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The behavior of aldehydes of astrobiological importance under irradiation

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Abstract. The steady-state γ-radiolysis of aldehydes of importance in astrobiology, in aqueous solutions or their pure state. The experiments were made using a ^{60}Co gamma source with doses up to 150 kGy, at two temperatures (77 and 295 K). For the analysis, we used various spectroscopic and chromatographic techniques. The results show that formaldehyde, glyceraldehyde, glycolaldehyde are labile under these conditions and decomposed into sugar-like compounds important for use in chemical-evolution studies. Radiolytic decomposition of aldehydes is by an abstraction reaction of OH radical, from the products formed from the radiolysis of water.

Key words. Chemical evolution – aldehydes – ketones – formaldehyde – gamma radiation

1. Introduction

Chemical evolution refers to the chemical reactions that allowed the formation of organic molecules from inorganic matter, a process that preceded the emergence of life on Earth. It is essential to consider the environment in which chemical reactions took place. For the transition between inorganic/organic matter, an energy source is needed. Ionizing radiation has been considered as a probable source of energy in the primitive Earth (Draganić et al. 1990; Mosqueira et al. 1996).

Aldehydes, a group of prebiotic molecules well distributed in the universe (Hollis et al. 2000; Jørgensen et al. 2012), are essential for living beings. Considered the precursors of sugars, they are necessary molecules for prebiotic processes. The aim of this work is to evaluate the stability of aldehydes of prebiological importance (formaldehyde, glycolaldehyde, and glyceraldehyde) under a high radiation field, and discuss the possible implications for chemical evolution and the origin of life.

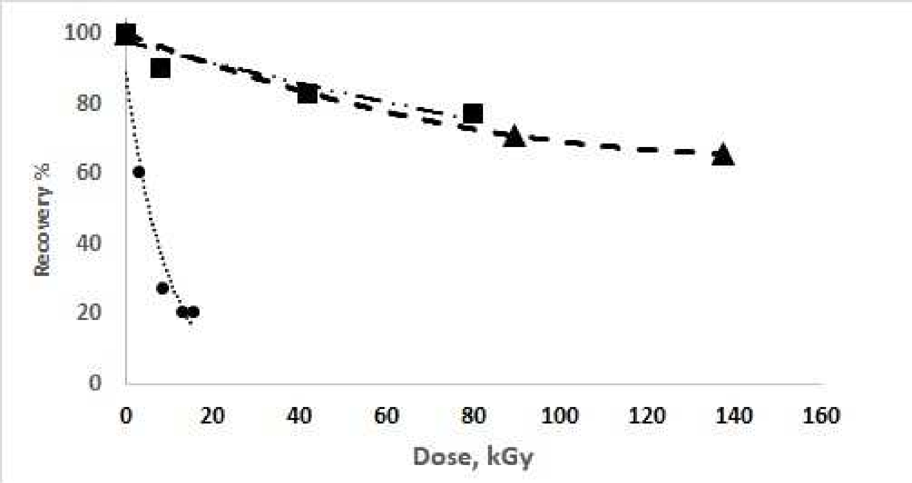

Fig. 1. *Filled circles:* Glyceraldehyde in aqueous solution (0.01 M). *Filled squares:* Formaldehyde in aqueous solution (0.3 M). *Filled triangles:* Glyceraldehyde in solid-state.

2. Experimental

2.1. Preparation and irradiation of the samples

The compounds studied (formaldehyde, glyceraldehyde, and glycolaldehyde) were purchased from Sigma-Aldrich Chem. Co. (USA) and were of the highest quality and purity available. The samples were prepared using triple distilled water and degassed as described by Draganić & Draganić (1971). The radiation source used was a ^{60}Co-source "Gammabeam 651 PT" (located at Instituto de Ciencias Nucleares, UNAM). The irradiation doses (0-150 kGy) were determined accordingly to the aldehyde studied. The samples were irradiated at 77 and 298 K. The low temperature was achieved using a Dewar flask containing liquid nitrogen.

2.2. Analysis of the samples

All samples were analyzed by using several techniques, as described by previous works regarding the stability of aldehydes under high radiation fields (López-Islas et al. 2018; Aguilar-Ovando et al. 2018). In this work, chromatography (GC, HPLC) and ultraviolet spectroscopy were used to detect the radiolytic products and monitor the analytes decomposition.

3. Results

Aldehydes in solution are labile towards radiation. The decomposition can be explained by the reactivity of the carbonyl group, caused by the attack of this functional group by free radicals formed through the radiolysis of water. Samples irradiated in solid-state and low temperatures are more stable than those in solution.

Figure 1 shows the decomposition of the aldehydes studied as a function of the irradiation dose. Glyceraldehyde and glycolaldehyde are very labile under irradiation when they are irradiated in aqueous solution at 298 K. The same samples, irradiated as powder, are considerably more stable. Similar behavior was observed in frozen formaldehyde solutions (77 K). Each one of the studied molecules has different radiolytic products. The main product of formaldehyde is formic acid; malondialdehyde is formed from the irradiation of glyceraldehyde. All the aldehydes studied formed sugar-like compounds as additional radiolytic products.

4. Concluding remarks

The preliminary results presented here have reinforced the possible role of ionizing radiation as a driving force in prebiotic processes. In the primitive Earth, ionizing radiation might have been essential for the reactions in the period of chemical evolution in which simple molecules led to more complex ones. Sugars are biocompounds of paramount importance in biological systems. For this reason, it is relevant to find the possible physicochemical and geological conditions of their possible abiotic synthesis and the mechanisms of their polymerization in chemical evolution studies. The results obtained in this study indicate that small aldehydes (formaldehyde, glycolaldehyde, and glyceraldehyde), in aqueous solution or solid-state, under the presence of a high energy source, readily decompose into sugar-like compounds. These molecules may have been a source of the building blocks of the first sugars in the primitive Earth.

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References

Aguilar-Ovando, E., et al. 2018, JRNC, 316, 971

Draganić, I. G. & Draganić, Z. D. 1971, The Radiation Chemistry of Water (Academic Press, New York)

Draganić, I. G., Draganić, Z. D. & Adloff, J. P. 1990, Radiation and Radiactivity on Earth and Beyond, (CRC Press, Boca Raton, FL)

Hollis, J. M., Lovas, F. J., & Jewell, P. R. 2000, ApJ, 540, L107

Jørgensen, J. K., Favre, C., Bisschop, S. E., et al. 2012, ApJ, 757, L4

López-Islas, A., et al. 2018, IJA, 1

Mosqueira, F. G., et al. 1996, OLEB, 26, 75