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Author
Norman, E.B.

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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

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E.B. Norman

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INFLUENCES OF ASTRONOMICAL ENVIRONMENTS ON NUCLEAR DECAY RATES

ERIC B. NORMAN
Nuclear Science Division, Lawrence Berkeley Laboratory,
University of California, Berkeley, CA, U. S. A.

It is generally taken for granted that nuclear decay rates are unaffected by environmental factors, Under terrestrial conditions, this is an extremely good approximation. In many astronomical settings, however, physical conditions are so extreme that nuclear decay rates can be significantly altered from their laboratory values.

At the high temperatures found in stellar interiors, nuclei are continuously irradiated by large fluxes of high-energy photons. These photons can be absorbed by a nucleus with the effect that the nucleus is excited to a higher energy level. In several cases of astrophysical interest, the beta decay of the ground state is a forbidden and hence very slow transition, while those of the excited states are allowed transitions. Thus, if these excited states are populated, significant increases in the decay rate of the nucleus can result.

Another effect of high temperatures is that during stellar nucleosynthesis, matter is essentially fully ionized. For nuclei which beta-minus decay, this leads to the possibility of bound-state beta decay. In this process, the beta particle is emitted directly into a previously unoccupied bound atomic orbital. For decays with low endpoint energies, the increase in decay energy provided by the atomic electron binding energy can lead to large increases in the nuclear decay rate.

A final effect that also results from the absence of atomic electrons is of importance in cosmic-ray physics. Some of the species present in the cosmic rays are radioactive nuclei which, under terrestrial conditions, decay by electron capture. High-energy cosmic rays are fully stripped of their atomic electrons in passing through the interstellar medium. Thus, because there are no bound atomic electrons to be captured, dramatic decreases in the decay rates occur for such cosmic-ray nuclei. For some species, the result is that they become "stable", while for others, terrestrially unobserved beta-minus or beta-plus decays will determine their decay rates.

Astrophysically interesting nuclei that have environmentally dependent half-live include:
^{7}Be --- (solar neutrino problem), ^{26}Al --- (chronometer for the early solar system),
^{54}Mn ---(cosmic ray clock), ^{56}Ni ---(cosmic ray clock),
^{99}Tc ---(s-process "fingerprint" in stars), ^{148}Pm ---(s-process neutron density),
^{163}Dy --- (s-process neutron density), ^{176}Lu --- (s-process chronometer),
^{180}Ta --- (s-process thermometer), ^{187}Re ---(r-process chronometer).

Two of the projects that we are now pursuing illustrate how laboratory experiments can provide some of the information required in order to answer these problems.

A major product of charged-particle induced nucleosynthesis in stars is the electron-capture decay nucleus ^{56}Ni. Soon after the supernova explosion that produces the ^{56}Ni takes place, temperatures are low enough that neutral atoms can exist. Thus the half-life of ^{56}Ni would be its laboratory value of 6.1 days. However, it is thought that supernovae may be sites of cosmic-ray production and acceleration. If ^{56}Ni produced in such explosions were accelerated to high energies, then it would be stripped of its electrons. Thus, the cosmic ray lifetime of ^{56}Ni would be determined by its beta-plus decay half-life. Future observations of ^{56}Ni in the cosmic rays could be used to determine the time interval between nucleosynthesis and cosmic-ray acceleration if this half-life were known (Casse, 1973). We are attempting to measure the beta-plus decay lifetime of ^{56}Ni using a fourfold coincidence technique. To date, no positive evidence of this decay mode has been observed but an upper limit of 2×10^{-6} has been established on the branching ratio for this decay. This establishes a lower limit on the cosmic-ray half-life of ^{56}Ni of 8×10^{3} years. Analysis of ten times more data is now in progress and should provide even more sensitivity to this mode of ^{56}Ni decay.

Recent measurements of the neutron-capture cross sections of $^{148,149,150}Sm$ have shown that a branch in the path of the s-process occurs at the nucleus ^{148}Pm (Winters et al. 1986). However, the use of this branch for extracting the s-process neutron density cannot yet be fully exploited because of the lack of information on the nuclear structure of ^{148}Pm. Until recently, only three levels in ^{148}Pm were known. The ground state, $^{148}Pm^{g}$, is a spin 1 level with a 5.37 day beta-decay half life. The second excited state at 137 keV is a spin 6 isomer, $^{148}Pm^{m}$, that decays almost entirely by beta-minus decay with a 41.3 day half-life. It has been estimated that during the s-process, the $^{147}Pm(n,gamma)$ reaction produces roughly equal amounts of $^{148}Pm^{g}$ and $^{148}Pm^{m}$. However, at the high temperatures at which the s-process is thought to occur, the question arises as to whether this population can be preserved or whether $^{148}Pm^{g}$ and $^{148}Pm^{m}$ could come into thermal equilibrium. It has been shown that the neutron density inferred from this branch point is a factor of three larger if equilibrium is reached than if the initial equal mixture of $^{148}Pm^{g}$ and $^{148}Pm^{m}$ is preserved. We have studied gamma-ray transitions in ^{148}Pm using the HERA system of 20 Compton-suppressed germanium detectors. We have located two levels below 500 keV excitation energy that have sizable decay branches to both $^{148}Pm^{g}$ and $^{148}Pm^{m}$. These levels thus serve as mediators during the s-process and allow $^{148}Pm^{g}$ and $^{148}Pm^{m}$ to come into thermal equilibrium. The resulting s-process neutron density inferred from this branch point is $3 \times 10^{8} / cm^{3}$. This work is supported by the U. S. Dept. of Energy under Contract No. DE-AC03-76SF00098.

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LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720