CONTINUAL MATTER ACCRETION INTO
THE SOLAR SYSTEM*

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Abstract. Rapid accretion of matter takes place while the solar system resides in a dark cloud of high density. The mass thus accreted may be comparable to the mass of the planetary system. Since the elemental abundances in a dark cloud are considered to be heterogeneous due to matter processed inside stars and then ejected, the continual accretion causes elemental heterogeneities in the solar system.

1. Introduction

Recent studies of the isotopic composition of meteoritic matter, for example, of the isotopic composition of oxygen (Clayton et al., 1976), have suggested elemental heterogeneities of the primordial matter of which the solar system was composed. Heterogeneous isotopic abundances are rather difficult to understand, if the solar system has been practically isolated since the formation of the solar nebula. If, however, the solar system continually accreted interstellar matter of different elemental abundances, heterogeneities result from an admixture of accreted matter of different origins.

Matter accretion is expected to be conspicuous when the solar system moves in dark clouds which have high gas densities. The solar system was probably born in a dark cloud (Alfvén and Arrhenius, 1976) and spent its youth inside the cloud. The probability of collision with other dark clouds is not negligible over the history of the solar system. Two different masses of matter accreted with an interval longer than the growth time of dust grains may form solid components of different elemental abundances.

The present paper demonstrates that the amount of matter accreted is a significant fraction of the mass of the planetary system, and discusses possible origins of nuclides of anomalous abundances.

2. Accretion in Dark Clouds

If the Sun of mass $M_\odot$ moves with velocity $v$, the accretion radius is given, neglecting a factor of about unity, by

$$r_a = \frac{2GM_\odot}{v^2},$$

(1)

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where $G$ is the gravitational constant. The velocity $v$ is of the order of the virial velocity

$$v = (GM/R)^{1/2} = (4\pi GqR^2/3)^{1/2}$$

(2)

for the spherical cloud of radius $R$ and mass $M$. The last expression results if the total mass of gas of average density $q$ is much greater than the total mass of stars. This is found to be the case for the nearest dark cloud $\rho$ Oph (Vrba et al., 1975). The rate of accretion is obtained as

$$\dot{M}_a = \pi r_a^2 q v = (12\pi Gq)^{1/2} M_\odot^2/M \simeq 6.5 n_a^{1/2} M_\odot^2/M \text{ My}^{-1},$$

(3)

where $n_a$ is the density of hydrogen atoms in $10^4$ cm$^{-3}$.

Since the mass and the lifetime of dark clouds are of the orders of $10^4$ $M_\odot$ and 10 My, respectively, the mass accreted during the initial 10 My of the solar system is as large as $10^{-3}$ to $10^{-2}$ $M_\odot$, comparable to the total mass of the planetary system. The accretion rate is not constant but fluctuates according to density fluctuations. High density regions are characterized by strong far infrared emission (Fazio et al., 1976) and molecular lines (Encrenaz, 1974). The 2.6 mm emission of CO indicates a higher $^{13}$C/$^{12}$C ratio (Burton et al., 1975), thus suggesting heterogeneous elemental abundances inside a dark cloud. Hence the matter accreted from different dense regions may have different abundances. If they are accreted at a time interval longer than the growth time of dust grains, solid materials of different abundances are formed in the solar system. Since the growth time of dust grains is estimated to be as long as 1 My (Kusaka et al., 1970), several kinds of solid materials of different abundances can be formed as primordial matter in the solar system.

3. Encounter with Dark Clouds

After disintegration of the dark cloud in which the solar system was born, there is an appreciable probability that the solar system encountered other dark clouds. If dark clouds of density $n_c$ and an average cross-section $S$ move with an average velocity $v$ relative to the solar system, the rate of encounter is given by

$$P_c = n_c S v = 10^{-9} n_c S r (1 \text{ kpc}/r)(v/10 \text{ km s}^{-1}) \text{ y}^{-1},$$

(4)

where $n_c S r$ is the fraction of sky area covered by dark clouds, which is (Allen, 1973)

$$n_c S r \simeq 0.2 \quad \text{for} \quad b \leq 10^\circ.$$

(5)

The value of $n_c S r$ for $b \leq 10^\circ$ is adopted on account of the fact that the solar system does not move far from the galactic plane. The value of $r$ may be a few kpc because $A_v \simeq 0.3$ mag/kpc between clouds, and $v$ is of the order of 10 km s$^{-1}$ because the solar velocity with respect to nearby stars is about 20 km s$^{-1}$. 
