

Zinc Nanoparticles as Efficient Catalyst for the Transesterification of β -Ketoesters

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Abstract

Introduction: Transesterification, one of the most effective methods for ester synthesis is usually conducted under acid or basic conditions. Although quite a few methods have been reported for transesterification, they are not general as far as β -ketoesters are concerned.

Aim: We have successfully performed transesterification of 6 type's β -ketoesters using Zinc powder and Zinc nanoparticles as catalyst. Comparison between the two catalysts in both yield and time of reaction were also done.

Materials and Methods: In this research, we study of reaction between *benzoyl ethyl acetate with 3-phenyl -1- propanol*, benzoyl ethyl acetate with cyclohexanol, ethyl benzoyl acetate with buthanol, ethyl benzoyl acetate with tertio buthyl alcohol, ethyl aceto acetate with 3-phenyl-1- propanol, *ethyl aceto acetate reaction with n-penthanol*.

Results: Some of these methods use toxic and expensive reagents and in relatively large of amount. In this research, transesterification reaction six types β -ketoesters achieved in present of Zn powder and Zn nanoparticles as catalyst and 5 β -ketoesters prepared using this method.

Conclusion: Zinc Nanoparticles is an efficient catalyst for the transesterification of β -ketoesters with several kinds of alcohols, leading to good yields with high selectivity.

Keywords: β -ketoesters, Zinc Nanoparticles, catalyst, transesterification

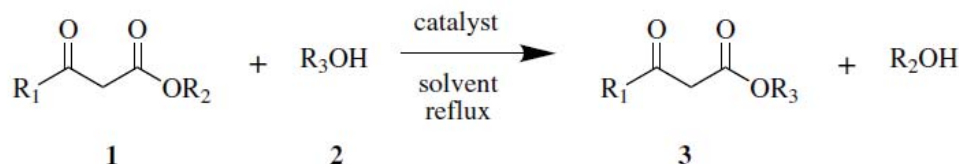
Introduction

Transesterification is an important reaction which has wide applications both in academic and industrial research.^[1, 2] β -ketoesters^[3] are multicoupling reagents having electrophilic carbonyl and nucleophilic carbon which make them a valuable tool for the synthesis of complex molecules. They are one of the basic building blocks in the total synthesis of sex pheromones like serricornine^[4] and other natural products like thiolactomycin,^[5] trichodiene,^[6] polyoximic acid,^[7] chokol,^[8] prostaglandin PGF_{2a},^[9] ar-pseudotsugonoxide,^[10] syncarpic acid,^[11] diploidalide^[12] and podophyllotoxin.^[13]

In the literature, there are various alternative routes to obtain β -ketoesters,^[14, 15] but the transesterification of these compound has been recognized as a very important and useful

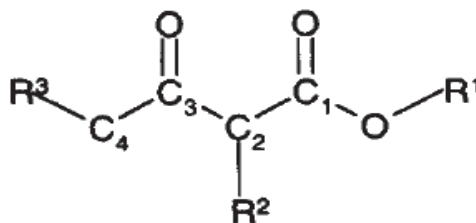
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process because it allows the preparation of more complex products from more easily accessible synthons.^[16] The transesterification of β -ketoesters (Scheme 1) is an equilibrium process^[16] that can be catalyzed by many kinds of catalysts, such as Bronsted base,^[17] DMAP,^[17] distanoxanes,^[18] solid superacids,^[19] zeolites,^[20] titanium(IV) alkoxides,^[21] indium triiodide,^[22] natural clays,^[23] transition metal complexes,^[24] Mo-ZrO₂,^[25] nonionic superbase,^[26] yttria-zirconia Lewis acid,^[27] Mg-Al-O-t-butyl hydrotalcite,^[28] diphenylammonium triflate,^[29] montmorillonite,^[30] zinc dust,^[31] basic silica,^[32] amberlyst,^[27, 33] sodium perborate,^[34] lithium perchlorate,^[35] and NBS.^[36]



Scheme 1- General Transesterification process for β -ketoesters.

Many procedures for the synthesis of β -ketoesters have been reported over a long time, but there exist many drawbacks and disadvantages necessitating improved methods for their synthesis. Of the many models of bond formation that exist for β -ketoesters synthesis, two notable ones are C2-C3 bond formation and C1-O bond formation (Scheme 2) [37].



Scheme 2- Structure of β -ketoester

Some of results, i.e. synthesis of β -ketoesters by condensation of aldehydes with ethyl diazoacetate catalysed by zeolites and by transesterification of β -ketoesters with different alcohols also catalysed by zeolites [37] and Copper-bipyridine-catalyzed for enantioselective α -amination of β -ketoesters [10] have been communicated recently.

We have successfully performed transesterification of 6 type's β -ketoesters using Zinc powder and Zinc nanoparticles as catalyst. Comparison between the two catalysts in both yield and time of reaction were also done.

Material and Methods

Experimental

General experimental procedure for transesterification

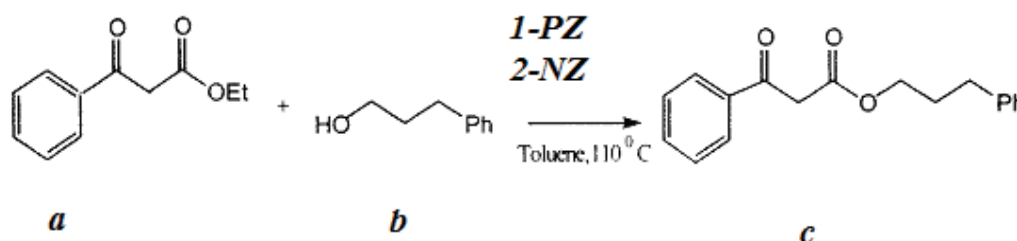
All solvents were distilled prior to use. Petroleum ether refers to the fraction collected in the boiling range 60-80°C (The IR spectra were recorded on Perkin-Elmer spectrophotometer model 683B. The ¹H and ¹³C NMR spectra were recorded on Bruker AC-200 instruments using tetramethylsilane as the internal standard using CDCl₃ as solvent. The mass spectra were recorded on Finnegan MAT-1020-B-70eV mass spectrometer. Zn Powder from Merck Company and Zn nanoparticles prepared from Nanostructured & Amorphous Materials, Inc (99.9% (metal basis, APS 35 nm, SSA: 30 - 50 m²/g).

General procedure for the synthesis transesterification of β -ketoesters

A mixture of ketoesters (1 equiv), alcohol (1 equiv), and catalyst (15% by weight) in toluene (10 mL) was refluxed using Dean–Stark apparatus for the indicated length of time (Table 2). The reaction was monitored by T.L.C. After completion of the reaction, the catalyst was filtered and the filtrate was concentrated to get the crude product which was purified by silica gel column chromatography using petroleum ether/ethyl acetate as elution to afford the pure transesterified product. All products were characterized by IR, ^1H NMR and mass spectroscopic data.

Results and discussion**Reaction between benzoyl ethyl acetate with 3-phenyl -1- propanol**

Reaction between benzoyl ethyl acetate (compound a, scheme 3) with 3-phenyl -1- propanol (compound b, scheme 3) in toluene using zinc powder and also nano zinc particles in 110 °C gives 3-phenyl 1-propyl benzoyl acetate red liquid (compound c, scheme 3)



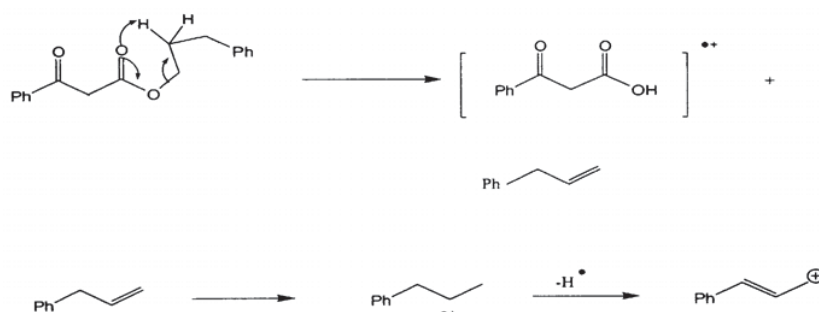
Scheme 3- Reaction between benzoyl ethyl acetate(a) and 3-phenyl -1-propanol (b) to give 3-phenyl 1- propyl benzoyl (c)-[1-PZ: particle Zinc powder and 2-NZ: nanoparticles Zinc powder]

In IR spectrum of compound c, strong peaks in 1680 and 1740 cm^{-1} correspond to C=O and absorption bands in 1475-1620 cm^{-1} are related to aromatic carbonyl group. Bands appearing in 2950 and 3100 cm^{-1} are related to aliphatic and aromatic C-H respectively. Combination of bending and stretching vibrations of PhCO appears in 1200-1300 cm^{-1} . Tautomerism compound of c in acetone is as scheme 4.



Scheme 4- Tautomerism of phenyl 1- propyl benzoyl acetate

Multiple peaks appearing in 1.5 ppm is related to hydrogens b, triplet in 2.3 ppm corresponds to c hydrogens. Triplet of hydrogens, singlet of d and f (produced by tautomerism) and e hydrogens, are seen in 3.6, 3.6, 5.45, and 20 ppm respectively. Spread peak in 6.7-7.5 is appeared as the result of phenyl ring hydrogens splitting. The peak appearing in $m/e=281.7$ in mass spectrum give the molecular weight. McLafferty rearrangement gives $[\text{PhCOCH}_2\text{COOH}^+]$ cation which is responsible for the peak appeared in $m/e=147.1$. During the rearrangement molecule first lose $\text{PhCH}_2\text{=CH}_2$ which then lose hydrogen and produce a stable allylic and benzylic carbonium which correspond to the peak appears in 117. This procedure may be shown as:

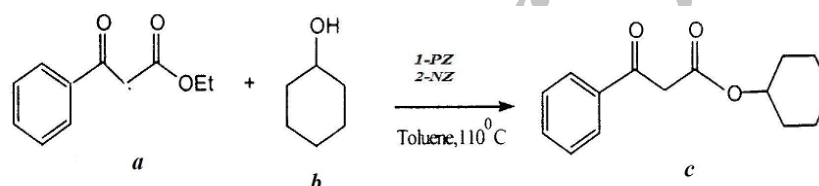


Scheme 5- McLafferty rearrangement which produce stable carbonium

The peaks appeared in $m/e=77.1$, 147.1 , 105 and 91.1 are related to $\text{PhCOCH}_2^+\text{CO}$, PhC^+O , PhCH_2^+ and Ph^+ respectively.

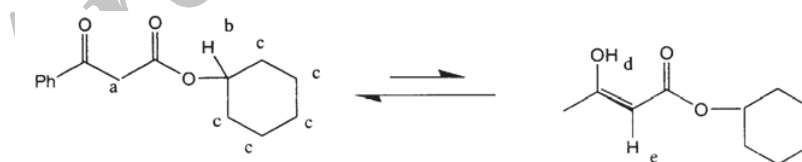
Reaction of benzoyl ethyl acetate with cyclohexanol

Ethyl benzoyl acetate (compound a, scheme.6) in reaction with cyclohexanol (compound b, scheme 6) gives cyclohexyl benzoyl acetate (compound c, scheme 6). This reaction was carried out in toluene and Zinc nanoparticles were used as catalyst.



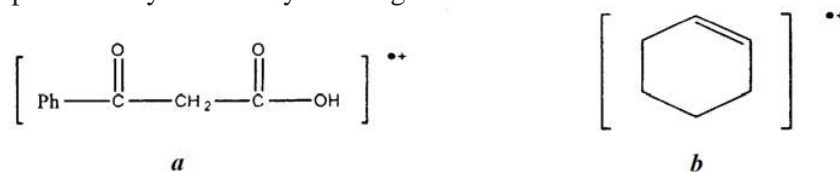
Scheme 6- Reaction of ethyl benzoyl acetate with cyclohexanol in toluene. Zinc powder and zinc nanoparticles are used as catalyst. [1-PZ: particle Zinc powder and 2-NZ: nanoparticles Zinc powder]

IR spectrum of compound c scheme 6, shows strong peaks in 1680 and 1740 ($\text{C}=\text{O}$) and also aromatic-carbonyl in 1475 and 1600 cm^{-1} . The band appearing in 1100 cm^{-1} and the ones in 1220 - 1300 cm^{-1} reveal bending and stretching vibrations of ketone carbonyl group. In 2950 - 3100 cm^{-1} appears aliphatic and aromatic C-O respectively. HNMR spectrum of this compound is as scheme 7.



Scheme 7- Tautomerism of cyclohexyl benzoyl acetate

The peak appearing in 0.5 - 1.7 ppm is related to c hydrogens of cyclohexane ring and sharp one in 3.4 ppm is showing hydrogen a. vinyl hydrogens appear in 4.2 - 4.7 and hydrogens d in 20 ppm. The peaks in 82.1 and 163.9 ppm in mass spectrum are related to cations a and b respectively produced by McLafferty rearrangement shown in scheme 8.

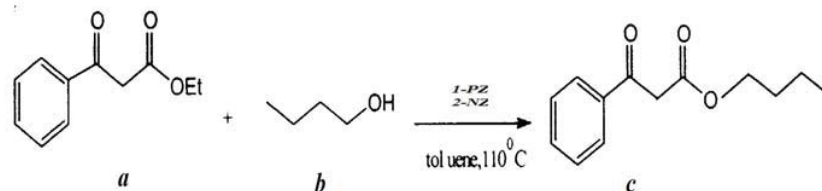


Scheme 8- mass spectrum of cation radical resulting from cyclohexyl benzoyl acetate

The peaks of 77.1, 104.2 and 147 are showing $\text{PhCOCH}_2^+\text{CO}^-$, PhC^+O^- and Ph^+ respectively.

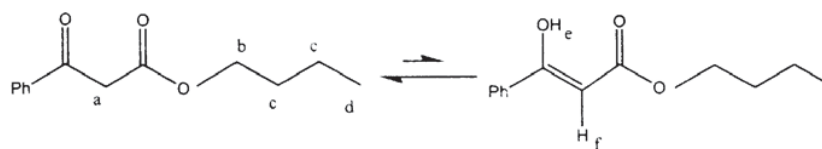
Reaction of ethyl benzoyl acetate with butanol

In presence of zinc powder and zinc nano particles as catalyst reaction of ethyl benzoyl acetate and n-buthanol in toluene produce buthyl benzoyl acetate (compound c, scheme 9).



Scheme9- Reaction between ethyl benzoyl acetate and n-buthanol. Buthyl benzoyl acetate is produced. [1-PZ: particle Zinc powder and 2-NZ: nanoparticles Zinc powder]

In IR spectrum of compound c absorption bands in $1470\text{-}1600\text{ cm}^{-1}$ are related to aromatic $\text{C}=\text{C}$ and the one in 2950 and 3100 cm^{-1} are representative of aliphatic and aromatic $\text{C}-\text{H}$ respectively. The bands in $1200\text{-}1300\text{ cm}^{-1}$ are the combinations of bending and stretching vibrations of ketone carbonyl group. Tautomerism of this compound is shown in scheme10.

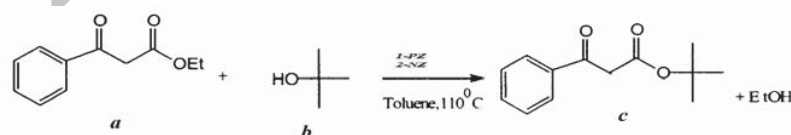


Scheme10- Tautomerism of buthyl benzoyl acetate

Multiple peaks in 0.5 ppm are related to d, 0.5-1.2 ppm to c and triple in 3.7 ppm to b hydrogens. F Hydrogens appear in 3.5 and benzene ring hydrogens in 7-7.8 ppm. The singlet in 20 ppm is hydrogen e. since the tautomerism like to shift to left, the intensity of peaks corresponding to e and f hydrogen is low.

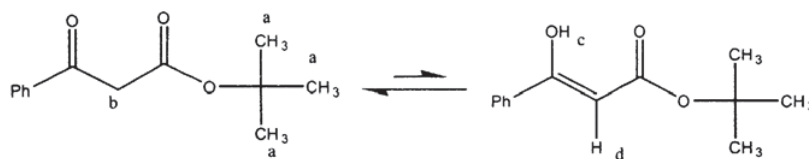
Reaction ethyl benzoyl acetate with tertio butyl alcohol

tertio butyl benzoyl acetate (compound. c, scheme 10) as the product of reaction of ethyl benzoyl acetate with tertio buthyl alcohol, using zinc powder and zinc nano particles as catalyst.



Scheme10- tertio buthyl benzoyl acetate as the product of reaction of ethyl benzoyl acetate with tertio buthyl alcohol, using zinc powder and zinc nanoparticles as catalyst. [1-PZ: Zinc powder and 2-NZ: Zinc nanoparticles]

The absorption bands in $1475\text{-}1620\text{ cm}^{-1}$ and 2950 and 3100 cm^{-1} are representative of aromatic $\text{C}=\text{C}$ and aliphatic and aromatic $\text{C}-\text{H}$ respectively. HNMR spectrum of this compound is shown in scheme 11.

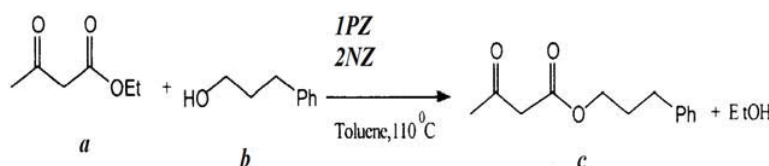


Scheme 11- Tautomerism equilibrium of tertio buthyl benzoyl acetate.

Singlet of hydrogens a and b appears in 0.8 and 3.4 respectively. Hydrogen e appears in 20ppm and the peaks seen in 7-7.6 ppm are related to phenyl ring hydrogens'.

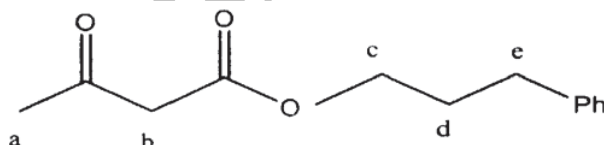
Reaction of ethyl aceto acetate with 3-phenyl-1- propanol

Reaction of ethyl aceto acetate (compound a, scheme 12) with 3-phenyl -1- propanol (compound b, acheme12) in presence of zinc powder and zinc nanoparticles.



Scheme12- Reaction of ethyl aceto acetate with 3-phenyl -1- propanol in presence of zinc powder and zinc nanoparticles. [1-PZ: particle Zinc powder and 2-NZ: nanoparticles Zinc powder]

In IR spectrum of the compound c, there can be seen strong bands in 1680 and 1740 cm^{-1} . Absorption bands in 1470 and 1600 and also 2950 and 3100 cm^{-1} are representative of aromatic C=C, aromatic and aliphatic C-H respectively. HNMR spectrum is shown below.

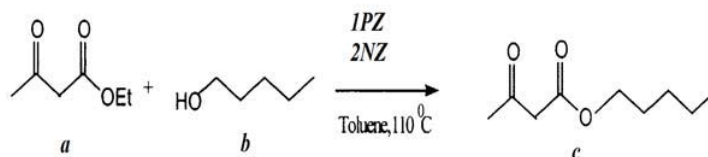


Scheme13- Hydrogens' of 3-phenyl -1- propyl aceto acetate

Multiple peaks in 1.4 ppm are corresponding to d hydrogens. In 1.6 ppm appear a hydrogens and triplet in 3.2 is representative of c ones. B, c and phenylic hydrogens appear in 3, 3.4 and 7.2 ppm respectively. In mass spectrum of this compound the peak appears in 221.3 is related to M^{+1} and the ones in 117, 105.1, 91 and 43.1 are corresponding to $\text{PhC}^+\text{HCH}=\text{CH}_2$, PhC^+O , PhC^+H_2 and $\text{CH}_3\text{C}^+\text{O}$ Respectively.

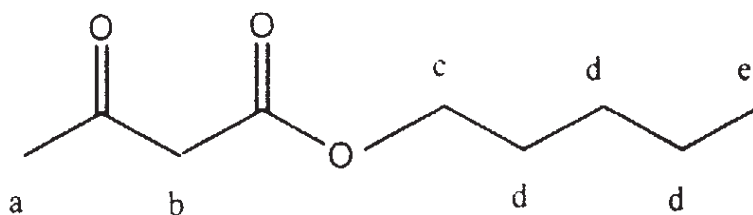
Reaction of ethyl aceto acetate reaction with n-pentanol

pentyl aceto acetate (compound c, scheme 14) is given in reaction of ethyl aceto acetate(compound a, scheme.14) with n-pentanol (compound b, scheme.14).



Scheme14- pentyl aceto acetate is given in reaction of ethyl aceto acetate with n-pentanol. [1-PZ: particle Zinc powder and 2-NZ: nanoparticles Zinc powder].

IR spectra of compound c shows strong bands in 1680 and 1740 cm^{-1} [$\text{C}=\text{O}$] and in 2970 and 2850 cm^{-1} is related to aliphatic C-H bonds. NMR spectrum of this compound in acetone is shown in scheme 15.



Scheme 15- hydrogen's of penthyl aceto acetate

Triplet in 0.9 ppm shows hydrogens e, singlet peaks appear in 2.2 and 3.5 are related to a and b hydrogens and the peaks seen in 3.5 and 4 ppm are demonstrating hydrogens a and c respectively. The structure is also proven using mass spectrometry. Apparently using nano size particles improved the yield of the reaction which can be related to the contact surface of the reactants and the catalyst species increase. It also decreases the time of reaction.^[38] The results are shown in table 1.

Table 1- Transesterification of β -ketoesters with different alcohols catalyzed by powder and nanoparticles Zinc

Entry	β -ketoesters	Alcohols	Catalyst (mg)	Reaction time (h)	Yield ^{a,b} (%)
1			PZ ^c =400	3.0	86.0
			NZ ^d =400	2.5	96.2
2			PZ ^c =400	3.0	86.0
			NZ ^d =400	2.5	97.4
3			PZ ^c =400	2.0	92.1
			NZ ^d =400	1.7	97.5
4			PZ ^c =400	12.0	45.3
			NZ ^d =400	10.5	65.8
5			PZ ^c =400	2.5	90.1
			NZ ^d =400	2.0	97.3
6			PZ ^c =400	2.0	94.2
			NZ ^d =400	1.6	98.5

a. Yields refer to isolated pure products.

b. All products were characterized by IR, ^1H NMR and Mass spectroscopic data.

c. Powder Zinc

d. Nanoparticles Zinc

Conclusions

Transesterification of a variety of alcohols were carried out using Zinc powder and Zinc nanoparticles as catalyst. The results demonstrate that nano-size catalyst is more efficient in both yield of the reaction and the time reaction needs to be compounded.

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