NOTIZEN

Extinct Radioactivity and the Prehistory of the Solar System *

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Murthy's [1] discovery of Ag^{107} from the decay of Pd^{107} in the Toluca iron meteorite, if confirmed, will throw an entirely new light on the subject of extinct radioactivity. It is the purpose of this letter to point out some of the implications of his discovery.

For an object containing the decay product Y^A of an extinct radioactivity X^A, a "decay" or "formation" interval, Δt, can be calculated. The beginning of this interval may be defined in two ways: either as the last nuclear event that contributed matter to the solar system ("sudden synthesis") or, as the time at which the solar system became isolated from the interstellar medium, containing steady-state proportions of extinct radioactivities ("continuous synthesis" [2, 3]).

The end of the interval measures the last chemical fractionation between elements X and Y; for nonvolatile decay products, (e. g. $Pb^{205}-Tl^{205}$ and $Pd^{107}-Ag^{107}$), this corresponds to the end of the last melting process, and for volatile ones, (e. g. I^{129}–Xe^{129} and Pu^{244}–Xe^{136}) to the cooling of the object to low enough temperatures to allow the retention and accumulation of the volatile decay product.

The currently most popular view is that the elements are continuously synthesized in stars. If the simplifying assumption is made [4] that the synthesis took place at a constant rate over at time T, then the abundance ratio of the decay product Y^A to X^{A+n}, a stable isotope of X^A, is given by

$$\frac{Y^A}{X^{A+n}} = \frac{K_A\,\tau}{K_{A+n}\,T}\,e^{-\Delta t/\tau} \qquad (1)$$

where τ is the mean life of X^A, T is the duration of nucleosynthesis, and K_A/K_{A+n} is the production ratio of isotopes X^A and X^{A+n} (equal to their ratio at the end of "sudden synthesis"). This equation can easily be adapted to branching decay, or to the case where the decay product is not isobaric with X^A.

It is instructive to review all the available information on extinct radionuclides. In Fig. 1, the straight line at $\Delta t=0$ gives the expected steady-state abundances of extinct radionuclides, relative to their "sudden synthesis" abundances in the Galaxy at the time of isolation of the solar system. This particular line has been drawn for $T=10^{10}$ years, but it is clear that a change in T would only raise or lower this line without changing its slope.

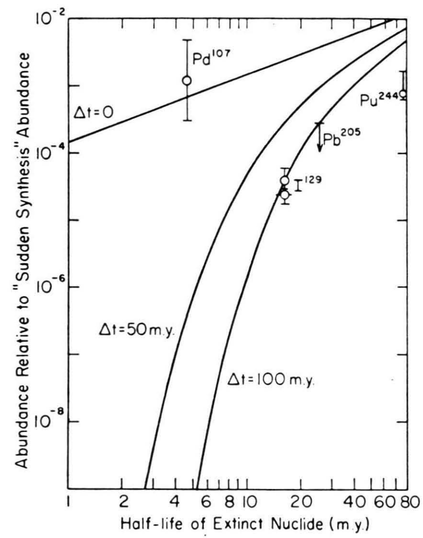

Fig. 1. Predicted and observed abundances of extinct radionuclides at various times (Δt) after the isolation of the solar system. The experimental points are for the following objects: Toluca [1] (Pd^{107}), Richardton and Indarch [6, 7] (I^{129}), Canyon Diablo [8] (Pb^{205}), and Earth [10] (Pu^{244}). The high abundance of Pd^{107} implies either a long cooling time for the meteorite parent bodies, or preferential production of Pd^{107} during the formation of the solar system.

The abundances at some later time should lie on an isochrone. Two such isochrones are shown, for $\Delta t=50$ and 100 m.y. If one now plots the observed data, a remarkable paradox emerges.

The $I^{129}-Xe^{129}$ data for the chondrites Richardton and Indarch [5–7] lie close to the 100 m.y. isochrone. The $Pb^{205}-Tl^{205}$ point for the Canyon Diablo iron [8], $\geq 1\cdot 10^8$ y., is only an upper limit, but it, too, falls on the same isochrone. (A value of $4\cdot 10^7$ y. was erroneously quoted by Murthy.) A point for Pu^{244}, based on

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its spontaneous-fission decay to Xe^{136}, is available for the Earth [9, 10]. This point lies at 290 m.y., definitely below the 100 m.y. isochrone, but since there is no a priori reason why the Earth and the meteorites should be of the same age, it does not follow that a discrepancy exists. Also, it has been suggested [11] that the errors in this case may be larger than indicated on the graph.

The situation is altogether different for Pd^{107}. The best estimate for its half-life is 4.5 m.y. [12] rather than 7.5 m.y. as assumed by MURTHY. Hence an abundance of $\sim 10^{-10}$ would be expected after 100 m.y. Actually, an amount on the order of 10^{-3} has been observed!

Though the absolute amounts of Ag and Pd in the meteorite are somewhat in doubt, these uncertainties cannot account for more than a very small part of the discrepancy. Likewise, no plausible change in the model itself will remove the discrepancy: for a longer T, or a declining rate of nucleosynthesis, the $\Delta t = 0$ isochron will lie parallel to the present one; for the sudden synthesis case, parallel to the abscissa; and for a "mixed" case [13], between these extremes.

One conclusion is certain: the high abundance of Pd^{107} is wholly inconsistent with a Δt of 10^8 years, as inferred from the longer-lived nuclides. If the presence of excess Ag^{107} in meteorites is confirmed by further work, then, in order to explain this discrepancy, one must look for factors that will either lengthen Δt for the long-lived nuclides, or increase the amount of Pd^{107} above the levels predicted by the model.

As pointed out above, the Δt's for I^{129} and Pu^{244} really refer to a later event than the Δt's for Pb^{205} and Pd^{107}: the cooling of the meteorite parent bodies and planetesimals. The cooling times for these bodies can easily exceed 10^8 years [14], and hence the Δt's need not agree with those obtained from Pd^{107} and Pb^{205}. The Δt for the latter is uncertain due to difficulties in estimating the production ratio of Pb^{205} and Pb^{204}, as well as the proportion of M-capture in the decay of Pb^{205}. Hence the Δt's for Pd^{107} and Pb^{205} are not necessarily in conflict with each other.

If these factors alone should prove insufficient to account for the discrepancy, it may be necessary to look for processes that will produce Pd^{107} in preference to the longer-lived extinct nuclides. MURTHY suggested that a near-by supernova might have raised the Pd^{107}/Pd^{105} ratio in the early solar system to 0.1, some 100 times above its steady state value. But in that case all extinct radionuclides should initially have been made in about one-tenth of their sudden synthesis abundances, and in any subsequent decay, the balance would be shifted even more in form of the longer-lived nuclides, contrary to observation. Moreover, the assumption of a ratio of 0.1 is completely arbitrary, and it is doubtful whether the decay intervals thus calculated have any meaning.

Perhaps a more promising possibility is offered by nuclear reactions directly in the solar nebula: either spallation, induced by charged particles [11, 15], or a small amount of neutron capture at low fluxes. Under these conditions, no Pu^{244} and only very little Pb^{205} would be produced, while the yield of I^{129}, though appreciable, would be smaller than that of Pd^{107} in both neutron-capture and spallation reactions.

If such reactions actually took place in the early solar system, at a level sufficient to produce $\sim 10^{-3}$ of the sudden synthesis abundance of Pd^{107}, then several other isotopic anomalies should also be observable. These include not only decay products of other extinct radioactivities (Hf^{182}, Be^{10}, Cs^{135}, Al^{26}), but also the rarer stable isotopes [11], and one may wonder if the "secondary anomalies" of meteoritic xenon [5, 6] are not due to this cause [10].

Fortunately, this problem lends itself to experimental attack, since each nuclear process gives rise to its own distinct abundance pattern. Further data should not only help decide whether short-lived extinct radioactivities were indeed responsible for melting the meteorite parent bodies [16], but should also contribute materially to our understanding of the events that preceded the formation of the solar system.

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Über die Zusammensetzung der terrestrischen Exosphäre

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Bekanntlich läßt sich aus der beobachteten Abnahme der Bahnenergie erdnaher Satelliten die Luftdichte $\varrho(h)$ ableiten gemäß der Gleichung

$$\varrho(h) = -(1+2\,\varepsilon)\; 3\, P(\bar{F}/M) \oint \varrho(h)\, \mathrm{d}s\,, \qquad (1)$$

$\mathrm{d}P/\mathrm{d}n$: Abnahme der Umlaufzeit P pro Umlauf, ε: Bahnexzentrizität, $\bar{F}$: mittlerer Satellitenquerschnitt senkrecht zur Bahntangente, M: Satellitenmasse.

Die Luftdichte der höchsten Atmosphäre zeigt mit der Höhe stark zunehmende Variationen, deren hauptsächliche Ursachen sind [1]:

1. Die solare variable Ultraviolettstrahlung unterhalb von 1000 Å mit der solaren Radiowellenstrahlung im dm-Gebiet als Indikator.

[1] H. K. PAETZOLD u. H. ZSCHÖRNER, Proc. I. Cospar Symposium Nice 1960, 24.