalytic activities [11-17]. On the contrary the chemistry of 1,3-keto ester is not much explored and there is huge scope to explore the chemistry of 1, 3-ketoester. There are only few reports available on use of cyclic 1,3-keto ester as a ligand for organic transformation which utilizes in situ in the preparation of metal complex [18]. There is tremendous scope in exploration of premade metal 1,3-keto ester complexes. The premade 1,3-keto ester metal complex will be stable, less-sensitive to water, easy to handle and having ability to exhibit catalytic and show medicinal properties. Considering all the above facts, we have prepared metal complex of α-acetyl-γ-butyrolactone with copper (II), characterized and study its biological and catalytic activities discussed in current research. α-Acetyl-γ-butyrolactone β ketoester, potentially reactive bis-electrophile, having ability to co-ordinate with metals due to presence of oxygen lone pair. The literature reports revealed that α-acetyl-γ-butyrolactone was used for the synthesis of various heterocyclic compounds having good biological activity. γ-Butyrolactone (GBL) is a hygroscopic colorless liquid with weak characteristic odour, soluble in water. GBL is a common solvent and reagent in chemistry as well as being used as a flavouring, as a cleaning solvent, as a superglue remover, and as a solvent in some wet aluminium electrolytic capacitors. In humans it acts as a pro-drug for γ-hydroxybutyric acid (GHBA) and it is used as recreational intoxicant with effects similar to alcohol. GBL is rapidly converted into GHB by paraoxonase (lactonase) enzymes, found in the blood animals which lack these enzymes exhibits no effect from GBL. GBL is more lipophilic (fat soluble) than GHB, and so absorbed faster and has higher bioavailability. Because of these pharmacokinetic differences, GBL tends to be more potent and faster acting than GHB, but has a shorter duration; where is the related compound 1, 4-butanediol (1,4-B) tends to be slightly less potent, slower to take effect but longer-acting than GHB.
The levels of lactonase enzyme can vary between individuals, meaning that first—time users can show unpredictable results, even from small doses. In many instances, as slow onset of effects, followed by headaches, semi-consciousness which is distinct from GBL sleep in normal users. If the user decides to try again at a later date, they appear to be able to enjoy the effects normally. Keto Ester complexes of Copper(I) was also used as catalyzed for C-N, C-O, and C-S coupling reactions. In literature variety in the coordination modes of β-dicarbonyl compounds in metal complexes.

Material and methodology
All reagents were purchased commercially and were used directly without any further purification. The complex was characterized by IR, UV, HRMS, CHN analysis, single crystal XRD and physical constant. IR spectra were recorded on Shimadzu FTIR-408 instrument. UV-visible spectra were recorded on Shimadzu 2450 UV-visible spectrophotometer. Mass spectra were recorded on a Shimadzu LC-MS: EI QP 2010A mass spectrometer with an ionization potential of 70eV. Elemental analyses were performed on Quest flash 1112 Series EA Analyzer at SAIF, Punjab University, Chandigarh. Molar conductivity of complexes was recorded using 1x10^-3 M solutions in DMSO on Toshniwal TSM 15 conductivity metre. Melting points were determined on a Gallenkamp melting point apparatus.

Results and Discussion
Elemental Analysis
The complex is hygroscopic having pale green and is table in atmosphere. It is soluble in DMSO and methanol. The elemental analysis data for percentage of carbon and hydrogen was determined, was in aggregate with the calculated based on proposed formula. The metal content in both complex measured and was in agreement with the calculated value. The elemental analysis data of the complex was calculated in Table No.1

Table 1: Analytical, physical data of lactone complexes

| Complex     | Colour          | % yield | Melting point °C | Elemental analysis found | Calculated % |
|-------------|-----------------|---------|------------------|--------------------------|--------------|
| C_{12}H_{14}CuO_{6} | Pale green (80%) | 220°C   |                  |                           |              |
| C_{12}H_{14}CuO_{6} | Pale green (80%) | 220°C   |                  |                           |              |

Infrared Spectra
Scan IR spectra of lactone and complex showed different stretching, and bending frequencies, indicates that complexation of lactone with metals. The IR spectra of the both complex was different when compound with that of 

Reactions were monitored by thin layer chromatography (TLC), carried out on 0.2 mm silica gel 60 F254 Merck plates using UV light (254 and 366 nm) for detection.

Synthesis of α-acetyl-γ-butyrolactone
α-Acetyl-γ-butyrolactone is prepared by condensation of γ-butyrolactone with an acetic ester in presence of strongly base. Enolate obtained was subjected to protonation. All these three reactants are continuously fed into the reaction mixture, where the ratio of acetic acid ester is 1.0-6.0 parts by moles, 0.9-1.6 parts by moles of strongly basic substance per part by moles of γ-butyrolactone. The reaction mixture obtained was removed from reaction zone and then it was protonated.

Synthesis of copper (II) complex with α-acetyl-γ-butyrolactone
A solution of α-acetyl-γ-butyrolactone (2.15 mL; 20 mmol) 1 in 30 mL ethanol was stirred for 10 min, and then a solution of copper acetate monohydrate (1.99 gm; 10 mmol) 2 in ethanol was added slowly at room temperature. The reaction mixture was stirred at reflux temperature for 5 hrs. After cooling to room temperature, the pale green colored complex 3 compound was filtered off, washed thoroughly with ethanol, followed by diethyl ether. The compound obtained was recrystallized from methanol and was finally dried under vacuum.

Scheme 1: Synthesis of copper (II) complex of α-acetyl-γ-butyrolactone

![Scheme 1](http://www.chemijournal.com)

Table 2: IR spectra data of lactone and Cu(II) complex

| Compound                  | νC=O ester cm⁻¹ | νC=O carbonyl cm⁻¹ | M - O cm⁻¹ | PPh₃ |
|---------------------------|-----------------|-------------------|------------|------|
| α-Acetyl-γ-butyrolactone  | 1779            | 1726              | --         | --   |
| C_{12}H_{14}CuO_{6}       | 1626            | 1531              | 460        |      |

International Journal of Chemical Studies
Fig 1: IR Spectrum of α-acetyl-γ-butyrolactone

Fig 2: IR spectrum of Cu (II) complex of α-acetyl-γ-butyrolactone

Mass Spectra
The mass spectrum of the Cu(II) complex were recorded showed molecular ion peak at MS( m/z – 339.99) M⁺ Na for Cu(II) complex C₁₂H₁₄CuO₆, which agrees with molecular weight of the Cu(II) complex 317. (Fig.3)

Fig 3: Mass spectrum of complex C₁₂H₁₄CuO₆
**Molar conductance Measurements**
The conductance value of complex $\text{C}_{12}\text{H}_{14}\text{CuO}_{6}$ when dissolved in DMSO was $28.7 \pm 2 \text{ cm}^2\text{cm}^{-1}\text{mole}^{-1}$ which indicates the non-electrolyte nature of the complex.

**Thermogravimetric Analysis; Complex $\text{C}_{12}\text{H}_{14}\text{CuO}_{6}$**

Thermoanalytical measurement was performed in the range of 25°C - 700°C temperature. Thermal decomposition takes place in one step. The complex is stable below 180°C. Gradual decomposition from 170°C to 250°C is related to loss of the organic moiety by a 71.874% weight loss (theoretical 79.454%). The weight of the residue is consistent with metal oxide CuO from the 34.31% residual weight (calcd=35.11%). (Fig. 5 & 6)

**X-ray diffractogram of Cu (II) complex**
The x-ray diffractogram of Cu (II) complex was scanned in the range 0-60° at wavelength 1.543 Å. The diffractogram and associated data depict the 2θ value for each peak, relative intensity and interplanar spacing (d-values). The diffractogram of Cu (II) complex of L had twelve reflections with maxima at $2\theta = 11.945°$ corresponding to $d$ value 7.0403 Å. The x-ray diffraction pattern of these complexes with respect to major peaks of relative intensity greater than 10% has been indexed by using computer programme. The above indexing method also yields Miller indices (hkl), unit cell parameters and unit cell volume. The unit cell of Cu II) complex of L yielded values of lattice constants, $a=8.9840$ Å, $b=11.9837$ Å, $c=10.4635$ Å and unit cell volume $V=19383.98$ Å³. In concurrence with these cell parameters, the condition such as $a=b=c$ and $a=\beta=\gamma=90°$ required for sample to be orthorhombic were tested and found to be satisfactory. Hence it can be concluded that Cu(II) complex has orthorhombic crystal system. (Fig.6)

**Table 3: The x-ray diffractogram data of Cu (II) Complex**

| 2θ (°) | Relative Intensity | d Spacing (Å) | hkl |
|-------|-------------------|---------------|-----|
| 11.945 | 100               | 7.0403        | 100 |
| 16.027 | 3.41675551        | 5.5256        | 111 |
| 24.336 | 7.067044315       | 3.6545        | 101 |
| 25.843 | 11.87224759       | 3.4448        | 110 |
| 26.523 | 12.37177182       | 3.3579        | 201 |
| 27.349 | 7.440973824       | 3.2584        | 222 |
| 28.467 | 10.06616278       | 3.1329        | 200 |
| 34.541 | 4.687262312       | 2.5946        | 202 |
Crystal structure analysis
Crystal structure of Cu (II) complex of α-acetyl-γ-butyrolactone:- For XRD the suitable single crystal were obtained by the slow evaporation of methanolic solution of the complex. The geometry of the complex is found to be square planar. The compound crystallises in monoclinic crystal system with the space group P21/C. The central Cu atom is four co-ordinated with four oxygen atoms of two bidentate ligands. A summary of crystallographic data and refinement parameters are given in Table No.4. The molecular structure of the compound was solved at 200(2) k. (Figure 7) gives the ORTEP diagram of the complex with atomic labelling scheme.

Fig 6: X-ray diffractogram of Cu (II) complex

Fig 7: ORTEP drawing of the complex a) with atomic labeling b) Crystal Packing of Cu II complex

Fig 8: Single crystal XRD of Cu (II) complex
The important inter atomic distances and angles are listed in Table 7. The complex geometry can be explained by a structure resulting in O(2)-Cu – O – Cu(1). The O(1) bond angles which is 180.0. In the co-ordination sphere, the Cu-O bond lengths are 1.9052(19) and 1.946(2) Å. The O-Cu-O bond angles are 85.77° and 94.28° and the sum of them indicating a square planar configuration of complex which is also evident from UV analysis.

### Table 4: Crystal data and structure refinement for cu_902_r_0m

| Identification code | cu_902_R_0m |
|---------------------|-------------|
| Empirical formula   | Cu1H14 Cu06 |
| Formula weight      | 317.77      |
| Temperature         | 200(2) K    |
| Wavelength          | 1.54178 Å   |
| Crystal system      | Monoclinic  |
| Space group         | P 21(c)     |
| Unit cell dimensions| a = 4.6948(3) Å, b = 14.8343(8) Å, c = 8.7072(5) Å |
| Volume              | 598.36(6) Å3 |
| Density (calculated)| 1.764 Mg/m3 |
| Absorption coefficient| 2.802 mm-1 |

### Table 5: Atomic coordinates ( x 104) and equivalent isotropic displacement parameters (Å2 x 103) for cu_902_r_0m. U(eq) is defined as one third of the trace of the orthogonalized Uij tensor

| X       | Y       | Z       | U(eq)  |
|---------|---------|---------|--------|
| Cu(1)   | 15000   | 5000    | 5000   | 21(1) |
| O(1)    | 13176(4)| 3821(1) | 4991(2)| 25(1) |
| O(1)    | 12225(4)| 5462(1) | 3347(2)| 24(1) |
| O(3)    | 9957(5) | 2785(1) | 4067(3)| 29(1) |
| C(1)    | 7365(7) | 2688(2) | 2893(4)| 31(1) |
| C(2)    | 6955(6) | 3579(2) | 1992(3)| 25(1) |
| C(3)    | 9304(6) | 4164(2) | 2884(3)| 21(1) |
| C(4)    | 10961(6)| 3631(2) | 4042(3)| 21(1) |
| C(5)    | 10087(7)| 3044(2)| 2611(3)| 21(1) |
| C(6)    | 8130(7) | 3584(2)| 1385(4)| 28(1) |

### Table 6: Bond lengths [Å] and angles [°] for cu_902_r_0m

| Bond lengths [Å] | Bond angles [°] |
|------------------|-----------------|
| Cu(1)-O(2)       | 1.9052(19)      |
| Cu(1)-O(1)       | 1.9462(2)       |
| O(1)-C(4)        | 1.2514(1)       |
| O(2)-C(5)        | 1.2904(2)       |
| O(3)-C(4)        | 1.342(3)        |
| O(3)-C(1)        | 1.4664(4)       |
| C(1)-C(2)        | 1.5344(4)       |
| C(2)-C(3)        | 1.5144(4)       |
| C(3)-C(5)        | 1.377(4)        |
| C(3)-C(4)        | 1.411(4)        |
| C(5)-C(6)        | 1.501(4)        |

### Table 7: Anisotropic displacement parameters (Å2 x 103) for cu_902_r_0m. The anisotropic displacement factor exponent takes the form: \(-2 \pi^2 h^2 a^4 + 2 \pi^2 k^2 b^4 + 2 \pi^2 l^2 c^4 + 2 \pi^2 h k a b + 2 \pi^2 h l a c + 2 \pi^2 k l b c\)

| U11   | U22   | U33   | U23   | U13   | U12   |
|-------|-------|-------|-------|-------|-------|
| Cu(1) | 24(1) | 16(1) | 20(1) | 1(1)  | -2(1) | -1(1) |
| O(1)  | 27(1) | 19(1) | 26(1) | 3(1)  | -3(1) | 0(1)  |
| O(2)  | 25(1) | 19(1) | 26(1) | 3(1)  | -3(1) | -2(1) |
| O(3)  | 32(1) | 16(1) | 36(1) | 2(1)  | -2(1) | -4(1) |
| C(1)  | 28(2) | 20(2) | 43(2) | -5(1) | -5(1) | -4(1) |
| C(2)  | 25(2) | 23(2) | 27(2) | -3(1) | -1(1) | -4(1) |
| C(3)  | 20(1) | 22(1) | 21(1) | -3(1) | 2(1)  | -2(1) |
| C(4)  | 24(1) | 16(1) | 23(1) | -2(1) | 5(1)  | -1(1) |
| C(5)  | 24(1) | 22(2) | 17(1) | -2(1) | 3(1)  | -2(1) |
| C(6)  | 30(2) | 23(2) | 28(2) | 6(1)  | -2(1) | -1(1) |

### Electronic Spectra

The spectra of complex shows shifting in wavelength. The complex shows stretching at 266, 330, 410 and d-d broad and weak band between 525 to 690 nm. This indicates \( \pi - \pi^* \), \( \pi - \pi^* \), \( n - \pi^* \) (LMCT) and d-d 2B_1g \( \rightarrow \) 2Eg and 2B_2g \( \rightarrow \) 2A_1g transition in metal complex. The broadness of band may be due to John Teller distortion, indicating square planar geometry of complex.
Catalytic activity
Inspired by the biological studies, we decided to explore the synthesized and well characterized copper (II) complex as a catalyst for coupling reactions. In order to test its applicability as catalyst, we used the complex for Sonogashira and Suzuki coupling reactions. The complex found to yield the desired products 4 and 5 for mentioned reaction in excellent yield of 84% and 79 % respectively. The yield and structure of coupling products were confirmed by GC-MS analysis. The reaction conditions used to test catalytic behaviour of copper (II) complex for Sonogashira and Suzuki coupling reactions are mentioned in following scheme.

**Reaction conditions:** 1 (2.0 mmol), 2 (1 mmol), Cu(II) Complex (10 mol %), K3PO4 (2.0 mmol), toluene (3 ml), 135 °C, Time: 48 h.

![Scheme 2: Copper (II) complex catalyzed Sonogashira coupling of phenylacetylene (1) with iodobenzene (2).](image)

**Yield 84%**

**Reaction conditions:** 4 (1.2 mmol), 5 (1 equiv), Cu(II) Complex (10 mol %), K2CO3 (2 mmol), toluene (5 ml), 130°C, Time: 12 h.

![Scheme 3: Copper (II) complex catalyzed Suzuki coupling of phenylboronic acid with iodo benzene.](image)

**Yield 79%**

Biological Activity
The synthesized copper (II) complex was tested in vitro against representative Gram-positive/negative bacteria species *E. Coli* and *Staphylococcus aureus*, and two fungal species *Aspergillus niger* and *Candida albicans* by agar well diffusion method. All the bacterial strains were incubated at 37 °C for 48hrs by inoculation into nutrient broth and the fungal strains were incubated for 72hrs by inoculation in to potato dextrose broth. The molten media were inoculated with 100μL of the inoculums and poured into the Petri plate. After medium was solidified, a well was made in the plates with the help of cup-borer (0.85cm). Then the test compounds were introduced into the well and Petri plates were incubated. Compound was dissolved in DMSO to prepare stock solution. Commercially available bactericide Gentamicin and antifungal Flucanozole were used as standard (100μg per 100μL of sterilized distilled water) concurrently with the test samples. The diameter of inhibition zones (in mm) was determined and data was statistically evaluated by Turkey’s pair-wise comparison test. All the experiments were repeated for three times and the results were confirmed.

The newly synthesized complex was found to reveal considerable antibacterial activity almost equal to the activity of Gentamicin. The complex was also screened for its antifungal activity against *Aspergillus niger* and *Candida albicans* by agar disc diffusion method. The results of the
antifungal testing of the complex was compared with the
typical broad spectrum of the potent antifungal drug
Flucanazole. The antifungal activity data shows that Cu (II)
complex had comparable activity for A. Niger and had
showed excellent activity against Candida albicans, which is
found to be better than the standard Flucanazole. The
antimicrobial assay evaluation
of the synthesized of Cu (II) complex was done using agar
well plate method. The antibacterial and antifungal assays
were performed in Muller-Hintonbroth and Crazek Dox broth.
The standard strains used for the antimicrobial assay was
procured from Microbial Culture Collection, Pune, India.
Antimicrobial evaluation was performed using the bacteria
reseeded in Muller-Hinton broth for 24 hr at 37 °C and fungi
reseeded in Crazek Dox broth for 48 hr at 25 °C. The
antibacterial activity of tested sample was studied in triplicate
against gram positive bacteria Staphylococcus aureus (ATCC
29737) and gram negative bacteria Escherichia coli (ATCC
25922). The same sample was tested for antifungal activity in
triplicate against Candida albicans (MTCC 277) and
Aspergillus niger (MCIM 545). The compound was dissolved
in DMSO at desired concentrations of 40, 20, 10 μg/ mL.
DMSO was loaded as negative control. Gentamicin (10 μg/
L) and Fluconazole (20 μg/ mL) was used as standards for
evaluating the antibacterial and antifungal activity. The zone
of inhibition (mm) was determined from the diameter of the
zone of inhibition using caliper as per National Committee for
Chemical Laboratory Standards (NCCLS, M7-A5, January
2000). Both metal complex shows good antibacterial as well
as good antifungal activity.

Table 9: Antimicrobial screening of compounds 1-12: Inhibition Zone Diameter (mm)

| Complex          | E. coli (ATCC25922) | S. aureus (ATCC 29737) | A. niger (MCIM 545) | C. albicans (MTCC 277) |
|------------------|---------------------|------------------------|---------------------|------------------------|
| C_{12}H_{14}CuO_6 | 20 +/- 0.8          | 21 +/- 0.4             | 22 +/- 0.7          | 26 +/- 0.7             |
| DMSO             | 11 ± 0.7            | 12 ± 0.9               | 12 ± 0.6            | 13 ± 0.3               |
| Gentamicin       | 22 ± 0.4            | 23 ± 0.7               | -                   | -                      |
| Fluconazole      | -                   | -                      | 23 ± 0.8            | 24± 0.5                |

Gentamicin (10 μg/ mL) and fluconazole (20 μg/ mL) Inhibition Zone= 9-14 mm: slight activity, 15-19 mm: moderate activity, 20 -24 mm : high activity, >25 mm: excellent activity NT: Not Tested

Table 10: Antimicrobial screening of complexes: MIC in μg / mL values

| Complex          | Escherichia coli (ATCC25922) | Staphylococcus aureus (ATCC 29737) | Aspergillus niger (MCIM 545) | Candida albicans (MTCC 277) |
|------------------|-----------------------------|------------------------------------|-----------------------------|----------------------------|
| C_{12}H_{14}CuO_6 | 10                          | 10                                 | 10                          | 10                         |
| Gentamicin       | 10                          | 10                                 | -                           | -                          |
| Fluconazole      | -                           | -                                  | 20                          | 20                         |

Gentamicin (10 μg/ mL) and Fluconazole (20 μg/ mL), (MIC in μg / mL)=10 μg / mL: excellent activity, 20 μg / mL: moderate activity,40 μg / mL: slight activity

The complex C_{12}H_{14}CuO_6 showed excellent antibacterial activity against Escherichia coli (ATCC25922) with MIC 20 μg/mL when compared with standard antibacterial drug Gentamicin (10 μg/mL). Similarly it also showed excellent anti fungal activities against Aspergillus niger (MCIM 545), Candida albicans (MTCC 277) with MIC 10 μg/mL when compared with standard antifungal drug Fluconazole (20 μg/mL). [45]

Fig 11: Biological Activity of 902 (C_{12}H_{14}CuO_6)
Conclusion
The novel copper (II) complex of α- acetyl- γ butyrolactone was synthesized as a ligand and were well characterized using various analytical tools viz. IR, UV, HRMS, elemental analysis, single crystal XRD, conductometer, physical constant etc. The Cu (II) complex was tested for antibacterial and antifungal activities by agar disc diffusion method and showed truly biological activities. The Cu (II) complex showed excellent catalytic activity towards Sonogashira and Suzuki coupling reactions.

Supporting Information
CCDC reference number 1520126 contains the supplementary crystallographic data for this paper. This data can be obtained free of charge via www.ccdc.cam.ac.uk or from the crystallographic data centre, 12 union road, Cambridge CB2 1EZ UK.

Acknowledgement
The authors are thankful to Organic chemistry research centre, K.T.H.M. College Nashik, Maharashtra and UGC New Delhi.

References
1. Regioselective synthesis of fluorinated pyrazole derivatives from trifluoromethyl-l, 3-diketone L. Song, S. Zhu, J Fluorine Chem. 2001; 111:201.
2. Nagpal A, Unny R, Joshi YC. Heterocyclic Commun. 2001; 32:1585.
3. Kost AN, Grandberg II. In: Advances in Heterocyclic Chemistry, A. R. Katritzky, A. J. Boulton (Eds.) Academic Press: New York and London, 1966.
4. Kochetkov NK, Sokolov SD. In Advances in Heterocyclic Chemistry, A. R.Katritzky, A. J. Boulton (Eds.), Academic Press: New York and London, 1963.
5. Structure activity relationship studies of novel heteroretinoids: Induction of apoptosis in the HL-60 cell line by a novel isoxazole-containing heteroretinoid D. Simoni, F. P. Invidiata, R. Rondanin, S. Grimaudo, G. Cannizzo, E. Barbusca, F. Porrett, N. D’ Alessandro, M. Tolomeo, J Med. Chem. 1999; 42:4961.
6. 5-(4-Chlorophenyl)-4-methyl-3-(1-(2-phenylethyl) piperidin-4-yl) isoxazole: a potent, selective antagonist at human cloned dopamine D4 receptors M. Rowley, H. B. Broughton, I. Collins, R. Baker, F. Emms, R. Marwood, S. Patel, C. I. Ragan, S. B. Freedman, P. D. Leeson, J Med. Chem. 1996; 39:1943.
7. [Citation] Synthesis of pyrazole, 1, 2, 4, 5-tetrazine, and 1, 2, 4-triazole derivatives from thiocarbonohydrazides and beta v. v. Alekseev, K. N. Zelenin, S. I. Yakimovich, Russ. J Org. Chem. 1995; 31:868.
8. New sterically hindered Hf, Zr and Y β-diketonates as MOCVD precursors for oxide films S. V. Pasko, L. G. Hubert-Pfalzgraf, A. Abrutis, P. Richard, A. Bartasyte, V. Kazlauskienė, J Mater. Chem. 2004; 14:1245.
9. Some aspects of competitive coordination of β-diketonates and nitrogencontaining ligands A. D. Garnovskii, B. I. Kharivox, L. M. Blanco, D. A. Garnovskii, A. S. Burlov, I. S. Vasilchenko, G. I. Bondarenko, J. Coord. Chem. 1999; 46:365.
10. Elliot JM, Sinn E. Abstracts of Papers, 223rd ACS National Meeting Orlando, FL, INORG-080, 2002.
11. Variety in the coordination modes of β-diketonyl compounds in metal complexes S. Kawaguchi, Coord. Chem. Rev. 1986; 70:51.
12. Palladiumbis (2,2,6,6-tetramethyl-3,5-heptanedionate) catalysed alkoxy carbonylation and aminocarbonylation reactions P. J. Tambade, Y. P. Patil and B. M. Bhanage, Applied Organometallic Chemistry, 2009; 23:235-240.
13. Palladium bis (2,2,6,6-tetramethyl-3,5-heptanedionate): an efficient catalyst for regioselective C-2 arylation of Heterocycles catalysed N. S. Nandurkar, M. J. Bhanushali, M.D. Bhor, B. M. Bhanage, Tetrahedron Letters. 2008; 49(6, 4):1045-1048.
14. Synthesis, characterization and Luminescent properties of polymer complexes of Nd(III) with β-dicarbonyl ligands O. Berezhnyska, Irina Savchenko, Nadiyavlkha, Olena Trunova, Nataliya Rusakova, Sergiy Smola and Oleksandr Rogovtsov, Nanoscale Research Letters. 2017; 12:338.
15. Galladium (II) compounds stabilized by β-diketonatesligands: synthesis, characterization and X-ray structural studies of [GaCl(acac)]; and [GaCl(tmhd)]; O. T. Beachley, Jr., James R. Gardinier, and Melvyn Rowen Churchill Organometallics. 2000; 19(22):4544-4549.
16. Low catalyst loadings for copper catalysed O-arylation of phenols with aryl and heteroaryl halides under mild conditions Fuji-Fong Yonga, Yong-Chua Teo, Yaw-Kai Yana, Guan-Leong Chua, Synlett. 2012; 1:101-106
17. Phospa-free palladium-catalysed carboxylative Suzuki coupling reaction of aryl and heteroarylidines P. J. Tambade, Y. P. Patil, A. G. Panda, B. M. Bhanage, European Journal of Organic Chemistry. 2009; 18:3022-3025.
18. A β-keto ester as anovel, efficient and versatile ligand for copper (I) catalyzed C-N,C-O and C-S coupling reactions Xin Lv and Weiliang Bao, J Org. Chem. 2007; 72(10):3863-3867.
19. A δ-Keto Ester as a Novel, Efficient, and Versatile Ligand for Copper(I)-Catalyzed C-N, C-O, and C-S Coupling Reactions, Xin Lv and Weiliang Bao; Department J Org. Chem. 2007; 72:3863-3867.
20. Variety in the coordination modes of β-dicarbonyl compounds in metal. complexes, Shinichi Kawaguchi, coordination chemistry reviews. 1986; 70:51-84.

http://www.chemijournal.com