PHOTOCHEMICAL FRACTIONATION OF $^{16}$O IN THE SPACE MEDIUM MODELED BY RESONANCE EXCITATION OF CO BY H-LYMAN $\alpha$

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Abstract. Inferences about the formation of primordial matter in our solar system rest on analysis of the earliest preserved materials in meteorites, of the structure of the solar system today, and of matter in evolving stellar systems elsewhere.

The isotope distribution in meteorites suggests that molecular excitation processes similar to those observed today in circumstellar regions and dark interstellar clouds were operating in the early solar nebula. Laboratory model experiments together with these observations give evidence on the thermal state of the source medium from which refractory meteoritic dust formed. They indicate that resonance excitation of the broad isotopic bands of molecules such as $^{12}$C$^{16}$O, MgO, O$_2$, AlO, and OH by strong UV line sources such as H-Lz, MgII, H$\beta$, and CaII may induce selective reactions resulting in the anomalous isotopic composition of oxygen and possibly other elements in refractory oxide condensates in meteorites.

1. Nature of the Space Medium and Origin of the Solar System

The space medium, wherever it has been studied experimentally in detail, is found to have a highly complex filamentary structure with large changes over short distances in number density, chemical composition, and thermal and electromagnetic parameters. This inhomogeneity is due to the pervasive magnetic fields and electric currents characteristic of matter in motion (see, e.g., Alfvén, 1981). The resulting excitation typically leads to large differences between rotational, vibrational, translational, neutral, ion, and electron temperatures. High internal molecular temperatures coupled with low kinetic temperatures give rise to extensive isotopic effects maintained in steady-state chemical reaction cycles or by isotopically selective resonance excitation.

There is no reason to believe that the situation was qualitatively different in the past, and particularly not during the formation of our solar system. If we wish to reconstruct those formative conditions it would thus seem necessary to rely on the processes known to control the circumstellar medium today, and to identify preserved features in the present day solar system which bear witness of the primordial conditions. An attempt to bring available information together in this way has been made by Alfvén and Arrhenius (1976). One of the few potential sources of information on the chemical state of the medium from which solids formed and on the properties of primordial condensates is provided by meteorites, particularly of the carbonaceous type which show the least effect of subsequent alteration.

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2. State of Excitation of the Source Medium

Some of the most productive clues to the state of excitation of the medium from which the solids formed in the early history of the solar system come from chemical isotope effects that can be determined with great precision on meteorite materials. Corresponding present day fractionation effects are observed at even larger scale by microwave spectrometry in dark interstellar clouds (see, e.g., Winnewisser et al., 1979).

The proposed relationship between the effects seen in the space medium and those observed in meteorites is most applicable to the widely varying isotopic composition of hydrogen, carbon, nitrogen, oxygen, and magnesium and possibly some of the effects observed in occluded noble gases, and in odd isotopes of heavy elements such as barium in carbonaceous meteorites. Polyisotopic elements such as oxygen, magnesium, and sulfur are of particular interest in this respect since single isotope enhancement as observed in the laboratory (e.g., Liuti et al., 1966, 1969; Vikis, 1977, 1978; Turro and Kraeutler, 1978) and predicted to be effective in the space medium (Haberkorn et al., 1977; Arrhenius et al., 1979b) can generally be verified only if at least two other isotopes exist as reference points. Such enhancement of single isotopes or isotope pairs has been shown or predicted to be caused by various mechanisms of selective excitation and/or transition into reaction complexes or predissociating states (see review in Arrhenius et al., 1979b). Selective resonance excitation by spectral line sources has been observed astronomically for several molecular isotopic species in the space medium (Gahm et al., 1977). Chemical effects of this kind, if found to be the likely cause also of was independent isotopic anomalies in meteorites, would give useful indications about the physical state of the source medium from which primordial solids formed in our solar system.

An alternative explanation of effects found in meteorites is that not only small anomalies in heavy elements, but also large effects in, e.g., $^2$H, $^{16}$O, $^{15}$N, and $^{26}$Mg, could be of nucleosynthetic rather than chemical origin. Observational proof one way or another is generally not possible as far as meteorites are concerned, since the effects recorded in them are caused by events in the past, and since confirming nucleosynthetic experiments can be in most cases not be carried out. In contrast, observations of currently active processes in the interstellar cloud medium provide direct evidence of large-scale chemical isotope fractionation in carbon, hydrogen, and nitrogen, and with more refined techniques the potential exists for discerning the details of selective fractionation of individual isotopes of oxygen and magnesium (Winnewisser et al., 1979). Selective enhancement of $^{16}$O relative to $^{17}$, $^{18}$O in CO has been observed in some regions of the interstellar medium and is considered as a puzzling feature if interpreted in terms of nucleosynthetic origin (Penzias, 1980).

3. Theoretical Investigations

Selective isotope effects can arise at molecular excitation (e.g., Liuti et al., 1966), predissociation (Murrell and Taylor, 1969; Schaefer and Miller, 1971; Arrhenius et al., 1979a, b) or vibrational relaxation (Basov et al., 1974; Arrhenius, 1976).