IASSNS-AST-92-5
Fermilab Library
0 1160 0009354 6

Astrophysics Preprint Series
IASSNS-AST 92/5

Is Stellar Evolution Theory Wrong and the Solar Neutrino Problem Solved?

J. N. Bahcall
Institute for Advanced Study, Princeton, NJ 08540

E. E. Salpeter
Newman Laboratory, Cornell University, Ithaca, NY 14853-06511

INSTITUTE FOR ADVANCED STUDY
OLDEN LANE
PRINCETON, NEW JERSEY 08540

IS STELLAR EVOLUTION THEORY WRONG AND THE SOLAR NEUTRINO PROBLEM SOLVED?

J. N. Bahcall

Institute for Advanced Study, Princeton, NJ 08540

E. E. Salpeter

Newman Laboratory, Cornell University, Ithaca, NY 14853 06511

In a widely circulated preprint entitled 'Solution of the Solar Neutrino Problem', Kurucz (1992) has announced that: "All current stellar interior and evolutionary models are incorrect." He suggests that new calculations of nuclear reaction rates in stars are required to take account of two physical processes that have been previously ignored; the processes that Kurucz proposes are: 1) electron shielding; and 2) three-body reactions involving electron capture. Kurucz discusses specifically the role of these processes in increasing the rate of the standard proton-proton reaction,

$$\mathrm{p} + \mathrm{p} \longrightarrow {}^2\mathrm{H} + \mathrm{e}^+ + \nu_e. \tag{1}$$

Without doing any calculations, Kurucz concludes that with the aid of the expected enhanced rates the "...solar luminosity can be maintained with a central temperature near 10^7K where the neutrino production rate corresponds to the observed rate."

Many colleagues have questioned us regarding these claims. We have therefore written this short note to remind interested scientists that both processes that Kurucz proposes were evaluated with proper quantum mechanical treatments more than a quarter of a century ago and from time-to-time thereafter. Because there is nothing new in the proposals by Kurucz, we do not intend to publish this note. We simply want to guide the interested onlooker to some of the key references where the research and explication are recorded.

The problem of calculating the effect of electron screening on nuclear reactions in non-degenerate stars like the sun was solved initially by Salpeter (1954) [see also Schatzman 1948].

Subsequent refinements in the treatment include discussions by DeWitt, Graboske, and Cooper (1973); Graboske, DeWitt, Grossman, and Cooper (1973); and Carraro, Schafer, and Koonin *et al.* (1988). Electron screening does indeed increase the rates of nuclear reactions in main-sequence stars like the sun, but only by relatively small amounts, approximately 5 % for the reaction, (Eq. (1)), discussed by Kurucz. The effects of electron screening have been taken into account in calculating all modern stellar evolution models and are discussed in the two references cited by Kurucz, namely, the books on nuclear astrophysics by Rolfs and Rodney (1988) and by Bahcall (1989). The effects of electron screening on the low-energy rate of the nuclear fusion reaction $^3He(d,p)^4He$ has recently been demonstrated in a laboratory experiment by Engstler *et al.* (1988) and is in good agreement with the a theoretical calculation by Assenbaum, Langanke, and Rolfs (1987).

The rate of the three-body electron capture reaction proposed by Kurucz,

$$\mathrm{p} + \mathrm{e}^- + \mathrm{p} \longrightarrow {}^2\mathrm{H} + \nu_e, \tag{2}$$

was evaluated by Bahcall (1964). The reaction proposed by Kurucz is known to afficianados of the solar neutrino problem as the *pep* reaction. The rates of all three-body nuclear reactions mediated by electron capture that are relevant to the solar interior are given in Bahcall (1990). An accurate evaluation shows (Bahcall 1989, 1990) that the rate of the three-body *pep* reaction is about two-tenths of a percent of the rate of the more familiar two body reaction described by Eq. (1); the *pep* reaction contributes three percent to the standard calculated event rate for the chlorine solar neutrino experiment and two percent to the calculated event rate of the gallium solar neutrino experiment.

The fundamental error made by Kurucz (1992) is in imagining that electrons are classical point-particles that can be localized between protons as they approach close to each other in the process of fusion. A dimensionless measure of this error is the ratio of the volume occupied by the De Broglie wavelength of electrons under solar interior conditions to the nuclear volume in which protons fuse. This ratio is

$$\frac{\lambda_e^3}{\text{Volume of nucleus}} \approx 10^{12}. \tag{3}$$

REFERENCES

Assenbaum, H. J., Langanke, K., & Rolfs, C., 1987, Z. Phys. A 327, 461

Bahcall, J. N., 1964, Phys. Rev., 135, B137

Bahcall, J. N., 1989, *Neutrino Astrophysics* (Cambridge University Press, Cambridge, England)

Bahcall, J. N., 1990, Phys. Rev. D. 41, 2964

Carraro, C., Schaffer, A., and Koonin, S. E. 1988, ApJ 331, 565

De Witt, H. E., Graboske, H. C., & Cooper, M. S. 1973, ApJ, 181, 439

Engstgler, S., Krauss, A., Neldner, K., Rolfs, Schroder, & Langanke, K. 1988, Phys. Letts B, 179

Graboske, H. C., De Witt, H. E., Grossman, A. S., & Cooper, M. S. 1973, ApJ 181, 457

Kurucz, R. L. 1992, Harvard-Smithsonian Center for Astrophysics preprint 3360

Rolfs, C. E. & Rodney, W. S. 1988, *Cauldrons in the Cosmos*, (Chicago: University of Chicago Press)

Salpeter, E. E. 1954, Aust. J. of Phys., 7. 373

Schatzman, E. 1948, J. Phys. Radium, 9, 46