69

ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
им. Г.И. Будкера СО РАН

V.F. Dmitriev,
I.B. Khriplovich and V.B. Telitsin

IS LARGE WEAK MIXING IN HEAVY NUCLEI CONSISTENT WITH ATOMIC EXPERIMENTS?

BudkerINP 94-98

НОВОСИБИРСК

Is Large Weak Mixing in Heavy Nuclei Consistent with Atomic Experiments?

V.F. Dmitriev[1], *I.B. Khriplovich*[2] *and V.B. Telitsin*[3]

Budker Institute of Nuclear Physics
630090, Novosibirsk 90, Russia

ABSTRACT

The hypothesis of a large weak matrix element between single-particle states in heavy nuclei (~ 100 eV) contradicts the results of atomic PNC experiments.

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[1] e-mail address: dmitriev@inp.nsk.su
[2] e-mail address: khriplovich@inp.nsk.su
[3] e-mail address: telitsin@inp.nsk.su

The scattering cross-sections of longitudinally polarized epithermal (1 - 1000 eV) neutrons from heavy nuclei at $p_{1/2}$ resonances have large longitudinal asymmetry. This parity nonconserving (PNC) correlation is the fractional difference of the resonance cross-sections for positive and negative neutron helicities. For a long time the most natural explanation of the effect was based on the statistical model of the compound nuclei. In fact, not only the explanation, but the very prediction of the huge magnitude of this asymmetry (together with the nuclei most suitable for the experiments) was made theoretically [1] on the basis of this model.

An obvious prediction of the statistical model is that after averaging over resonances, the asymmetry should vanish. However, few years ago it was discovered [2, 3] that all seven asymmetries for ^{232}Th have the same, positive sign. This tendency was observed also in other nuclei.

All the attempts [4, 5, 6, 7] to explain a common sign require the magnitude of the weak interaction matrix element, mixing opposite-parity nuclear levels, to be extremely large, ~ 100 eV. The same assumption seems to be necessary to explain unexpectedly large P-odd correlations observed in Mössbauer transitions in ^{119}Sn and ^{57}Fe [9, 10].

In a recent paper [8] it was pointed out that such a large magnitude of the weak mixing can be checked in an independent experiment. The proposal is to measure PNC asymmetry in the M4 γ-transition between the (predominantly) single-particle states $1i\ 13/2^+$ and $2f\ 5/2^-$ in ^{207}Pb. The experiment sensitivity to the weak matrix element value is expected to reach $5 - 13$ eV.

In the present Comment we wish to note that close upper limit on the weak mixing in ^{207}Pb can be extracted now from the measurements of the PNC optical activity of atomic lead vapour [11]. The experiment was performed at the atomic M1 transition from the ground state $6p^2\ {}^3P_0$ to the excited one $6p^2\ {}^3P_1$. The nuclear spin of ^{207}Pb being $i = 1/2$, the total atomic angular momentum of the ground level is $F = 1/2$, and the upper level is split into two: $F' = 1/2, 3/2$. The following upper limit was established at the 95% confidence level for the relative magnitude of the nuclear-spin-dependent (NSD) part of the optical activity:

$$\frac{P_{NSD}}{P} < 0.02 \qquad (1)$$

Here

$$P_{NSD} = P(F = 1/2 \to F' = 1/2) - P(F = 1/2 \to F' = 3/2)$$

and P is the main, nuclear-spin-independent, part of the PNC optical activity.

In heavy atoms the NSD P-odd effects were shown to be induced mainly by contact electromagnetic interaction of electrons with the anapole moment of a nucleus which is its P-odd electromagnetic characteristic induced by PNC nuclear forces [12, 13].

The electromagnetic PNC interaction of electrons with nuclear AM is of a contact type. It is conveniently characterized in the units of the Fermi weak interaction constant $G = 1.027 \times 10^{-5} m^{-2}$ (m is the proton mass) by a dimensionless constant κ.

To calculate κ let us present the effective P-odd potential for an external nucleon in a contact form in the spirit of the Landau-Migdal approach:

$$W = \frac{G}{\sqrt{2}}\,\frac{g}{2m}\,\vec{\sigma}[\vec{p}\rho(r) + \rho(r)\vec{p}\,]. \qquad (2)$$

Here $\vec{\sigma}$ and $\vec{p}$ are respectively spin and momentum operators of the valence nucleon, $\rho(r)$ is the density of nucleons in the core normalized by the condition $\int d\vec{r}\rho(r) = A$ (the atomic number is assumed to be large, $A \gg 1$). A dimensionless constant g characterizes the strength of the P-odd nuclear interaction. It is an effective one and includes already the exchange terms for identical nucleons. This constant includes also additional suppression factors reflecting long-range and exchange nature of the P-odd one-meson exchange, as well as the short-range nucleon-nucleon repulsion.

Under some simplifying assumptions the anapole constant κ can be estimated for a heavy nucleus even analytically with the following result [13]:

$$\kappa = \frac{9}{10}\,g\,\frac{\alpha\mu}{m r_0}\,A^{2/3}. \qquad (3)$$

Here μ is the outer nucleon magnetic moment, $r_0 = 1.2$fm. The enhancement $\sim A^{2/3}$ compensates to a large extent the small fine structure constant $\alpha = 1/137$. That is why the nuclear AM is perhaps the main source of the nuclear-spin-dependent PNC effects in heavy atoms [12, 13]. This formula predicts for lead

$$\kappa(^{207}\text{Pb}) = -0.08\, g_n. \qquad (4)$$

More serious numerical calculations using a realistic description of the core density and a Woods-Saxon potential including the spin-orbit interaction give [13, 14]

$$\kappa(^{207}\text{Pb}) = -0.105\, g_n. \qquad (5)$$

On the other hand, atomic calculations predict the magnitude of the NSD optical activity in lead at given κ with the accuracy about 20% [15, 16]. At the experimental value of P obtained in Ref. [11] this prediction for the ratio (1) constitutes $0.023\,\kappa(^{207}\text{Pb})$. Combining the experimental result (1) with this theoretical one, we get the following upper limit for the anapole constant:

$$\kappa(^{207}\text{Pb}) < 1, \qquad (6)$$

and for the effective neutron PNC constant:

$$g_n < 10. \qquad (7)$$

Close upper limits on the effective constant g_p for an outer proton can be extracted from the optical experiments with atomic cesium [17] and thallium [18]. Less strict bound on g_p follows from the experiment [19] with bismuth.

A simple-minded estimate for the weak mixing matrix element, based on formula (2), leads to its following value:

$$< W > \simeq 2\,g\;eV. \qquad (8)$$

More sophisticated calculations based on a Woods-Saxon potential with the spin-orbit interaction gives for the concrete matrix element of interest for the proposed experiment with ^{207}Pb

$$\langle 3d\,5/2^+ | W | 2f\,5/2^- \rangle = 1.4\, g_n\; eV \qquad (9)$$

in a reasonable agreement with the results of other single-particle nuclear calculations cited in Ref. [8]. Combining (7) and (9), we get the following upper limit on this matrix element

$$\langle 3d\,5/2^+ | W | 2f\,5/2^- \rangle < 14\; eV \qquad (10)$$

which is close to the expected accuracy of the experiment discussed in Ref. [8]. Nevertheless, this experiment would be obviously both interesting and informative, so much the more that it would be the first occasion when PNC effects in the same nucleus were measured both in atomic and nuclear experiments.

As to the hypothesis itself, according to which the magnitude of the weak mixing matrix element is as high as 100 eV, such a large its value does not agree with the results of atomic PNC experiments.

This investigation was financially supported by the Russian Foundation for Basic Research, grant No. 94-02-03942-a.

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V.F. Dmitriev, I.B. Khriplovich and V.B. Telitsin

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В.Ф.Дмитриев, И.Б.Хриплович, В.Б.Телицын

Согласуется ли большое слабое смешивание
с атомными экспериментами?

BudkerINP 94-98

Ответственный за выпуск С.Г. Попов
Работа поступила 7 декабря 1994 г.

Сдано в набор 9.12. 1994 г.
Подписано в печать 9.12 1994 г.
Формат бумаги 60×90 1/16 Объем 0,6 печ.л., 0,4 уч.-изд.л.
Тираж 200 экз. Бесплатно. Заказ N 98

Обработано на IBM PC и отпечатано на
ротапринте ИЯФ им. Г.И. Будкера СО РАН,
Новосибирск, 630090, пр. академика Лаврентьева, 11.