ISOTOPIC COMPOSITION OF H, HE AND NE IN THE PROTOSOLAR CLOUD

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Abstract. Observations and measurements in the solar wind, the Jovian atmosphere and the gases trapped in lunar surface material provide the main evidence from which the isotopic composition of H, He and Ne in the Protosolar Cloud (PSC) is derived. These measurements and observations are reviewed and the corrections are discussed that are needed for obtaining from them the PSC isotopic ratios. The D/H, $^{3}\text{He}/^{4}\text{He}$ (D$^{+3}\text{He}$)/H, $^{20}\text{Ne}/^{22}\text{Ne}$ and $^{21}\text{Ne}/^{22}\text{Ne}$ ratios adopted for the PSC are presented. Protosolar abundances provide the basis for the interpretation of isotopic ratios measured in the various solar system objects. In this article we discuss constraints derived from the PSC abundances on solar mixing, the origin of atmospheric neon, and the nature of the “SEP” component of neon trapped at the lunar surface. We also discuss constraints on the galactic evolution provided by the isotopic abundances of H and He in the PSC.

1. Introduction

Isotopic abundance measurements are invaluable for tracing the origin and evolution of matter in the universe, the galaxy, and the solar system as a whole as well as the sun, planets, asteroids, moons and comets. In this paper we present the best estimates presently available of the isotopic abundances of H, He and Ne in the Protosolar Cloud (PSC) out of which the bodies in the solar system formed. In order to achieve this, the isotopic ratios observed in these bodies of the solar system have to be corrected for chemical or physical isotope fractionation and for possible alterations by nuclear reactions.

Generally, isotope fractionation by physical or chemical processes are most severe in the case of strong element depletion. From this it follows that measurements of the composition in the Outer Convective Zone (OCZ) of the Sun and in the atmosphere of Jupiter gives us the best evidence for deriving elemental and isotopic abundances of H, He and Ne in the PSC.

TABLE I

\[ \frac{^{3}\text{He}}{^{4}\text{He}} \] in the “Planetary Component” of Meteorites and in Jupiter.

<table>
<thead>
<tr>
<th></th>
<th>[ \frac{^{3}\text{He}}{^{4}\text{He}} (10^{-4}) ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planetary Component in Meteorites(^1,^2)</td>
<td>(\approx 1.5 \pm 0.2)</td>
</tr>
<tr>
<td>Q-Phase of the Carbonaceous Chondrite Isna(^3)</td>
<td>1.23 ± 0.02</td>
</tr>
<tr>
<td>Jupiter(^4)</td>
<td>1.66 ± 0.06</td>
</tr>
<tr>
<td>Protosolar Cloud(^5)</td>
<td>\textbf{1.66 ± 0.06}</td>
</tr>
</tbody>
</table>

\(^1\) Eberhardt (1974); \(^2\) Frick and Moniot (1977); \(^3\) Busemann et al. (2000, 2001); \(^4\) Mahaffy et al. (1998); \(^5\) see text.

2. Protosolar \(^{3}\text{He}/^{4}\text{He}\)

For several decades the \(^{3}\text{He}/^{4}\text{He}\) ratio measured in the “Planetary Component” of meteorites served as a proxy for the isotopic abundance of helium in the PSC (e.g., Eberhardt, 1974; Frick and Moniot, 1977), see Table I. More recently, it was realized that this Planetary Component is a mixture of components with somewhat different compositions. We have included in Table I the \(^{3}\text{He}/^{4}\text{He}\) ratio measured in the “Q-phase” of the carbonaceous chondrite Isna (e.g., Busemann et al., 2000). This meteorite has a very short cosmic ray exposure age and, therefore, the data can be relatively well corrected for cosmic ray-produced \(^3\text{He}\).

The situation changed when the \(^{3}\text{He}/^{4}\text{He}\) ratio in the atmosphere of Jupiter was measured by the Galileo Probe Mass Spectrometer (GPMS), see Niemann et al. (1996). The ratio of \((1.66 \pm 0.06) \times 10^{-4}\) obtained by Mahaffy et al. (1998) given in Table I is presently the best approximation to the protosolar value.

In the Jovian atmosphere helium is depleted by \(\approx 18\%\) relative to the protosolar cloud (von Zahn et al., 1998). The degree of helium depletion in the OCZ of the Sun is similar, but the processes that led to the helium depletion in the Solar and Jovian atmospheres are quite different, diffusive separation in the case of the Sun, and — probably — descent of helium-rich droplets in the case of Jupiter (Stevenson and Salpeter, 1976; von Zahn et al., 1998). The Jovian process should be less efficient in fractionating isotopes than the solar process, and, therefore, \(^{3}\text{He}/^{4}\text{He}\) fractionation in the Jovian atmosphere ought to be less than the 2\% fractionation that has occurred in the OCZ of the Sun (Gautier and Morel, 1997; Vauclair, 1998). Thus, we adopt the Jovian \(^{3}\text{He}/^{4}\text{He}\) ratio obtained by Mahaffy et al. (1998) as the protosolar value without correction.

The \(^{3}\text{He}/^{4}\text{He}\) ratios in the Planetary Component of meteorites are typically lower by 10 to 20\% than the Jovian ratio (cf. Table I). This is not surprising, because in many trapping and loss processes, the lighter isotope is depleted relative to the heavier one. For instance, the diffusion constants \(D_1\) and \(D_2\) of two