FORMATION OF PYRUVIC ACID AND 1,2-ETHENEDIOL IN INTERSTELLAR ANALOG ICES

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More than 200 molecules have so far been detected in the interstellar medium (ISM), of which close to one third are complex organic molecules containing six or more atoms. Over the last decades, laboratory experiments simulating the conditions in cold molecular clouds have demonstrated that these COMs can form from interaction of ionizing radiation with simple ices deposited on interstellar dust particles. These experiments have unveiled multiple pathways towards the formation of acetaldehyde (CH_3CHO) in such ices, explaining its detection in many interstellar and circumstellar environments including tentative detections in interstellar ices. By condensing acetaldehyde and carbon monoxide at 5 K and irradiating the ice with 5 keV electrons, we simulate secondary electrons generated in the track of galactic cosmic rays interacting with ices around cosmic dust particles. Combined infrared and photoionization reflectron time-of-flight mass spectrometry studies were employed to unambiguously identify pyruvic acid ($CH_3COCOOH$) and its enol, 2-hydroxyacrylic acid ($CH_2(COH)COOH$), as reaction product from the irradiation by a barrierless radical-radical reaction of the acetyl (CH_3CO) and hydroxycarbonyl (HOCO) radicals. These results present an abiotic pathway towards the formation of this prebiotic molecule in the interstellar medium. Pyruvic acid constitutes a key starting material for the Krebs cycle, which supplies living organisms with energy. Furthermore, it is a precursor for more complex biomolecules such as lactic acid or alanine.

In a second experiment, condensing pure methanol and mixed methanol and carbon monoxide ices, 1,2-ethenediol (HOCH=CHOH) was detected after irradiation with 5 keV electrons at 5 K. Three distinct pathways to its formation could be inferred from isotopic substitutions. 1,2-ethenediol, the enol of glycolaldehyde, is the reactive key intermediate in the formose cycle to form complex sugars from formaldehyde but has hitherto not been isolated. The detection of 1,2-ethendiol in such simple ices therefore suggests a facile reaction network to enable complex sugar formation.