Radiolysis of CO₂ in
Cosmic Ice Simulations

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Abstract

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Radiolysis of iced CO$_2$ in water has been observed for information in the evolution of compounds in our solar system. The radiolysis was done by bombarding thin layers of ice with an electron beam at different energies and currents. This irradiation of ice was performed using a vacuumed chamber used to simulate the conditions our solar system. The conditions achieved in this chamber were a vacuum of about $10^{-8}$ mbar, ices of about 77 Kelvin, and electron irradiation.

The electron radiation device is newly installed replacing a 100 eV electron gun and had to be tested and calibrated to the right energies and currents in order to obtain desired results and good irradiated ices. Recent results show that with energy of 1,000 eV and 4 Amps of current is strong enough to blow the ices off the substrate. Future experiments will be at lower energies and currents so that the ices will not evaporate but will be strong enough to undergo radiolysis.
Introduction

In the quest for understanding the origins of life on Earth, the scientific community has been deeply interested in discovering the types of molecules present outside our atmosphere as well as those in the early Earth’s atmosphere. This interest arises from the fundamental question: “Did the building blocks of life formed on Earth or were they escorted from deep outer space by a traveling cosmic body?” Answering this question would be one step further to knowing whether we are alone in the universe or if life can be found elsewhere in our galaxy. There have been many attempts to experimentally answer this question in the past such as the Urey-Miller experiment in the 1950’s. This experiment proved that it is possible to create new organic molecules by mixing water with methane, ammonia, and hydrogen and applying electrical charges to represent lightning and assuming these were the early atmospheric conditions. Now, scientists believe the atmospheric conditions were not as chemically active as Urey and Miller believed. The early atmosphere contained molecules of carbon dioxide and nitrogen and did not support the formation of prebiotic molecules. On the other hand, observations of the interstellar medium show the presence of significant amounts of organic molecules. Amino acids are believed to be present as well but they are not yet found due to instrumentation difficulties (Mason, Dawes and Holtom). Well designed experiments are important to investigate whether the chemical origins of life were created on Earth or in space to open our understanding of how life started and where we came from.

This research report will focus on cosmic ice electron irradiation. Many cosmic bodies in our solar system contain ice water as well as CO₂ that are exposed to several types of radiation (Hudson). The investigation in this project is carried out by freezing water and CO₂ at very low temperatures and to irradiate that ice with an electron beam in a vacuum to simulate the
conditions that cosmic ice is experiencing. There are publications of projects that have been
carried out with the same chemical mixture but irradiated with proton or photon beams instead.
Some of these publications are listed in the reference page.

**Description of the Instrument**

The main part of the apparatus is a three dimensional cross-shaped sealed chamber made
of 4 inch stainless steel pipe. The top part of the apparatus has a one-liter cryogenic reservoir
with a copper rod attached to its bottom. This copper rod extends to the center of the cross-
shaped chamber and has a 1 centimeter aluminum cube bolted to its tip. One of the faces of the
cube has a highly polished surface which is used to place thin layers of ice. Highly polished
surfaces generate excellent reflected images, which is precisely what is required from this
surface to be able to see the chemical composition of the layers of ice using of an infrared
spectrometer. The spectrometer is located on the back side of the cross-shaped chamber. This
end of the chamber is sealed with a metal flange that has two clear round kBr windows of about
1 inch in diameter for the IR spectrometer’s beam to travel in through one glass window and get
reflected out by the substrate through the other window. The figure below describes the IR beam
trajectory with red lines.
Figure 1. IR beam.

A fine valve is used to let the mixture of CO₂ and water pass through a thin rod whose end is pointed towards the aluminum substrate. This valve is located on the left side of the chamber and has a small, clear, round glass reservoir connected to it. The right side of the chamber has an electron gun that is capable of radiating at energies of 1,000 eV to 50,000 eV and currents from 10⁻⁹ amps (nA) to 10⁻³ amps (mA). The electron gun is connected to a power supply that has digital metering and controls for the energy, focus, anode, and emission current.

The bottom part of the chamber has a turbomolecular vacuum pump and a gate valve to open and close the vacuum. This turbomolecular pump has a high speed turbine that forces out the gas molecules that are inside the chamber.

Experimental Procedure
Carrying out this experiment is, to some extent, time consuming for the reason that every step goes at a slow rate. The first step when starting this experiment is to open the gate that is located between the chamber and the turbomolecular pump. When the chamber’s pressure is in equilibrium with the room pressure, the power switch of the vacuum pump can be switched on. The electronics takes a couple of minutes to start up. The turbo pump is turned on starts spinning and creates a vacuum. It takes about five minutes for the pressure inside the chamber to reach $10^{-7}$ mbar.

The next step is to start adding the cryogenic fluid to the reservoir located at the very top part of the chamber. Liquid nitrogen is the only cryogenic fluid used for this experiment so far. This cooling process is very time consuming at the beginning because the reservoir and the entire chamber device is at room temperature. As soon the cryogenic fluid is added through the small opening of the reservoir, boiling and evaporation starts to take place inside the reservoir. Since this opening is small (about 1 inch in diameter), the evaporated nitrogen build up inside the reservoir causing it to eject with pressure through the opening. As a result, the adding of cryogenic fluid is interrupted due to the pressurized gas being ejected. This process is repeated until the substructure of the reservoir reaches a temperature that will not dramatically boil the liquid nitrogen.

After the cryogenic fluid settles on the reservoir, its work is to cool down the copper rod that is in contact with the aluminum substrate. This process takes about 15-20 minutes until the substrate reaches a temperature of $-180 \, ^\circ\text{C}$ or about 93 K. Once the substrate is at this temperature, an infrared spectrum is taken as a background. This IR spectrum does not produce any graph but serves as a background that the software uses to compare to the samples with an actual ice present. When the background is set, the substrate has to be rotated to face the left side
of the chamber where the fine valve and the thin rod is pointing. The gate valve is closed to keep
the vacuum pump from sucking the vapor. Once the valve is open and the gate valve closed, the
vapors of the CO₂ plus water mixture are condensed on to the substrate at about 93 K. The
process of opening the valve and waiting for the vapor to condense is repeated several times. The
time intervals of ice deposition will create nice layers of ice. As each ice layer is deposited, an IR
spectrum has to be taken for that layer of ice to monitor how much the ice is being deposited.
The layers have to be deposited until the absorption is about 50%. On the other hand, if the valve
is left open for a long period of time, only one layer of ice will be formed and the structure of the
ice will not be uniform but clumpy. A good representation of how an ice should look before
irradiating is in the figure below which shows four layers of ice.

Figure 2. Example of an ice ready for irradiation.
With the layers of ice uniformly distributed on the substrate, the substrate is rotated to face the electron gun so that the ice gets irradiated for a period of time that depends on the energy and current settings.

Results

No results were obtained from the firsts trials of this experiment due to the new uncalibrated electron gun. At first, the energy and current were very high and the thin ices evaporated almost completely. Therefore, the current was lowered and tested on a new ice for a period of 10 minutes. No significant changes on the composition were detected. The ice continued to be irradiated on increased time intervals of 30 minutes and 1 hour with the same amount of electron current. Very small changes in the composition of the ice were detected. The figure below shows the most recent results between 3500 and 2500 wavenumbers.

![Graph showing transmittance vs wavenumber](image)

**Figure 3. Recent results showing small peaks near 3000 cm\(^{-1}\)**
The IR spectrum shows a very small developing peak at about 3050 wavenumbers. Although this peak looks insignificant, it is evidence of the presence of a new chemical composition formed from the mixture of water and CO$_2$. This new peak probably corresponds to the presence of formic acid or formaldehyde. This determination is a result from comparing previous experiments with the same ice sample but with a different electron beam source. The figure below shows the spectrum from previous experiments.

Future Work

Since this project is able to irradiate with electrons only, future work involves the addition of a different source of radiation. A good source to add would be UV and proton beams because they are more common in our solar system. Another component to add in the future would be another vacuum pump to achieve and maintain better vacuums. Further work will focus on the formation of ices. They must be very uniform and with very specific concentrations of the various components.
Works Cited


