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The effect of host medium on the half-life of ^{7}Be

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Abstract

We discuss recent results of E.B. Norman et al. [Phys. Lett. B 519 (2001) 15] in relation to our earlier work [A. Ray et al., Phys. Lett. B 455 (1999) 69] and point out that the apparent disagreement between the two sets of experimental results is most likely due to the choice of different reference samples with which the comparisons have been done. In addition, the irradiation by heavy ion beam might also damage the lattice structure of the medium and such effect was not included in our calculations. We think that our earlier conclusion regarding the downward revision of predicted ^{8}B solar neutrino flux by $\approx 2\%$ should stand.

It is well known that ^{7}Be is the lightest radioactive nucleus that decays by electron capture and its half-life is most susceptible to the surrounding environment. The study of half-life of ^{7}Be implanted in different media is a topic of current interest. Recently, E.B. Norman et al. [1] measured ^{7}Be decay rates in gold (Au), graphite, boron nitride and tantalum (Ta). Among those materials, they find [1] that the ^{7}Be half-life is longest in Au and shortest in graphite. According to their measurements, the decay rate of ^{7}Be in Au is lower than that in graphite by $(0.38 \pm 0.09)\%$.

Earlier, we measured [2] the difference of ^{7}Be decay rates in Au and Al_2O_3 and found that the decay rate in Au is lower than that in Al_2O_3 by $(0.72 \pm 0.07)\%$. This and other available results were explained [2] quantitatively using linear muffin-tin orbital method calculations [3] and Hartree's results [4]. Qualitatively speaking, these observations can be understood in terms of the electron affinity of the medium and its lattice structure.

It was found [1] by Norman et al. that the difference between the decay rates of ^{7}Be in graphite and Au is about half of what was observed [2] between Al_2O_3 and Au. By comparing with other people's results [5,6], they also find [1] that the ^{7}Be decay rates in graphite, lithium flouride and aluminum are not much different ($\approx 0.1\%$ difference). On this basis, they concluded that the decay rate of ^{7}Be in graphite and Al_2O_3 should be about the same and so they are seeing [1] half of the predicted effect [2]. Using similar line of arguments, they concluded [1] that because of such atomic physics effect, the predicted ^{8}B solar neutrino flux should be reduced by 1% rather than about 2% as we concluded [2] earlier.

We think that the conclusions of Norman et al. [1] in relation to our work [2] could be somewhat misleading. We actually measured the change of ^{7}Be

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decay rate in Au and Al_2O_3 and also calculated the difference of decay rates in aluminium (Al), Au, Al_2O_3, Ta and LiF. In Table 1, we compare our calculations [2] with the available experimental results [1,2,5,6].

We find from Table 1 that there is general agreement between our calculations and experimental observations. However it appears that Norman et al. [1] found somewhat smaller increase in the half-life of ^{7}Be in Au compared to our calculations. The discrepancies between experimental and calculated half-life differences are certainly much less than a factor 2 (typically less than 50% in the worst cases) and they almost agree within the error bars even in the worst cases.

It is possible that the radiation damage of Au lattices by ^{7}Li beam could be responsible for such discrepancies. Norman et al. [1] used ^{7}Li beam for their implantation studies in Au and Ta, whereas we used [2] proton beam for our irradiation work. The half-lives of ^{7}Be in Al and LiF were also measured [5,6] using proton irradiation technique. In the case of irradiation by ^{7}Li beam (as was done by Norman et al.) the radiation damage on gold lattice sites where ^{7}Be nuclei stop would be much larger [7] (3×10^{-4} vacancies/Angstrom/ion) than the corresponding damages (1×10^{-5} vacancies/Angstrom/ion) for proton irradiation work. The effective electron affinity of gold lattice will be reduced because of such damages and this effect should reduce the half-life of the implanted ^{7}Be nuclei in gold. Our calculations do not take into account any such lattice damage effects.

In fact, we find (from Table 1) when the differences between ^{7}Be half-lives are obtained from proton irradiation data (such as between Au and Al_2O_3; Al and LiF), then there is excellent agreement between data and calculations. When the measured ^{7}Be half-lives from two heavy ion irradiation experiments are compared (such as between Au and Ta), then also there is good agreement. However, when the measured ^{7}Be half-life from a heavy ion irradiation experiment is compared with that obtained from a proton irradiation experiment (last two rows of Table 1), then the experimental half-life differences are about 40% smaller than the calculated differences. It is plausible that Norman et al. [1] measured slightly smaller half-life of ^{7}Be in Au because of radiation damage effect in Au lattices. So we think that our calculations are in reasonable agreement with the available data.

The electron affinities of Au, Ta, Al are 2.3 eV, 0.322 eV and 0.5 eV, respectively [8]. It is generally thought that the electron affinities of LiF and Al_2O_3 would be close to zero. One can see from Table 1 that the half-life of ^{7}Be generally increases when it is implanted in a material having higher electron affinity. However, the lattice structure of the medium also plays an important role since it really matters how close to a host atom a ^{7}Be sits.

We have not done linear muffin-tin orbital method calculations for boron nitride or graphite because of their much more complex lattice structures. However, the decay rate of ^{7}Be should not be expected [1] to be about the same in graphite and Al_2O_3, because the electron affinity [8] of carbon is 1.25 eV, whereas that of Al_2O_3 is essentially zero. Hence the decay rate of ^{7}Be in Al_2O_3 is likely to be higher compared to that in graphite. The observation [1] regarding similar half-life of ^{7}Be in Al and LiF is due to very small electron affinity (0.5 eV) of Al and similar lattice structure and dimensions of Al and LiF lattices. As shown in Table 1, our calculation also gives [2] a very small difference be-

Table 1
Comparison between experimental and calculated values of change of ^{7}Be decay rates in different media

Difference between the half-lives of ^{7}Be implanted in	Percentage increase of half-life of ^{7}Be in 1st medium compared to that in 2nd medium of column-1		References
	Experimental value	Calculated value	
Au and Al_2O_3	$(0.72 \pm 0.07)\%$	0.74%	[2]
Al and LiF	$(0.1 \pm 0.2)\%$	0.08%	[5], [6]
Au and Ta	$(0.22 \pm 0.13)\%$	0.3%	[1]
Au and Al	$(0.27 \pm 0.15)\%$	0.45%	[1], [5]
Au and LiF	$(0.36 \pm 0.15)\%$	0.53%	[1], [6]

tween the half-lives of ^{7}Be implanted in Al and LiF.

The decay rate of ^{7}Be should also not be expected to be about the same in Al_2O_3 and LiF. The lattice structures of Al_2O_3 and LiF are drastically different. This would certainly affect the decay rate of ^{7}Be in the two media. In fact our calculation predicts [2] that ^{7}Be should decay faster in Al_2O_3 compared to that in LiF by about 0.21% (compare 3rd column of 1st and 5th rows of Table 1). So we think that Norman et al.'s results are in reasonable agreement with our calculations and experimental results. The apparent difference between the results of Refs. [1,2] is most likely due to the choice of different reference samples with which the comparisons have been done. In addition the radiation damage effect on Au lattices due to heavy ion irradiation might also be partly responsible for the apparent discrepancies.

We agree with Norman et al. [1] that the results of Souza et al. [9] are in complete disagreement with both Refs. [1,2] regarding both the sign and magnitude of the change of ^{7}Be decay rate.

Since there is general agreement between our calculations and observations, we are justified to apply our linear muffin-tin orbital method calculations for taking care of (usually ignored) atomic physics effect in the extraction of nuclear matrix element of $^7\text{Be} + e^- \to {}^7\text{Li} + \nu$ reaction. It was shown in Ref. [2] that as a result of such atomic physics correction, the predicted ^{8}B solar neutrino flux should be lowered by 1.9%. It is not justified [1] to arbitrarily reduce this number by a factor of 2 since Norman et al.'s work [1] does not contradict our calculations [2].

We certainly agree with Norman et al. [1] that the present large uncertainty on the predicted ^{8}B neutrino flux, mainly coming from about 10% uncertainty in the measurement of $^7\text{Be}(p,\gamma)^8\text{B}$ reaction rate, is much larger than this small atomic physics correction. However, recently Junghans et al. [10] measured astrophysical S factor of $^7\text{Be}(p,\gamma)^8\text{B}$ reaction to better than 5% accuracy. So the results of our work would be useful for better understanding of the solar interior, solar helioseismological data as well as the neutrino physics using the solar neutrino data from the current-generation experiments.

Recent measurement [11] of the ratio of L to K-shell electron capture in ^{7}Be nucleus shows that the measured ratio is less than half of existing predictions for free ^{7}Be. This discrepancy is most likely due to the distortion of L-shell orbitals by the host medium and our linear muffin-tin orbital method calculations [2] could be used to understand such effects.

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References

[1] E.B. Norman et al., Phys. Lett. B 519 (2001) 15.
[2] A. Ray et al., Phys. Lett. B 455 (1999) 69.
[3] O.K. Andersen, O. Jepsen, D. Glotzl, Highlights of Condensed Matter Theory, North-Holland, New York, 1985;
O.K. Andersen, Z. Pawlowska, O. Jepsen, Phys. Rev. B 34 (1986) 5253.
[4] D.R. Hartree, W. Hartree, Proc. Roy. Soc. London A 150 (1935) 9.
[5] F. Lagoutine, J.L. Legrani, C. Bac, Int. J. Appl. Rad. Isotop. 25 (1975) 131.
[6] M. Jaeger, S. Wilmes, V. Koje, G. Staudt, Phys. Rev. C 54 (1996) 423.
[7] J.F. Ziegler, J.P. Bierserk, U. Littmark, The Stopping Range in Solids, Pergamon, New York, 1985.
[8] CRC Handbook of Chemistry and Physics, R. David (Ed.), Lide, 1994–1995.
[9] D. Souza et al., Bull. Am. Phys. Soc. 42 (1997) 1679, and Univ. of Massachusetts-Lowel. Rad. Lab. Prog. Rep. (DOE/ER/40246-12) October, 1997, p. 16.
[10] A.R. Junghans et al., Phys. Rev. Lett. 88 (2002) 041101.
[11] P.A. Voytas et al., Phys. Rev. Lett. 88 (2002) 012501.