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Trapping and release of noble gases from amorphous H_2O ice

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Abstract

For the first time in comets, noble gases – Ar, Kr, Xe and their isotopes – were detected in the coma of comet 67P/Churyumov-Gerasimenko by ROSINA (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis) and by other instruments onboard the Rosetta spacecraft. Here we present results of laboratory experiments, where Kr and Xe are trapped in amorphous H_2O ice and released upon heating of the ice. The isotopic ratios in the escaping gas are consistent with the fractionation observed in the in-situ measurements, where an enrichment of the light isotopes and depletion of the heavy ones is detected.

1. Introduction

The Rosetta spacecraft detected noble gases, Ar, Kr and Xe, and their isotopes by ROSINA (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis) and by other instruments (Rubin et al. 2018, Marty et al. 2017). Since in view of their low sublimation temperatures, it is unlikely that these gases survive in the comet nucleus as ices, we assume that they were trapped in amorphous water ice when the nucleus was formed. Here we present a set of experiments, meant to measure – for the first time – the trapping efficiency of all the isotopes of Kr and Xe in amorphous ice and the rate of release as a function of temperature. The experimental results are then compared to the measurements of the ROSINA mass spectrometer.

2. Experiments

The ice sample is formed by deposition of a gas mixture – with noble gas ratios to water vapor of H2O:Ar:Kr:Xe=20:20:8:4 – on a cold (50-60K) plate, in a chamber where the pressure is 10^{-6} torr. When the deposition is completed, the sample is heated at a rate of 1 K min^{-1}, and the gas released as well as the water molecules are measured by a quadrupole mass filter. For data reduction, we use a MATLAB program designed for separating the different isotopes and for calculating their fluxes as a function of temperature and time.

3. Results

During the heating phase, first the frozen gases (Xe) were released by sublimation and at the same time the trapped gases and their isotopes were released together with the annealing of the ice (110-120 K). Upon further heating, gases were released during the transformation to cubic ice (140 K), to hexagonal ice (160 K) and together with water sublimation (190 K), as shown in Fig.1.

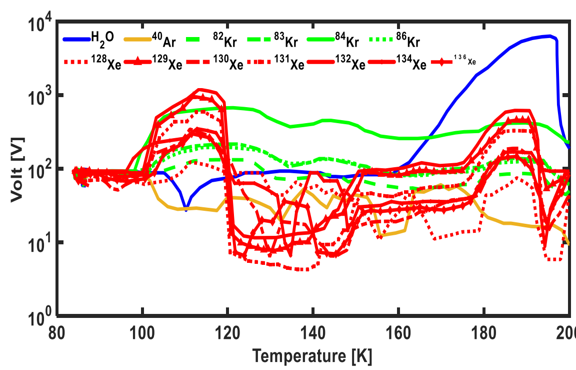

Figure 1: The release of Ar, Kr and Xe isotopes from the water ice as a function of temperature. The output flux is in Volts.

In Table 1 we compare the enrichment factors (final to initial isotopic ratios) obtained in our experiments in two temperature ranges with the ratios measured by ROSINA divided by the solar wind ratios for three different observations, 67P-1, 67P-2 and 67P-3

(Rubin et al. 2018, Marty et al. 2017, Meshik et al. 2014).

Table 1: The Kr and Xe enrichment factors of isotopic ratios, calculated for the comet in-situ measurements with respect to the solar wind ratio, and the experimental results with respect to the initial gas mixture, for Kr at 120 K and 190 K, and for Xe at 113 K and 190 K.

Isotope ratio	67P - 1/SW	67P - 2/SW	67P - 3/SW	Enrichment 120 K, 113 K/ Gas mixture	Enrichment 190 K/ Gas mixture
$^{82}Kr/^{84}Kr$	1.00	1.00	0.96	1.00	1.05
$^{83}Kr/^{84}Kr$	0.92	0.93	0.91	1.00	1.03
$^{86}Kr/^{84}Kr$	0.95	0.97	0.95	0.93	0.97
$^{128}Xe/^{132}Xe$	0.95	0.90	0.80	0.20	0.24
$^{129}Xe/^{132}Xe$	1.40	1.34	1.36	1.14	1.06
$^{130}Xe/^{132}Xe$	1.21	1.12	1.24	1.40	1.50
$^{131}Xe/^{132}Xe$	1.08	1.05	1.21	1.15	1.10
$^{134}Xe/^{132}Xe$	0.57	0.64	0.67	0.79	0.74
$^{136}Xe/^{132}Xe$	0.38	0.39	0.45	0.75	0.74

4. Summary and Conclusions

ROSINA and the other instruments on the Rosetta spacecraft successfully measured isotopes of Kr and Xe for the first time in comets. In our experimental results, for both Kr and Xe, there is a distinct isotopic mass-fractionation. Our results show the same fractionation trend as the observed one: depletion of heavy isotopes and enrichment of lighter ones, as compared to initial isotopic ratios. This can be explained by release of trapped gases in amorphous ice: the lighter isotopes escape more freely than the heavier ones.

Acknowledgements

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