OTHER

RADIATIVE ALPHA-CAPTURE RATES LEADING TO A=7 NUCLEI APPLICATIONS TO ASTROPHYSICAL PROBLEMS

T. Kajino[a*], H. Toki[a,b], and Sam M. Austin[b]

Rates for radiative capture of alpha particles by ^{3}He and ^{3}H are important in several areas of astrophysics. One of these is the solar neutrino problem: only about one fourth of the expected number of events is observed in a detector sensitive mainly to the high energy neutrinos from decay of ^{8}B produced by the ^{3}He$(\alpha,\gamma)^7$Be reaction in the sun.[1] Another application is to nucleosynthesis of ^{7}Li in the Big Bang expansion: production of primeval ^{7}Li is mediated by the ^{3}H$(\alpha,\gamma)^7$Li reaction at lower densities and by the ^{3}He$(\alpha,\gamma)^7$Be reaction followed by electron capture at higher densities.

Experimental values of the reaction rates are based on extrapolation to low energy of the experimental data as represented by the S factor

$$S(E) = \sigma E e^{+2\pi\eta}.$$

Here σ is the cross section and η is the Sommerfeld parameter. The extrapolation is made by normalizing an assumed excitation function for S to the data. Detailed resonating group calculations[2] now give a reliable description of the data both in shape and in magnitude; we have chosen to fit the experimental results to these new theories. Details of the theoretical approach can be found in Ref. 2 and the results of fits to the available data are summarized in Fig. 1.

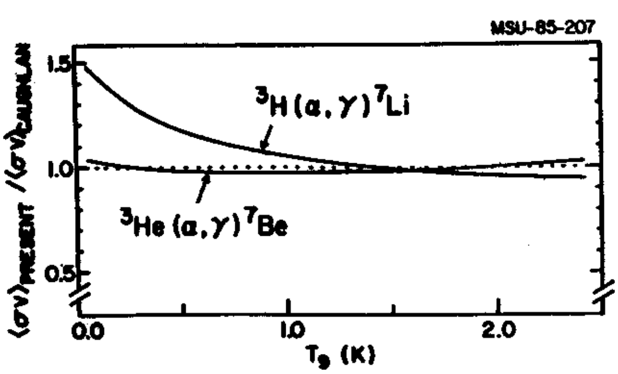

Fig. 1 Ratio for the (α,γ) reactions, of the nuclear reaction rates calculated in this paper to those from Harris, et al.[3]

For $T_9 < 1$, the present rate for ^{3}He$(\alpha,\gamma)^7$Be is close to Harris's.[3] On the other hand, the rate for ^{3}H$(\alpha,\gamma)^7$Li has a stronger temperature dependence and is 10-40% larger. In the following sections, we shall study the consequence of these changes in the reaction rates for the solar neutrino problem and for ^{7}Li production in the Big Bang.

In the experiment of Davis and his collaborators,[1] neutrinos from the sun are detected through inverse β decay induced in a ^{37}Cl detector. Based on reaction rates available at the time, Bahcall, et al.[4] predicted a counting rate R=7.6 ± 3.3 SNU(1 Solar Neutrino Unit = 1 capture /sec/10^{36} detector atoms), significantly larger than the observed value[1] of 2.1 ± 0.3 SNU. Our value of the S factor for the ^{3}He$(\alpha,\gamma)^7$Be reaction is about 8% larger than the value used by Bahcall et al; since $R \propto S(0)^{0.8}$, this tends to increase the predicted value of R. However, there have been changes in other reaction rates which affect solar neutrino production; we discuss these changes before presenting a predicted rate.

The largest change is in the rate for the ^{7}Be$(p,\gamma)^8$B reaction, which, in the sun, produces the ^{8}B neutrinos responsible for most events in Davis's detector. New measurements of the cross section for this reaction[5] and a re-analysis of previous results leads to a recommended value of $S_{17}(0) = 0.0238 \pm 0.0023$ keV barns. This value is signigicantly smaller that (0.029 ± 0.010keV barns) used by Bahcall, et al., and tends to decrease the predicted rate.

Another change is in the rate of the reaction $p + p \rightarrow D + e^+ + \nu$. The value of S_{11} is directly proportional to the square of the axial vector coupling constant g_A governing Gamow-Teller β decay. Bahcall et al. obtained g_A from the neutron halflife; because of the large spread in available measurements of the halflife

g_A was quite uncertain. Here we obtain g_A from the well known values[6] of $\lambda = g_A/g_V$ and g_V. This results in

$$S_{11}(0)=(3.78\pm.095)(1.0394\pm0.0073)(1.01+0.01)^2 \times 10^{-25} \text{MeV barns},$$

where the first factor is from Bahcall and May[7] with the uncertainty representing the error in the nuclear matrix elements, the second factor is the correction for the new value of $g_A^2 = \lambda^2 g_V^2$ and the third factor is the correction for meson exchange. Then $S_{11}=(4.01\pm0.12)\times10^{-25}$ MeV barns, compared to Bahcall, et al.'s value of $(3.88 \pm 0.12)\times10^{-25}$ MeV barns.

In Table I, we summarize the S factors for reaction rates which differ from those used by Bahcall et al., the associated changes in the neutrino detection rates, and the error due to a one standard deviation uncertainty in the reaction rates. In addition to the uncertainty of ± 0.9 SNU associated with the nuclear reaction rate, there is an additional ±0.6 SNU(10%) uncertainty associated with the detection efficiency of the ^{37}Cl detector and ±0.4 SNU associated with the solar physics(one-third of the three standard deviation uncertainty quoted by Bahcall). Since Bahcall. et al. predict R = 7.64 SNU, our results imply:

R(predicted) = 6.4 ± 1.1 SNU

R(measured) = 2.1 ± 0.3 SNU.

We conclude that the remaining uncertainty in the S factors for the nuclear reactions involved(and for the ^{3}He$(\alpha,\gamma)^7$Be reaction in particular) is not the source of the solar neutrino problem; it must lie in the realm of solar physics or particle physics.

Nuclear reactions occurring when the temperature in the expanding Universe is about 10^9 K synthesize the elements ^{2}H, ^{3,4}He, and ^{7}Li in amounts comparable to their observed abundances.[8,9] Since the amount of a given isotope which is created depends on the baryon density ρ_B, the assumption that a given element is created in the Big Bang yields an estimate of that density (often expressed as η, the ratio of baryon to photon density). It has been found that a single value of η simultaneously reproduces the observed abundances of the four isotopes,[8,9] yielding a consistent estimate of η. It is important to determine the effects of the new reaction rates obtained here and of a new measurement[10] of the ^{7}Li abundance on the determination of η.

To do so , we have performed calculations of Big Bang nucleosynthesis with Wagoner's code.[11] The rates of Ref. 3 as implemented by Scherrer were used except that the present rates were used for the (α,γ) reactions leading to ^{7}Li. We assumed a neutron halflife of 10.30 minutes, consistent with the value of g_A obtained previously, and that there were three (or four) light neutrinos. The results for the production of ^{7}Li are summarized on Fig. 2; the

Table I: Changes in detection rate-^{37}Cl

Reaction	S(ref.21)	S(New)	Δ(SNU)†	Error(SNU)††
$p+p\to D+e^+ +\nu$	$(3.88 \pm0.12)10^{-25}$ MeV b	$(4.01 \pm0.12)10^{-25}$ MeV b	-0.58	±0.51
$^3He+^3He\to^4He+2p$	4.7 ±0.5 MeV b	4.7 ±0.5 MeV b	0	±0.30
$^3He+^4He\to^7Be+\gamma$	0.52 ±0.05 keV b	0.56 ±0.04 keV b	0.45	±0.42
$^7Be+p\to^8B+\gamma$	0.029±0.0033 keV b	0.0239±0.0023 keV b	-1.08	±0.58
	TOTAL		-1.2	±0.9

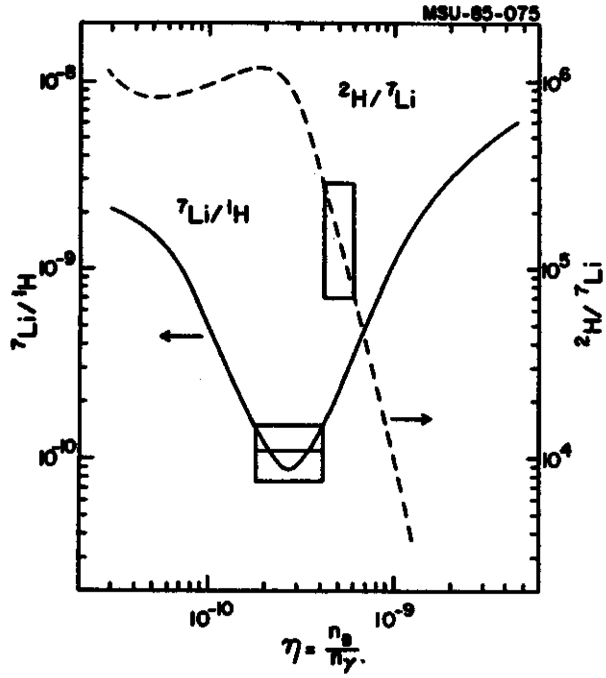

Fig. 2. Values of the ^{7}Li abundance and of the ratio ^{2}H/^{7}Li calculated as described in the text and compared with the experimental values. The experimental value of ^{2}H/7Li is taken to be $(2\pm1)\times10^{-5}$.

values shown differ by more than a factor of two from Wagoner's results at some densities but are fairly close to calculations using more recent rates. An important question concerns the uncertainty in the rate of the ^{7}Li$(p,\alpha)^4$He reaction, which destroys ^{7}Li after its formation. There has been a controversy about the rate of this reaction, with published values of the cross section differing by up to a factor of two. Such an uncertainty leads to an uncertainty in the production of ^{7}Li at low density(where ^{3}H$(\alpha,\gamma)^7$Li is dominant) of a factor of $\pm$ 2.7. The controversy has now been resolved(see King, et al.[12]); it is our conclusion that the predicted values of the ^{7}Li abundance are probably accurate to within about $\pm$35%.

As shown on Fig. 2 the abundances of Spite and Spite[10] and the present Big-Bang calculations indicate that $\eta=(1.7-4)\times10^{-10}$.Also shown on the Fig.2 is the ratio of the ^{2}H and ^{7}Li abundances. Following the argument of Yang, et al.[9] that ^{2}H is decreased at least as much by stellar processing as is ^{7}Li, the value of this ratio given by the present abundances is an upper limit and the resulting value of η is an upper limit, implying $\eta\leq6\times10^{-10}$. These values obtained from the ^{7}Li abundance are marginally consistent with the results of Ref. 9 and correspond to baryon densities about an order of magnitude too small to close the universe. For the largest value of η consistent with the ^{7}Li abundance (4×10^{-10})we calculate a value of the ^{4}He abundance by mass of Y=0.2413 (Y=0.2535) for three(four) light neutrino species; these results are consistent with measured values of the helium abundance[9], but are close enough to the upper limit of Y to make another (fifth) light neutrino species unlikely.

a Tokyo Metropolitan University
b NSCL

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CELLULAR MICROIRRADIATION: SURVIVAL VS. LET

W.C. Parkinson[a], John Bardwick[a], Frizell L. Vaughan[b]

The objectives of these experiments on cellular microirradiation are the advancement of a new experimental technique of mircoirradiation and the use of the technique to determine the fate of individual mammalian cells as a function of the amount and location of energy deposited in each cell. Cells were plated on a thin substrate etched with a fiducial grid. The substrate was then placed directly on the surface of a nuclear emulsion and the assembly irradiated with 35 MeV/A ^{14}N ion particles at normal incidence. The assembly was then exposed to light. Because the emulsion is opaque to visible light an image of the cells and fiducial grid is formed on the top surface of the emulsion, while a charged particle leaves a track of developable grains through the emulsion. Following the exposure the cells were followed over several mitotic periods using time-lapse microphotography.

In May, 1984 a test of the beam energy and intensity and of the biological cassette indicated the intensities, particle range, and track densities were satisfactory. Using the same experimental arrangement nine exposures of cultures of mouse fibroblast cells were made on 17 October, 1984. The results were negative in that the number of analyzable events were too few to be statistically significant. On seven of the nine emulsions there were no cell images on the emulsion surface, this in spite of careful preliminary calibration of light exposures. In addition the cell density was low, but this by itself would have been disasterous.

We conclude that this type of biological experiment which requires using a mobile cell-culture laboratory, thus with limited facilities and with tightly scheduled beam times presents unusual and severe problems.

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a Department of Physics University of Michigan, Ann Arbor, MI
b School of Public Health University of Michigan, Ann Arbor, MI