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LIMITS TO ENERGETIC-PROTON IRRADIATION OF THE PRIMEVAL NEBULA AS THE ORIGIN OF ISOTOPIC ANOMALIES

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Anomalies in meteorites due to extinct ^{22}Na *and* ^{26}Al *have been interpreted as due to energetic-proton irradiation of the primeval nebula. I discuss quantitative limits that can be placed on this hypothesis. I describe other abundance effects that would have to coexist if this idea were correct and energetic constraints of an astrophysical type. The existing evidence is more easily explained by presolar carriers that are needed in any case for other anomalies.*

For decades it has been assumed that the solar system was once a hot, chemically and isotopically homogeneous gas. The apparent uniformity of isotopic composition gave strength to that belief, but the many recent discoveries of anomalous isotopic compositions have called it into serious question. One way to save the old picture is an intense bombardment by energetic protons of matter condensing into grains or onto the surfaces of larger solids. The combined effects of radiation plus fractionation during condensation can then be supposed to have caused the isotopic variations. This idea was initially developed at length by Fowler, Greenstein and Hoyle (1962) and has recently been revived, most explicitly by Heymann and Dziczkaniec (1976) for the establishment of ^{26}Al and ^{22}Na induced anomalies.

To help evaluate this very important possibility, Clayton, Dwek and Woosley (1976) have calculated with a Hauser-Feshbach type nuclear reaction theory a number of cross sections for reactions that should lead to significant anomalies. We then averaged these cross sections over power-law proton spectra $d\phi/dE = kE^{-\gamma}$ characterized also by a low-energy cutoff E_0. The average reaction cross section per incident proton is called $<\sigma>$, and tables of their values may be found in our paper. As an outcome it seems to me that the radiation picture faces severe difficulties which I will now briefly describe.

The ^{26}Al gas concentration $^{26}Al/^{26}Mg = 4 \times 10^{-5}$ would require at least 2×10^{20} cm^{-2} of MeV protons irradiating a gas phase, and even more if the radiation lasts more than 10^6 years. Al condensation could then follow. But we find that Ne-E faces a different problem. Because of the short ^{22}Na half-life (2.6 y), the grains must already exist while the radiation is actually occurring, for otherwise no excess ^{22}Ne would exist in the solids. Therefore the grains must also be irradiated, a fact necessitating many other isotopic anomalies. The ^{22}Na due to ^{25}Mg (p,α) ^{22}Na in the grains will in fact exceed that deposited from the gas by a factor 10^4, so that the irradiation interpretation of Ne-E rests on relative (p,α) yields of the Ne isotopes. However, it is virtually impossible for these to give the correct isotope ratio unless the protons are restricted to energies lying between roughly 5 and 9 MeV. Lower energy particles give too much ^{23}Na (p,α) ^{20}Ne for the low $(^{20}\mathrm{Ne}/^{22}\mathrm{Ne})_E$, whereas higher energy particles give too much ^{24}Mg(p,α) ^{21}Na for the very low $(^{21}\mathrm{Ne}/^{22}\mathrm{Ne})_E$. Power-law spectra even as steep as $\gamma = 4$ or 5 greatly overproduce $(^{21}\mathrm{Ne}/^{22}\mathrm{Ne})_E$, so that a nearly monoenergetic spectrum, unlike those known naturally, must be postulated. It does seem likely that ^{22}Na is the parent of Ne-E, on the other hand, because of the strong concentration of Ne-E in the 1000° C temperature fractions (Black 1972). Na bearing minerals that condensed near 1000° C might be expected to release daughter ^{22}Ne near the same temperature range. This important point was made by Clayton (1975a), who argued that rapid grain condensation in nova and supernova expansions, where ^{22}Na should be abundant, provides a compelling origin for Ne-E if these interstellar grains can then survive the meteoritic accumulation. The trapping of ^{22}Ne by ^{22}Na deposition on the surface of a grain seems to require that the grain growth occur on a time scale of years, and an explosively expanding star does provide such a time scale. In the same paper Clayton (1975a) pointed out that ^{26}Mg excesses due to ^{26}Al should be interpreted in the same way. The ^{26}Al simply does not live long enough after ejection from stars to be extant during the period of meteorite accumulation.

The irradiation of small grains with steep low-energy spectra would also result in overabundances of (1) ^{36}Ar due to ^{39}K (p,α) ^{36}Ar by a factor of 10^4, (2) ^{80}Kr due to ^{80}Se (p,n) by a factor 10^4, (3) ^{126}Xe due to ^{126}Te (p,n) by a factor 10^3. Correlated anomalies in these nuclei would in fact make the best evidence for a solar irradiation. Their absence requires that the grains must lose all but about one part in 10^4 of those noble gases produced within their interiors. The unlikelihood of such an extreme requirement suggests that Ne-E is not due to irradiation, even if ^{26}Al is due to irradiation of gaseous matter only. Differences between irradiated and shielded material should also be evident in the rare odd-odd nuclei, ^{50}V, ^{92}Nb, ^{138}La and ^{180}Ta, and in the isotopes of Li and B. More attention to these ratios in primitive material will be helpful. Primitive samples should not only be dissimilar, but different from terrestrial samples, because irradiation of a gas containing an earth mass of condensible solids is not energetically feasible. About $0.2\ L_{\odot}$ in fast protons for 10^6 years would be required. Only $10^{-2}\ M_E$ can be penetrated by 10 MeV protons if that matter is spread out into a solar disk 1 AU in width, however, so the irradiated material is probably $\ll M_E$. Cometary dust should also be different in this regard, suggesting interesting tests if such dust could be accumulated for study.

The proposed early irradiation is in any case incapable of the very large anomalies in ^{16}O (Clayton *et al*. 1973) and in ^{202}Hg (Jovanovic and Reed 1976). Presolar grains are therefore needed for those, for Ne-E, and perhaps for so-called CCF Xe and special ^{129}Xe (Clayton 1975b) and trapped ^{129}Xe (Drozd and Podosek 1976). The negative evidence given above for early irradiation therefore suggests that it is more reasonable to assume that presolar grains are the exclusive source of isotopic anomalies.

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