Possibility of a modification of life time of radioactive elements by magnetic monopoles

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ABSTRACT. We consider a possibility of modification of life time of radioactive elements by magnetic monopoles which are induced by a strong magnetic field of the monopoles. Besides, some development of G. Lochak magnetic monopole concept, which could also be connected with the variations of radioactive element decay rates, are briefly discussed.

1 Introduction

The existence of magnetic charges has appeal from the theoretical point of view: it explains the quantization of the electric charge and symmetrizes Maxwell's equation. Therefore, from 1931, when the famous Dirac paper [1] was published, searches for magnetic monopoles were carried out at every new generation of accelerators, but all those attempts were futile. Now it is generally accepted that magnetic monopoles, if they exist, should be very heavy, with mass $\geq$ 500–1000 GeV. Nevertheless, an interesting possibility of existence of relatively light magnetic charges follows from G. Lochak's magnetic monopole concept [2]–[4]. Indeed, all accelerator magnetic monopole searches are based on the existence of the vertex $\gamma \to M + \overline{M}$, suggested by analogy with $\gamma \to e^- + e^+$. The most straightforward way to prevent the monopole–antimonopole creation in the accelerator experiments is to permit the following violation of C invariance in the electromagnetic interactions[1]: it is possible to assume that antimonopole, $\overline{M}$, corresponding to the solution of the Dirac

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[1]We believe that Prof. G. Lochak will agree with our interpretation of his theory. A possibility of violation of C invariance in the electromagnetic interactions was supposed earlier, although in a different physical context, by T.D. Lee et al. [5].

equation with negative energy, does not take part in the electromagnetic interactions (in contrast to e^+). This means that the vertex $\gamma \to M + \overline{M}$ does not exist, in spite of the existence of the vertex $M \to M + \gamma$.

There is a close analogy of such a violation of C invariance with P violation in the weak interaction. In the latter case ν_R and $\overline{\nu}_L$ do not take part in the $V - A$ interaction (are "sterile" particles). The only difference refers to the question of the existence of the particles. Since any interactions of ν_R and $\overline{\nu}_L$ are unknown, the very existence of these particles is still doubtful, whereas the existence of negative energy particles follows from the requirement of the possibility of spatial localization of the positive energy solution [6]. The monopoles may be even massless (the linear variant of the Lochak theory [2]–[4]). In this case positive and negative energy monopoles (interacting and "sterile" ones) are present in the wave packet in the equal ratio, in the complete analogy with the massless neutrino field. Decay of the vacuum to monopole-antimonopole pairs, possible in principle only through the chain

$$|0\rangle \to \gamma + M + \overline{M} \to M + \overline{M}$$

is, in fact, forbidden. Indeed, the vertex $\gamma + M + \overline{M}$ with a virtual γ, which is absorbed by M in a subsequent moment of time, is blocked due to the sterility of $\overline{M}$.

In papers [2]–[4], some heuristic arguments, based on a macroscopic gedanken experiment, are given in favour of generalization of C, P, T operations on the case of observable particles with different helicities, which remain in the theory after "deleting" the negative energy states from the Dirac spinor.

Since Lochak's monopoles are unregistered in the accelerator experiments, two interconnected problems arise: to formulate a theory describing monopole production (it should include a new force beyond the Standard model of electroweak interaction), and to point the way to monopole observation. G. Lochak et al. assumed these monopoles to be produced by strong magnetic pulses inside atomic nuclei able to the weak decays (see [4] for the references). In the present paper we consider a possibility, closely related to these and some other experiments, of a modification of life time of radioactive elements by magnetic monopoles. The first part of the article is devoted to purely electromagnetic impact of monopoles, caused by the vertex $M \to M + \gamma$. The second part, more speculative one, is based on experimental evidences in favour of the ex-

istence of some axial vector currents, responsible for a new force, which can stimulate, or suppress, decays of radioactive elements.

2 Electromagnetic interactions

It is common knowledge that a possibility of β-decays into bound states begins to play a crucial role if the energy released in this process is comparable with binding energies of electrons in the atom. Experiments demonstrate a great difference, up to nine orders, between the decay rates of neutral atoms and their totally bare ions [7], [8]. These results are quite clear from the general formula for probability of quantum transition,

$$\lambda = 2\pi \sum_f | < f|H_{int}|i > |^2 \delta(E_f - E_i),$$

since in the above-mentioned experiments the final phase space is substantially extended after ionization even only one energy level, $|f>$, which can be occupied by an outgoing electron.

The decay rate of radioactive atoms placed in an external magnetic field should vary too if the field is strong enough to modify the number of allowed final states. Thereupon it should be noted that a weak magnetic field responsible for the Zeeman, or Paschen-Back splitting does not change the number of states which could be simultaneously occupied by electrons in atom (this splitting can be observed only in atomic spectra). Otherwise already the Earth magnetic field should lead to a disaster, bringing down all electrons' orbits. Nevertheless, the radioactive atom create one more vacancy which can be occupied by an electron produced in β decay due to the increase of the nuclear charge, $Z \rightarrow Z + 1$, in these processes. The probability of these transitions is proportional to the density of unoccupied electron levels in the vicinity of the nucleus. In the absence of a magnetic field, the density of excited electron orbit at the position of the nucleus decreases very fast with increasing the principal quantum number n_p, in proportion to $1/n_p^3$, and the probability of β-decay with a small energy release is really tiny. The present state of affairs changes drastically if the β-radioactive atom is placed into a strong magnetic field.

Loudon was the first who considered the behaviour of atomic electron in a very strong magnetic field [9]. In this case the energy of magnetic interaction begins to dominate over the Coulomb one, atom acquires an elongated shape along the magnetic field with the transverse spread

much smaller than the longitudinal extent, and one has a quasi-one-dimensional atom with Coulomb interaction[2]

$$V(z) = -e^2/|z|.$$

In the high magnetic field regime, one is dealing with the motion of almost free electrons in a magnetic field. The corresponding physical conditions can be expressed in different equivalent forms:

$$\mu_B B = \hbar\omega_L >> Ry, \qquad r_L = (B_0/B)^{1/2} r_B << r_B, \qquad (1)$$

where $\mu_B = e\hbar/2m_e c$ and $r_B = \hbar^2/me^2 \approx 0.53 \times 10^{-8}$ cm are the Bohr magneton and radius, $\omega_L = eB/2mc$ and r_L are the Larmor frequency and radius for an electron moving along a circular orbit in a magnetic field, $Ry = mc^2\alpha^2/2 = 13.6$ eV is the Rydberg energy, $B_0 = cm^2e^3/\hbar^3 = 2.35 \times 10^9$ G. In this approximation, the wave function of the electron is simply a product of a Landau wave function for the very fast transverse motion, and a function for the comparatively slow motion parallel to the field.

In Fig. 1 the energies (in Ry) of low-lying states with principal quantum number $n_p \leq 3$ for a Coulomb potential are shown as functions of the magnetic field strength, $\beta = B/2B_0$ [11]. The states at the left, at $\beta < 0.1$, are labelled by atom's field-free quantum numbers, n_p, l, m. The states at $\beta > 10$ are enumerated by n (Landau quantum number), m and ν (number of nodes of the longitudinal part of the wave function). One can see that the strong magnetic field not only increases the number of electron state in atom, but also decreases the energy of these states due to the electronic orbit squeezing (in the plane perpendicular to the field) towards the nucleus. This results in a strong increase of the density of electron states near the nucleus, which now falls down only as $1/\nu$ with the increase of the number ν. Estimates show [12] that the probability of decays into the Landau levels for an atom containing all its electron, but immersed into a high magnetic field, should even exceeds the probability of decay of the totally ionized atom if

$$B/B_0 > 2Z^2. \qquad (2)$$

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[2]It is interesting to note that the *genuine* one-dimensional Coulomb problem has a solution [10] different from that found by Loudon, but that solution is not so important from the physical point of view. In fact, Loudon investigated electron with a small effective mass in the matter with a big dielectric constant. This increases the magnetic interaction energy and decreases the Coulomb one so that a laboratory field of 2.4×10^4 G corresponds to an effective magnetic field of 3.6×10^{10} G.
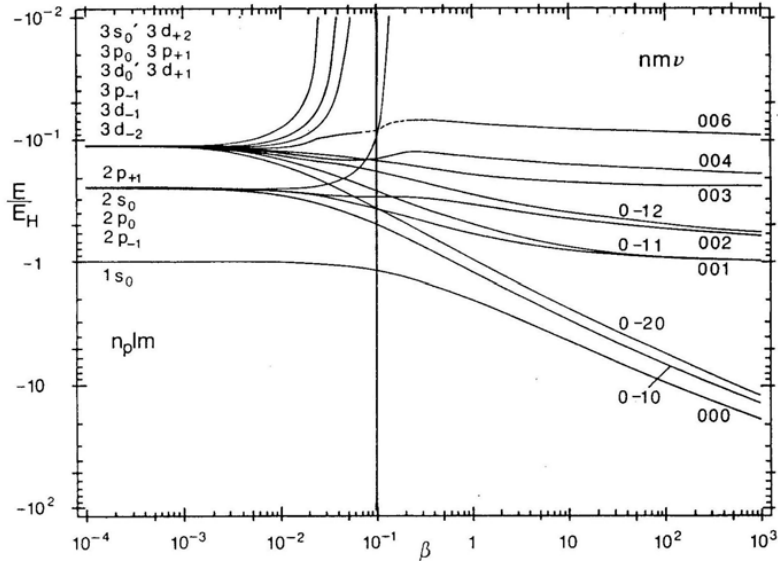
Figure 1: Energies of the electron in the hydrogen atom as a function of an external magnetic field field [11] (see text).

Of course, the field induced by the magnetic monopole is inhomogeneous and one should take this into account. The potential energy of the Larmor circle in an external magnetic field is:

$$U_L = -\vec{\mu} \cdot \vec{B},$$

where $\vec{\mu}$ is the magnetic moment corresponding to the electron circular current in the plane perpendicular to the external magnetic field,

$$\mu = \frac{1}{c} IS = \frac{1}{c} \frac{e\omega_L}{2\pi} \pi r_L^2 = \frac{mv_\perp^2}{2B} = \frac{\hbar\omega_L}{2B},$$

which is directed against $\vec{B}$,

$$\vec{\mu} = -\mu \frac{\vec{B}}{B}.$$

The magnetic moment is an adiabatic invariant iff the Larmor radius is sufficiently less than a characteristic scale at which the magnetic field
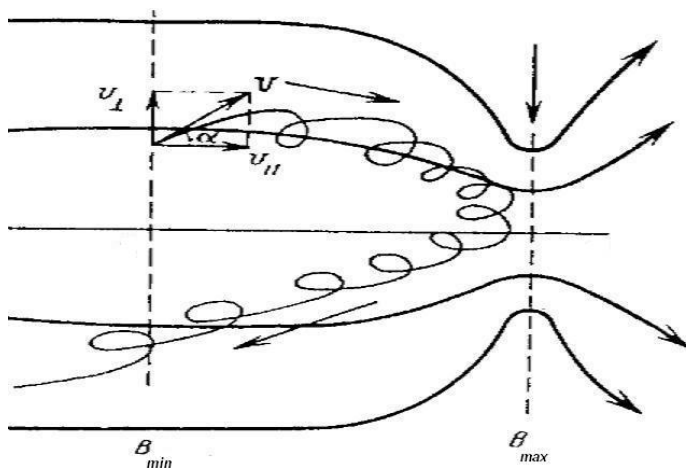
Figure 2: Plasma mirror-machine [13].

changes distinctly. For electrons localized inside atoms, $r \sim r_B$, one should consider the adiabatic condition to be applicable at the scale of about r_B. Thus, the condition takes the form

$$r_L \ll r_B,$$

reproducing exactly the condition (1).

The inhomogeneity of the monopole magnetic field gives an additional force,

$$\vec{F} = -\vec{\nabla} U_L = -\mu \vec{\nabla} B,$$

which is well-known in the plasma theory as the magnetic mirror effect[3] (see Fig.2). This force is always directed outside from the magnetic charge and leads to the electron knocking out if

$$U_L = \frac{\hbar \omega_L}{2} > \text{Ionisation energy.} \tag{3}$$

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[3]Poincaré showed [14] that a trajectory of electric charge moving in a coulombian magnetic field follows a geodesic line on a cone. Therefore, in contrast to the plasma mirror-machine shown in Fig.2, a trajectory of electron bombarding magnetic pole and a trajectory of electron reflected from it belong to the same cone.

For external electrons, the ionization energy is of order 1 Ry, and the condition (3) becomes even weaker than (1), but, of course, one should always take the strongest of them.

As a preliminary resume, we conclude that the condition (1) is the weakest for the external magnetic field to influence on the atom β-decay. This means that the external magnetic field should be much stronger than $B_0 = 2.35 \times 10^9$ G. Magnetic monopole with the minimal charge $g_{\min} = 68.5e$ creates, on the atomic scales $\sim r_B$, the field of order 10^8 G. This implies that only multi-charge monopoles with $g \sim 100 g_{\min}$ could have an essential action upon atom β-decay rates.

It is known (see, e.g., the right side of Fig.1) that a large magnetic field increases the binding energy of electrons in the atom. As far as the condition of stability of atoms against β-decays is given by the condition of the atom mass minimum [15], [16], the change of the electron binding energy due to the applied magnetic field should also lead to the change of the β-decay rate. However, the role of this effect is much less than those discussed above and it becomes important if the condition

$$\frac{B}{B_0} >> Z^3 \tag{4}$$

is fulfilled [12]. For ^{187}Re, this gives $B \sim 10^{15}$ G, or $g \sim 10^7 g_{\min}$.

The increase of the electron binding energy in a strong magnetic field means that an effective potential between the atom and magnetic charge arises. It accelerates atoms toward the monopole and could cause nuclear reactions between them, i.e. could accomplish a magnetic monopole catalysis. However, the magnetic mirror force will, of course, depress the process due to the premature ionization of the atoms.

In the paper [17], a hypothesis was suggested that the magnetic monopoles of Georges Lochak type are responsible for the explosion at the Chernobyl Nuclear Power Plant. According to it, the magnetic monopoles were formed in the vicinity of turbine generators and got to the steam pipes. Since the oxygen is paramagnetic, the magnetic particles formed "bound states" with oxygen and moved along the steam pipes, together with the steam. After entering the reactor, the monopoles interacted with ^{238}U and, what is prior, with nuclei emitting delay neutrons.

The scheme of decay of a nucleus emitting a delayed neutron is shown in Fig.3. Here the mother nucleus, with atomic weight in the range from
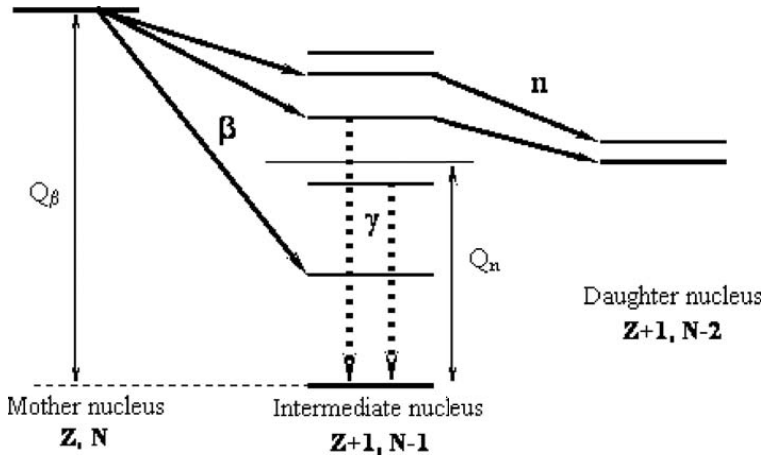
Figure 3: The scheme of decay of nuclei capable to emit delayed neutrons.

A=72 to 160, is produced after the fission of ^{235}U. The mother nucleus is unstable with respect to the β-decay because of an excess of neutrons in it, and the corresponding β-transition gives an intermediate nucleus in an excited nuclear state. If the excitation energy exceeds the binding energy of neutron, Q_n, the intermediate nucleus emits a neutron. Although this emission takes place practically instantaneously, a time necessary for the β-decay is spent before the delayed neutron is emitted (and this explains the term "delayed neutron"). The authors have shown that there were about 500 mother nuclei capable of emitting neutrons per each neutron which was in the reactor at some instant. In the steady-state regime of reactor operation delayed neutrons amount to only a small fraction, $\sim 5 \times 10^{-3}$, of a total number of neutrons participating in the nuclear fission process at some instant. But a distortion of the mechanism of decays should certainly cause a huge increase of the neutron density due to the huge number of mother nuclei. It was suggested the following mechanism of the distortion: the magnetic monopoles deformed electron shells around the mother nuclei. The consequences of the deformation were much stronger for β-decays with small energy release, and, therefore, the number the decays into the intermediate nuclei capable to emit the delayed neutrons rose sharply.

According to our previous consideration, such a scenario is possible only if the monopoles had an unusually large charge $g \geq 100\ g_{min}$. The following alternative scenario based on monopoles with the minimal magnetic charge may be also suggested. The monopoles, after their creation in the vicinity of turbine generators, could form bounded states with atoms of steam because of some kind of attraction between them and the atoms due to an increase of the electron binding energy of atoms in the strong magnetic field (as it was discussed above). After penetration in the reactor, monopoles should be captured by atomic nuclei because the deepest point of the potential energy is reached there. Indeed, the monopole with the minimal charge induces the magnetic field of order $B \sim 10^{17}$ G at distances $r \sim 10^{-13}$ cm. It gives an energy up to 1 MeV for interaction with the nucleon magnetic moment $\mu_N = 3.2 \times 10^{-18}$ MeV/G. This means that intermediate nuclei may be significantly excited after the monopole absorption. If the intermediate nuclei have a high magnetic momentum, an essential part of them should be transmitted from the lower part of the diagram, Fig.3, to the upper one. Nuclei of ^{238}U have zero magnetic moment and can not capture the monopoles.

3   A new interaction

In paper [18], changes of β-decay rate, with periods 24 hours and 27 days, were observed at two laboratories 140 km apart. Extremum deviations of count rate (0.7% for ^{60}Co and 0.2% for ^{137}Cs) from the statistical average took place for the both laboratories when they were oriented properly along the three definite directions established in the outer space. Bursts of count rate of beta-radioactive sources during long-term measurements, similar to data of Ref. [18], were also reported in an independent paper [19].

Series of papers devoted to a demonstration of a dependence of α-activity on cosmological factors was published by Prof. S.E. Shnol et al. (see, e.g., [20], [21]). In these studies, a phenomenon of a deviation of probability distributions from the expected Poisson one was established. The measurements were carried out in fixed with respect to the Earth's surface laboratories during 5 minute time intervals. Non-randomness of repetitions of the shape of the observed distributions was also established at the regular time intervals. In short, the main results were the following:

1. Re-appearance of the same form of a probability distribution took place most likely in the nearest interval of observation.

2. There was a reliable growth of probability of the same form to re-appear after 24 hours, 27 days, and one year.

3. Synchronous measurements of the form carried out in different laboratories showed that for distances less than 100 km about 60% pairs of the distributions had the same form. Probability to observe similar distributions turned out to be high also for measurements on a research ship in the Indian Ocean and in a remote laboratory near Moscow, which were in the same time zone.

These data, in the case of their conformation, will almost undoubtedly testify against the invariance of the radioactive atom (and/or detector) properties with respect to spatial rotations. According to the experiments of Shnoll at al., it is natural to connect the observed effect with the influence of the nearest cosmic environment, such as the Sun and the Moon. Authors of [18] explain a dependence of β-decay rate by the mutual orientation of atoms and unknown cosmic field directed toward the Constellation Hercules.

It is possible to give an explanation of the observed phenomena, based on an idea that the decay rate depends on the atom orientation with regards to some preferential direction in the space. A concrete realization of this suggestion may be the following. Generators of the spinor representation of the rotation sub-group,

$$\sigma^z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}, \qquad \sigma^+ = \sigma^x + i\sigma^y = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}, \qquad \sigma^- = \sigma^x - i\sigma^y = \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix},$$

can be factorized by means of the relations:

$$\sigma^+ = a^\dagger b, \qquad \sigma^- = b^\dagger a,$$

where

$$a = |0\rangle\langle +|, \qquad b = |0\rangle\langle -|,$$

and $|0\rangle$ is the vacuum state. Sign † denotes the hermitian conjugation. Actually, we introduce in such a way the birth and annihilation operators for atoms capable and incapable of decay (atoms of the type a and b, correspondingly). They satisfy the fermion anticommutative relations,

$$aa^\dagger + a^\dagger a = 1, \qquad bb^\dagger + b^\dagger b = 1,$$

which can be also interpreted as resolutions of identity in the Fock spaces for particles of types a and b.

From the physical point of view, the undertaken factorization implies the definition of new quantum numbers,

$$n_a = a^\dagger a, \qquad n_b = b^\dagger b,$$

which correspond to probabilities of atom to decay and to survive, correspondingly. Since $\sigma^z = n_a - n_b$ and eigenvectors of operators n_a and n_b coincide with eigenvectors of σ^z, it is evident that the atom orientation which controls the radioactive atom decay is described here in the close analogy with the description of spin $1/2$ particles. Two different values of such a quasi-spin correspond to atoms capable and incapable to decay.

Under spatial rotations, the ability of the system of the atom plus the measuring instrument to demonstrate the decay, in the general case, are changed:

$$Tr[\rho n_a] \rightarrow Tr[U\rho U^\dagger \, V n_a V^\dagger].$$

Here U_g and V_g are unitary operators describing transformations of an atom state, ρ, and the measuring device under a spatial rotations g. The probability distribution will be invariant under the g transformation iff

$$U_g = V_g.$$

In our consideration we suggest that the measuring device does not change its properties at spatial rotation, $V_g = 1$.

If, e.g., we take an atom completely ready to decay, $\rho_+ = |+\rangle\langle+|$, and rotate it relatively to the fixed instrument, than corresponding transformations appear as follows:

$$U \, |+\rangle = \alpha|+\rangle + \beta|-\rangle,$$

where $|\alpha|^2 + |\beta|^2 = 1$. Thus the spatial rotations lead, in our model, to changing the probability to observe the decay by the factor $|\alpha|^2$. We suggest that there are fixed directions in the cosmic space such that atoms are the most unstable if their quasi-spins are oriented along them.

A given source of radioactivity will demonstrate a dependence of the decay rate on the orientation in the space only if its quasi-spin polarization is not equal to zero. However, the very concept of the polarization implies that there is some interaction which should orient atoms according to the minimum of their energy. Thus, we come to a conclusion that

the energy of an unstable atom should depend on its orientation. This can be described by inclusion into the Hamiltonian of the system a term

$$H_0^{atom} = \frac{E}{2} \sum_{i=1}^{N} \sigma_i^z,$$

where summation is carried out over all radioactive atoms, and E is the energy differences between states with opposite polarizations. The capability for decay of atoms can be changed by an external field, φ, interacting with their quasi-spins[4]. Our non-relativistic consideration does not forbid us to introduce the following interaction in the spirit of the Lee model [22]:

$$H_{int} = \frac{\lambda}{\sqrt{N}} \sum_{i=1}^{N} (\varphi a_i^\dagger b_i + b_i^\dagger a_i \varphi^\dagger),$$

where λ is a coupling constant. The Hamiltonian of the field φ has a usual form

$$H_0^\varphi = \hbar \omega \varphi^+ \varphi,$$

where ω is the frequency of quanta of the external field. The total Hamiltonian,

$$H = H_0^{atom} + H_0^\varphi + H_{int},$$

conserves the total number of atoms,

$$\sum_{i=1}^{N} a_i^+ a_i + b_i^+ b,$$

and the total "readiness to decay"

$$\frac{1}{2} \sum_{i=1}^{N} (a_i^+ a_i - b_i^+ b_i) + \varphi^+ \varphi.$$

In other words, quanta of φ take off and restore the capability of atoms to decay.

According to this model, experimentally observed variations of nuclear decay rates could be a consequence of exchange between radioactive

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[4]It is clear that the energy of the able-to-decay atom should be higher than the energy of one which is unable. Therefore, quanta of φ transmit some kind of excitations.

atoms on the Earth and the Sun by quanta of the φ field (the corresponding Feynman graph is quite obvious).

Interactions between radioactive atoms can be also written in the form of the Fermi 4-particle interaction, i.e. as "current×current" [5]. As far as the current components here are the Pauli matrices, σ_x, σ_y, σ_z, an interaction invariant with regard to the spatial rotations can be written in the form:

$$v = v(r)\,(\vec{\sigma}_1 \cdot \vec{\sigma}_2).$$

It does not modify the total quasi-spin, $\vec{S} = \vec{\sigma}_1 + \vec{\sigma}_2$, of two interacting atoms. The obtained potential resembles the spin dependent nucleon potential, and the theory of nuclear forces prompts one more possible potential,

$$u = u(r)\,[3(\vec{\sigma}_1 \cdot \vec{n})(\vec{\sigma}_2 \cdot \vec{n}) - (\vec{\sigma}_1 \cdot \vec{\sigma}_2)],$$

which preserves $\vec{S}^2$. Apparently, assumptions of this model could be tested and, if needed, $v(r)$, $u(r)$, could be established in space ship experiments.

A current acting upon the radioactive atom may be not only the quasi-spin of other atoms, but a pseudovector of a different nature. In this connection, an assumption that the pseudovector of current of the light monopole suggested by of G. Lochak can be an effective catalyst of the weak decays is of interest.

We are grateful to G. Lochak for numerous interesting discourses and to D.V. Filippov for a useful discussion of an influence of the external magnetic field on probability of the β-decay.

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