

Formation of A New Nanostructured Material During An Organometallic Synthetic Process

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† In memoriam

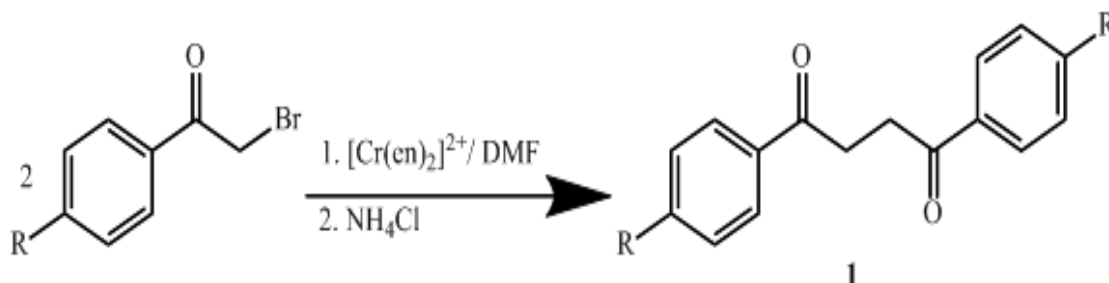
ABSTRACT: We synthesized some 1,4-diones by reductive dimerization of α -bromocetones in the presence of the $[\text{Cr}(\text{en})_2]^{2+}$ complex in DMF. (S)-4-benzyl-3-(2-chloroacetyl)-oxazolidin-2-one was subjected to the same procedure used to obtain 1,4-bis[(S)-4-benzyl-2-oxooxazolidin-3-yl]butane-1,4-dione. The water liquor from this procedure generated a gel, which was analyzed by EM-FAB, TGA, DSC, TEM, SEM/EDS and EDS. Analyses by these techniques confirm that the gel afforded is a nanostructured material and that it gelled water and DMF.

Keywords: Cr(II) complex, DMF gelation, Gels, organogelator, oxazolidin dione

I. INTRODUCTION

The design of supramolecular materials has attracted the attention of numerous researchers among other factors by their applications in biomedical and technological fields, suffice it to point out the release of drugs, catalysis and the nanomaterials. [1-5]. Metallogels are formed by metal-ligand interactions and have the capacity of greatly amplifying the properties of metal complexes, which in turn can be employed in organic synthesis [6]. Molecular gels are formed by the self-assembly of low-molecular mass compounds, called gelators, by non-covalent molecular interactions (e.g. hydrogen bonds, π - π interactions, etc.) in suitable liquids [7-9]. These gels offer a large variety of ways in which molecular recognition can transcribe information from the molecular to the nanoscale level and finally express macroscopic properties in materials [7, 8]. We herein describe the formation of a gel in an organometallic process, and provide its characterization.

We synthesized 1,4-diketones (1) by reacting $[\text{Cr}(\text{en})_2]^{2+}$ and α -bromo acetophenones Scheme 1 [10, 11], a procedure applied to the synthesis of dione 2 as well Fig. 1, which we wanted to probe as *antiquorum sensing* molecule. Gel formation was detected in the mother liquor of this procedure. This is interesting considering that DMF and water were present in large quantities and DMF has a b.p. of 159 °C. After obtaining the gel, the next step was to investigate its components and initiate studies for their characterization.



Scheme 1. Diketone synthesis mediated by $[\text{Cr}(\text{en})_2]^{2+}$

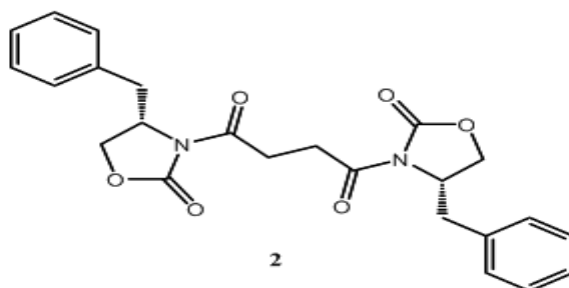


Figure 1. 1,4-bis[(S)-4-benzyl-2-oxooxazolidin-3-yl]butane-1,4-dione (**2**)

II. EXPERIMENTAL SECTION

2.1 Materials

DMF was dried over CaH_2 and ethylenediamine over Na° , as previously reported [10-12]. All reagents and N_2 were purchased from Sigma Aldrich and used without purification. Solvents were purchased from REASOL, dried by following established procedures, and distilled under N_2 immediately prior to use.

The spectra of ^1H NMR and ^{13}C NMR were recorded on a Varian at 500 and 125 MHz respectively. Positive-ion FAB mass spectrum (FAB+-MS) of gel was read on a JEOL-102 mass spectrometer and the matrix was 3-nitrobenzyl alcohol. The mass spectra of compounds **4** and **5** were recorded using an ESI-Ion-Trap Mass Spectrometer coupled to a HPLC Bruker amaZon speed. Differential scanning calorimetry (DSC) and thermogravimetry (TGA) were conducted in a 2910 MDSC V4.4E calorimeter. Scanning electron microscopy (SEM) was recorded on a JEOL JSM 5800 LV microscope and transmission electron microscopy (TEM) on a JEOL model JEM1010 microscope in copper grids with formvar film.

II. 2 Formation of gel inside the mother liquor of 1,4-bis[(S)-4-benzyl-2-oxooxazolidin-3-yl]butane-1,4-dione, **2**.

A suspension of CrCl_2 (0.3091 g, 2.51 mmol) in 10 mL of anhydrous DMF was added dropwise under magnetic stirring at room temperature (RT) to a solution of ethylenediamine (0.34 mL, 5.03 mmol) in 3 mL of DMF. This mixture was stirred for 15 minutes until completely homogenized and blue in color, which corresponded to the $[\text{Cr}(\text{en})_2]^{2+}$ complex. It was subsequently immersed in a bath of ice/salt between -10 and -5 $^\circ\text{C}$ and stirred for another 15 minutes, followed by the addition of a solution of (S)-4-benzyl-3-(2-chloroacetyl)oxazolidin-2-one (0.2965 g, 1.17 mmol) in 4 mL of DMF. After stirring the reaction mixture for 60 minutes longer in the ice bath, the reaction was quenched with a solution of 5 % ammonium chloride (15 ml) and left to hydrolyze for 1 hour at RT. The hydrolyzed mixture was extracted by using methylene chloride (8 x 20 mL), and the organic phases were collected and washed with brine (2 x 20 mL) until reaching $\text{pH} = 7.0$. The organic phase was dried by using Na_2SO_4 anhyd. then evaporated under vacuum to remove DMF. The separation was carried out by column chromatography using silica gel with a hexane:AcOEt gradient, obtaining 0.0160 g of (S)-3-acetyl-4-benzyl-oxazolidin-2-one (**3**) as a white solid with 6 % yield and 0.0312 g of (S)-4-benzyl-oxazolidin-2-one (**4**) as a white solid with 15% yield. No other compound was isolated. The mother water was stored at RT to await further study, but it was transformed into a gel.

III. RESULTS AND DISCUSSION

When bromine diketones are reacted with the $[\text{Cr}(\text{en})_2]^{2+}$ complex, a dimer is generated. However, when (S)-4-benzyl-3-(2-chloroacetyl)oxazolidin-2-one (**3**) was reacted with the $[\text{Cr}(\text{en})_2]^{2+}$ complex, the reduction (**4**) and hydrolysis (**5**) products were afforded Fig. 2.

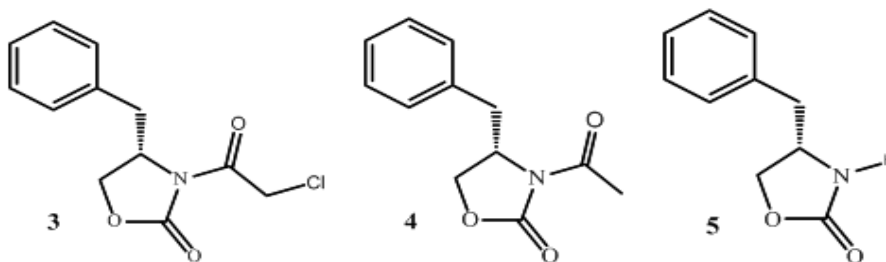


Figure 2. Raw material used **3**. Reduction compound **4**. Hydrolysis compound **5**.

Both compounds **4** and **5**, were characterized by spectroscopic methods: ^1H NMR, ^{13}C NMR and MS. Their melting points and spectroscopic data are in concordance with the original materials. No other compound was isolated. The mother water was completely transformed into a lilac gel in 120 days, having the same color as the mother liquor. The resulting gel was analyzed by FAB-MS, TGA, DSC, SEM, TEM, SEM/EDS and EDS. The fact that the gel contained large amounts of DMF caused the ^1H NMR spectrum to display very wide signals, and the presence of paramagnetic Cr (III) made the signals even wider. Consequently, the gel could not be analyzed by NMR. The only signal detected in the ^1H NMR spectrum of the gel was a multiplet at 3.4 ppm. FAB mass spectroscopic analysis showed a peak at 630 m/z, attributed to the [M+1] formed by oxazolidine dione **2**, DMF, 4 OH ions and Cr (III), the latter oxidized during the reaction.

The yields of organic compounds **3** and **4** provided after the intensive workup clearly does not justify the amount of raw material used. Therefore, there are at least traces of dione **2** in the water liquor. Since reports exist of molecular gels formed by fatty acids and metal ions [13], as well as by 1,3-diketones with Cu (II) [14,15], the C=O units present in dione **2** could possibly be significantly involved in the gelation process. As in similar works [8, 16], the gel was analyzed by differential scanning calorimetry (DSC; Fig. 3), thermogravimetry (TGA; Fig. 4), scanning electron microscopy and energy dispersive spectroscopy (SEM/EDS; Fig. 5), transmission electron microscopy (TEM; Fig. 5 and 6), scanning electron microscopy (SEM; Fig. 7) and EDS analysis Fig. 8.

Gels showed thermostability in most cases. Since the transition sol-gel is close to the solvent boiling point [17], here 121.54 °C, the gel may be attributed to sol-gel transition (Figure 3). Considering the regular behavior of this curve, it does not correspond to that expected for matter decomposition. Interestingly, the boiling point of H_2O is not observed in the DSC analysis, not even in trace amounts Fig. 3, suggesting that water was bound to the structure of the gel and thus no longer existed as an isolated molecule.

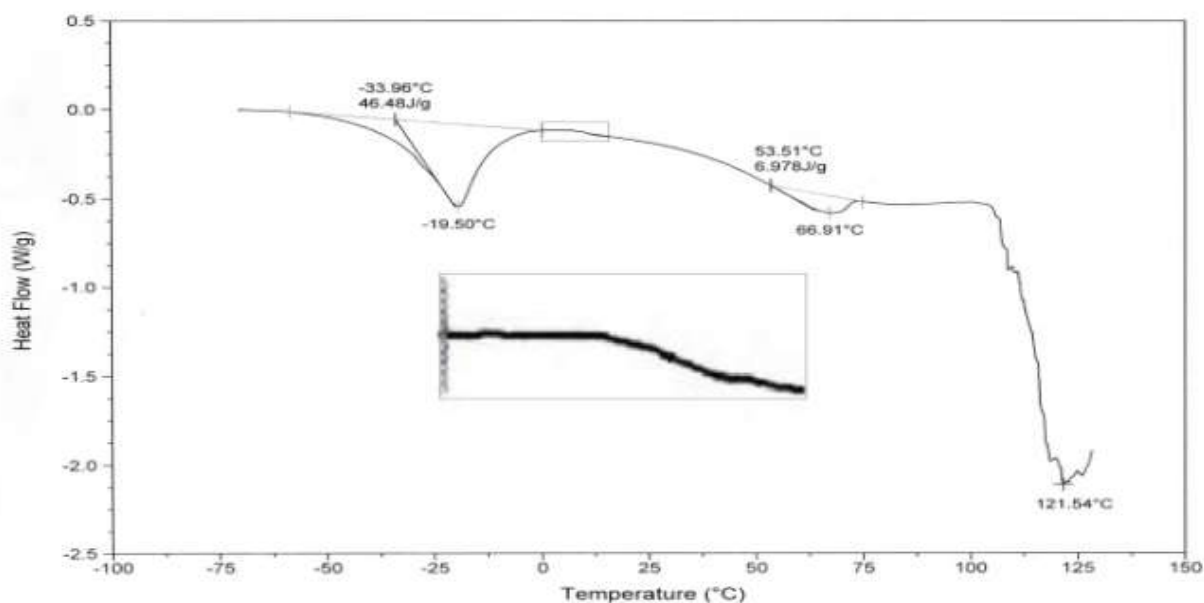


Figure 3. DSC of the molecular gel

The loss of ethylenediamine and DMF can be appreciated in the TGA Fig. 4, considering 113.60 °C as the boiling point of ethylenediamine and 154.76 °C as that of DMF. There was a residue of 11.35% remaining at 300 °C, which according to its melting point should be ethylenediamine dihydrochloride.

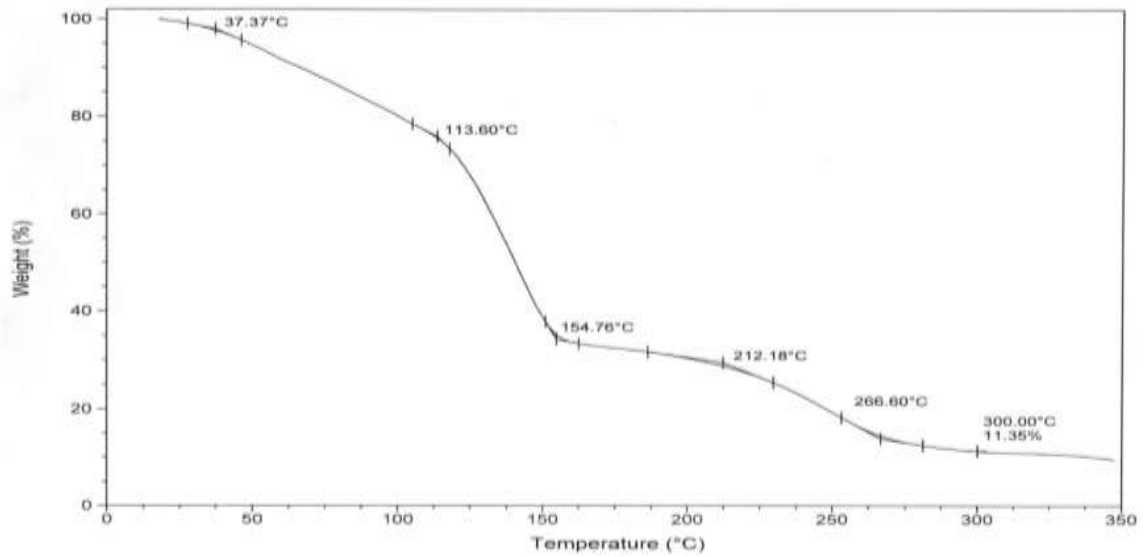


Figure 4. TGA of the gel

The microstructure was also analyzed by SEM/EDS, which allowed the gel topography to be observed after subjecting the gel to a high vacuum, Fig. 5. TEM generated diffraction data Fig. 6, that showed a crystalline structure, but was unable to elucidate a gel structure. The electron diffraction pattern evidenced by TEM, Fig. 6 corroborates the presence of crystals in gel. Nanocrystals (12-22 nm) were also evidenced by TEM, Fig. 7.

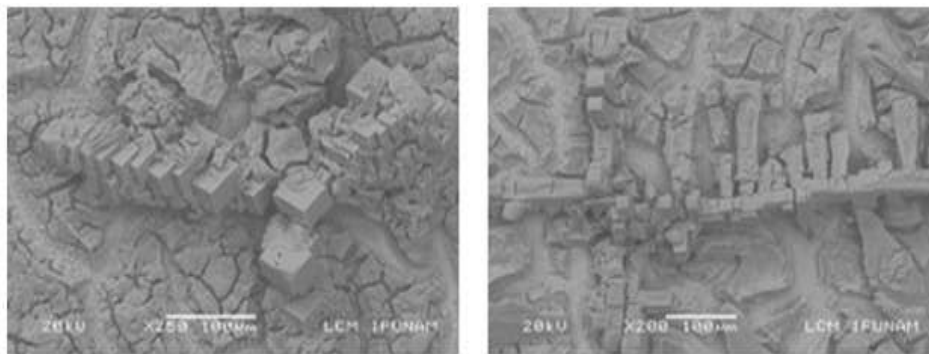


Figure 5. Micrographs by SEM/EDS, showing the topography of the gel under a high vacuum



Figure 6. Electron diffraction pattern by TEM. Please notice this figure was distorted



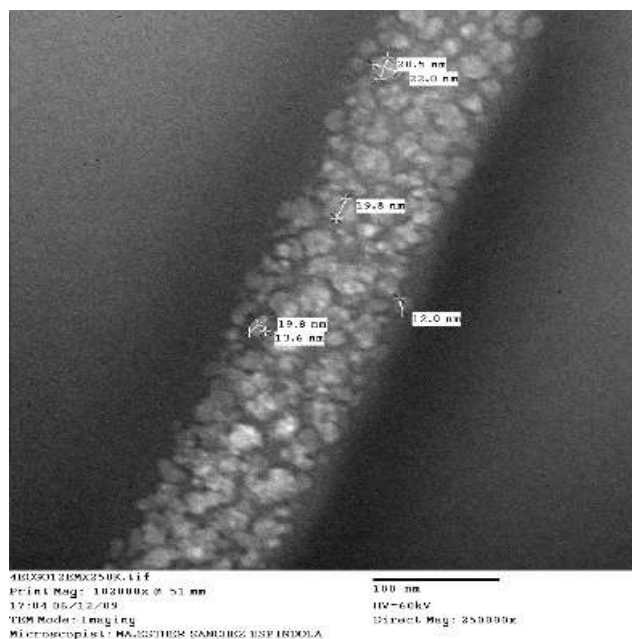


Figure 7. TEM micrograph of the gel

With EDS analysis of mixed materials, the detection limit is ~ 1000 ppm of the sample. This technique assures that the gel was formed without the participation of metals other than Cr, Fig. 8. Al appears due the sample holder employed in this analysis.

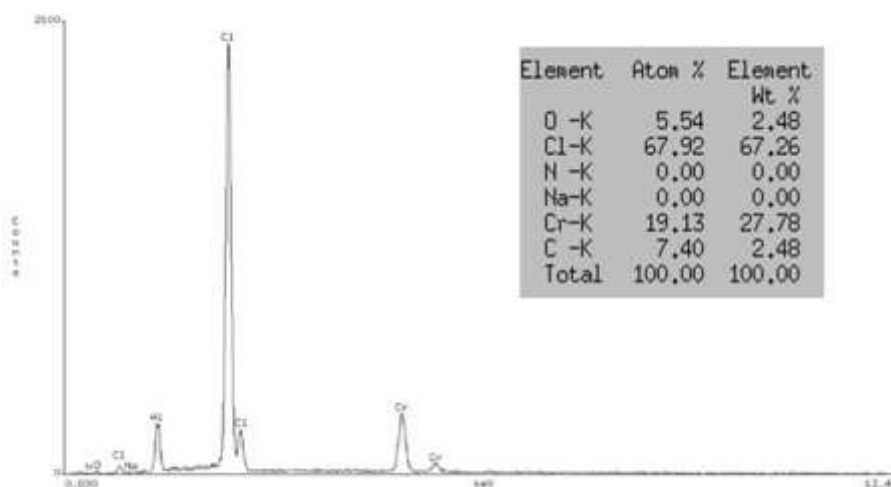



Figure 8. EDS Analysis of the nanostructured material
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Solubility of the gel was also evaluated, which proved to be insoluble in organic solvents such as hexane, CH₂Cl₂, ethanol, ethyl acetate, THF and toluene. The gel was suspended but not solubilized in DMF. When placed only in contact with acetone, it broke and immediately formed an amorphous solid. Fig. 9 shows its SEM micrograph. The transformation of the gel in this way can be attributed to the fact that the air bubbles that normally form a gel are displaced by acetone, which denatures the gel and probably transforms it into a composite. It would be interesting to attempt to demonstrate this hypothesis.

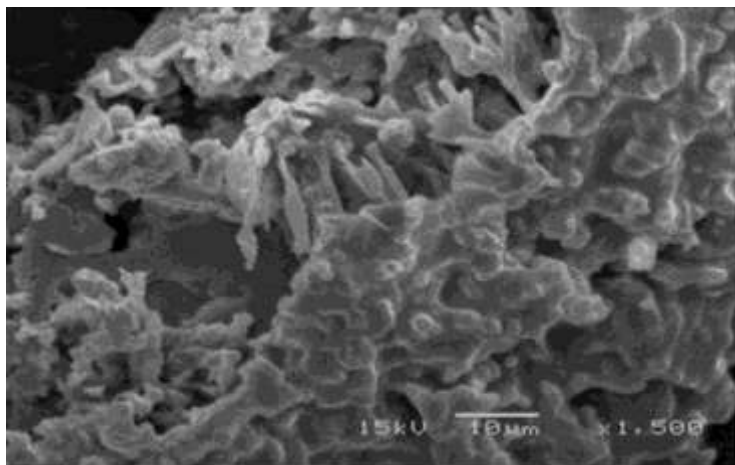


Figure 9. SEM micrograph of the molecular gel after shaking in acetone, base coal

All known organogelators are molecules that have several hetero-atoms arranged in such a way that they can be considered good ligands or chelating agents. [8, 9] This fact favors the consideration of dione **2** as the gelling agent, not the hydrolysis or reduction product. As mentioned above, we have performed the dimerization of some haloketones [11] and the dimerization of numerous aldehydes [10, 18-20] and never obtained a gel. The difference in this event is that the dimerization product has always been isolated and the raw material, **3** used in the present case, has an asymmetric center. Finally, it is important to point out that the gel had a lifetime of 6 months. Everything seems to indicate that the gel was formed by DMF, dione **2**, Cr(III), ethylenediamine and OH^- . Hence, dione 1,4-bis[(S)-4-benzyl-2-oxooxazolidin-3-yl]butane-1,4-dione **2** is an unknown compound, and for the first time DMF was turned into a gel in reactions mediated by $[\text{Cr}(\text{en})_2]^{2+}$. To determine the chemical structure of the gel and to identify the organogelator, other experiments are underway.

IV. CONCLUSION

A nanostructured material was herein formed, so far is known, by traces of 1,4-bis[(S)-4-benzyl-2-oxooxazolidin-3-yl]butane-1,4-dione, Cr (III), DMF, hydroxyl and water. It could be said that 1,4-bis[(S)-4-benzyl-2-oxooxazolidin-3-yl]butane-1,4-dione functioned as an organogelator. The material consisted of nanoparticles with an average of 17 nm. The material generated fulfills the criteria of a nanogel.

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