EARLY IRRADIATION OF ASTEROIDAL MATERIAL: AN ABSORBING PROBLEM.
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An "early irradiation" of solar nebular material or the partially accreted solar system has been called upon to account for a variety of phenomena, for example, removal of nebular gas from the inner solar system, production of magnetic fields, a heat source in the early system, presence of solar wind gases in meteorites, certain isotopic anomalies in meteorites, etc. There is no direct evidence that such an irradiation took place. Nevertheless, because of the persistent recurrence of this suggestion we decided to calculate the effect of an early irradiation on nebular material to see under what conditions one could expect to detect the effects of an early irradiation in meteorites.

In our initial calculations we have adopted a very simple model for the absorbing medium, i.e., the nebula. It consists of two absorbing components: solid spherical particles and hydrogen gas. These are distributed uniformly throughout a cylindrical disk of radius 3 A.U. and thickness 0.1 A.U. As a starting point we took the mass of the particles in the cloud to be a specified fraction, f_m, of the mass currently contained in the terrestrial planets. This will result in an upper limit on the ranges of solar particles because undoubtedly, early on, there existed more solid material in the inner solar system than that represented by the terrestrial planets. The mass of absorbing gas in the nebula is specified by f_g, the fraction of the total cloud mass which is gaseous. Absorption cross sections (or range-energy relationships) were taken from standard sources. Calculations were made for protons of various energies, specifically covering solar wind and solar flare energies, up to 10 MeV/nucleon.

Some results are plotted for protons of intermediate energy, 0.5 MeV in Figures 1 and 2. The vertical (z-axis) is the probability that a particle successfully penetrates the cloud to a distance of 3 A.U. We computed a probability because a solar particle will traverse a random thickness of absorbing particles due to the random positions of absorbers. This probability is plotted as a function of cloud particle size and f_m. Both Figs. 1 and 2 correspond to absorbers composed of olivine having the cosmic Fe/Mg ratio.

The figures show the values of f_m and particle size which allow protons to penetrate the cloud. The case plotted in Fig. 1, corresponds to no absorbing gas in the nebula. Penetration to 3 A.U. is improbable when 10^{-4} (or more) of the mass of the terrestrial planets is present in the form of dust. This means implantation of solar flare particles in materials at 3 A.U. in the asteroid belt could take place only under conditions more nearly resembling those in the present solar system than in the solar nebula. Note that present day conditions ($f_g \simeq 10^{-5} - 10^{-6}$) easily allow the 0.5 MeV protons to penetrate to 3 A.U.

When gas is introduced into the cloud (Fig. 2, $f_g = 0.5$) penetration becomes more difficult. For small values of f_m, absorption is not likely

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to occur. For larger f_m, i.e., a higher total mass of absorbing particles, the amount of gas increases since the gas represents a constant fraction of the total cloud mass. For some critical value of f_m, the gas is sufficiently abundant to cause absorption by itself. For all f_m greater than this critical value, penetration cannot occur. Thus, when only 3×10^{-5} (or more) of the mass of the terrestrial planets is left unaccreted as dust, protons cannot irradiate material at 3 A.U. From these considerations it is clear that accretion must be substantially complete before low energy solar particles can penetrate as far as the asteroid belt.

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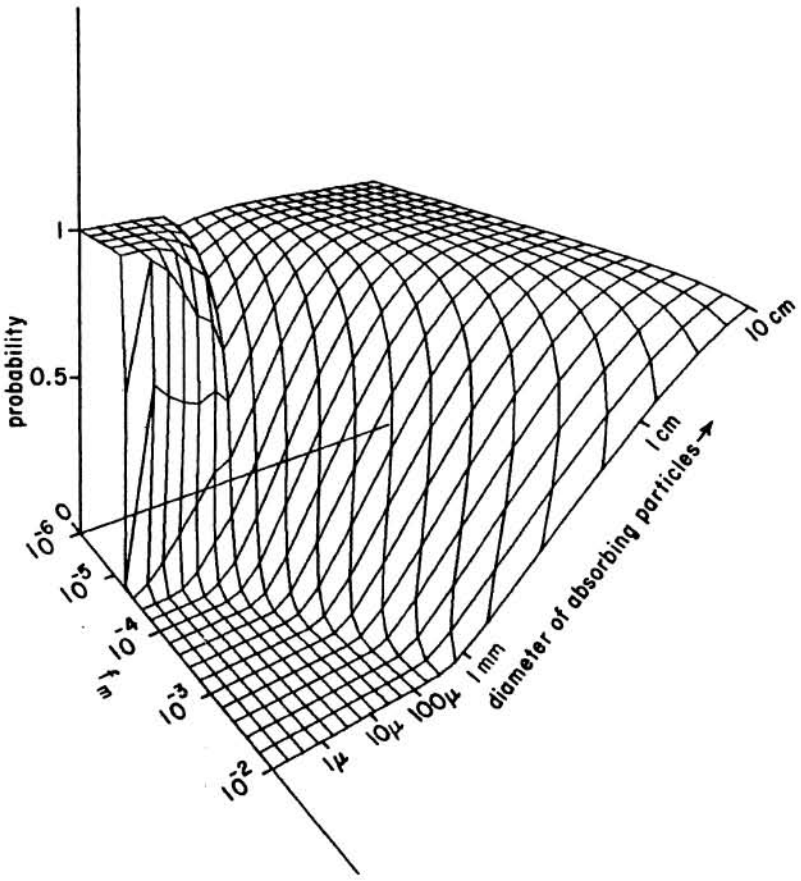

Fig. 1. Probability that a solar 0.5 MeV proton will penetrate a cloud of absorbing particles to a distance of 3 A.U. The probability is plotted as a function of the size of absorbing particles and the total mass of absorbers, expressed as a fraction, f_m, of the total mass of the terrestrial planets. Low energy irradiation of asteroidal material is improbable until accretion is nearly complete ($\lesssim 10^{-4}$ of the mass left unaccreted as dust).

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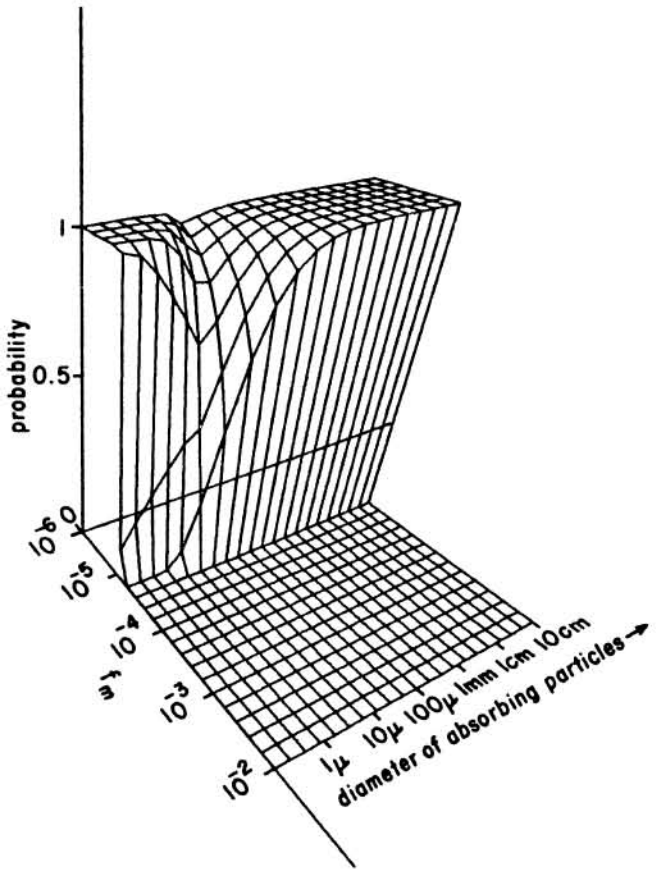

Fig. 2. Probability of penetration when the absorbing particles are accompanied by an equal mass of absorbing gas. The gas acts to reduce the probability of penetration. Irradiation at 3 A.U. becomes impossible (probability = 0) when the gas is sufficiently abundant to cause absorption by itself.

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