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MICROPOLYELECTRONS AS POSSIBLE SOURCES OF THE ANOMALOUS POSITRON PEAKS IN HEAVY-ION REACTIONS*

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Abstract

We propose that aggregates of electrons and positrons in a small assembly [micropolyelectrons $(e^+e^-)^n$], held together by their own electromagnetic interactions, are probably the sources of the anomalous positron peaks observed in heavy-ion reactions. The quasistability of the micropolyelectrons arises from a strong noncentral, short-range, attractive interaction between an electron and a positron in their 0^{++} state, which may be supercritical and may lead to a condensation of such pairs. These entities are strongly attracted to a nucleus with a large charge, due to the quadratic Coulomb interaction between the nucleus and the constituents, and may therefore have binding energies greater than their rest masses to render them spontaneously produced in a strong Coulomb field. Final-state interactions between the produced micropolyelectrons and the receding nuclei may lead to their being nearly at rest and back-to-back decay into e^+ and e^- in some cases, and their being captured into stationary orbits and asymmetrical decay in some other cases.

1. Introduction

A positron being an electron traveling backward in time, polyelectrons were first proposed by Wheeler[1)] in 1946 to be a system of electrons and positrons held together by their mutual electromagnetic

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interactions. A micropolyelectron is a small polyelectron with the dimensions of the classical electron radius (a few fm)[2)-7)]. In connection with the anomalous positron peaks observed in heavy-ion reactions, it is now possible to piece together a coherent picture as to how this type of entity may be the origin of the peculiar phenomenon. Our support for such a proposal comes from an extrapolation of the physics of quantum electrodynamics to small distances, and to intense Coulomb fields.

The main experimental characteristics of the anomalous positron peaks we wish to examine consist of the following peculiarities[8)-11)]: (1) many narrow positron lines, (2) positions of lines relatively independent of combined charge $Z > 163$, (3) electrons of about the same sharp energies are observed in coincidence with the anomalous positrons, (4) the emission of e^+ and e^- occurs nearly at rest and back-to-back in the center-of-mass system in some cases[9),10)] but asymmetrical in energy in some other cases[11)]. From the first three characteristics, we infer that the anomalous positron lines arise from a two-step process: the production of neutral objects with rest masses around 1.6 MeV in an intense Coulomb field in the first stage, and the decay of the objects after the strong Coulomb field disappears following the receding of the scattered nuclei in the second stage. The sharpness of the energy lines implies that the neutral objects are quasistable even in the absence of the intense Coulomb field. They must maintain their quasistability from the mutual interactions between their constituents. What is the nature of these quasistable neutral objects? How are they produced? How do they interact with atomic nuclei?

2. Stability of Micropolyelectrons

Without introducing new forces, we suggested that the unknown objects have electrons and positrons as constituents and are held together by their mutual electromagnetic interactions[2)-7)]. The nonrelativistic Breit interaction between an electron and a positron is well known. The noncentral interactions such as the spin-orbit and the tensor force can be attractive when the spin and the angular momentum of an electron and a positron are properly aligned, as in the $J^{PC} = 0^{++}$ state, to which our attention will be focused. These interactions have a radial dependence of r^{-3}, which overwhelms the centrifugal potential and the Coulomb interaction at distances in the range of the classical electron radius. At such distances, the nonrelativistic approximation is not valid; it is important to find out how these attractive and singular $1/r^3$ interactions will evolve in a relativistic treatment of the two-body problem.

When we use a model (magnetic moment)-(charge current) interaction between the electron and the positron in the 0^{++} state in a Dirac equation, we find an effective potential pocket at short distances deep enough to hold a resonance[2),3)]. Previously, Crater and van Alstine[12)] gave a covariant and nonperturbative treatment of the relativistic two-body problem in the framework of relativistic constraint dynamics. With the Crater and van Alstine equations for e^- and e^+, we again find for the 0^{++} state an attractive interaction at short distances. The noncentral interactions, which vary as $1/r^3$ at large distances, behave as $1/r^2$. They are strong enough to overcome the centrifugal barrier so that there is a barrier separating the long-distance region from the short-distance region. The combined interaction from all contributions is nevertheless supercritical[7)]. Such a supercritical behavior occurs only for the 0^{++} state. While the Crater and van Alstine interaction may still have some degrees of ambiguity, the complexity of the experimental spectrum indicates a complex structure of the unknown objects. It is therefore useful to examine phenomenologically the consequences of a supercritical e^+e^- interaction in their 0^{++} states[4),5)]. In that case, the system is unstable against a collapse to the center, and there will be a change of the vacuum leading to a condensation of these pairs. To make the problem simple, we can describe the (e^+e^-) composite pair in the 0^{++} state as a scalar particle $\varphi = (e^+e^-)$ with an imaginary mass and a repulsive self-interaction. Then the equilibrium states of an (e^+e^-) system is a micropolyelectron $(e^+e^-)^n$ with a finite density of these pairs. These equilibrium states are doubly degenerate. Oscillations about the density of the scalar particle φ give rise to equally spaced levels. Thus, the spectrum of such a micropolyelectron as a condensate of (e^+e^-) pairs will be characterized by approximately equally spaced levels which are nearly doubly degenerate. While more accurate experimental measurements are needed, the experimental spectrum does exhibit such a feature[4),5)].

The range of the mass of the neutral observed objects is below the threshold for the emission of more than one (e^+e^-) pair. We expect that as the micropolyelectron oscillates in the number of the (e^+e^-) pairs, only in the one pair configuration can the system decay into an e^+ and an e^- by tunneling through the barrier separating the short-distance region from the long-distance region.

3. Production of Micropolyelectrons

Experimental data in the reactions considered indicate the production of neutral particles. If these neutral particles are neutral micropolyelectrons $(e^+e^-)^n$, how do they interact with a nucleus to lead to their production? If we consider a micropolyelectron to have a radius of the order of the classical electron radius, the polarization interaction is not large enough to lead to their spontaneous production. The interactions leading to the production come mainly from the quadratic Coulomb interaction. To understand how this comes about, we first consider the interaction of a single constituent electron with a charge e in an external potential V(R) of a point nuclear charge $Z|e|/R$ and shall focus our attention to small-distance regions. The Dirac equation leads to a Schrödinger-like equation with effective interactions $-(eV)^2$ and $-ie\vec{\alpha}\cdot\nabla V$, in addition to the usual Coulomb term. The quadratic Coulomb interaction $-(eV)^2 = -Z^2\alpha^2/R^2$ is attractive and dominates the short-distance region. At short distances, the spinor interaction $-ie\vec{\alpha}\cdot\nabla V$ gives rise to an effective repulsive interaction $3/(4R^2)$. The quadratic Coulomb interaction depends on Z^2 and not on the sign of the constituent charge, while the spinor interaction at short distances is independent of the nuclear charge Z. So, for a neutral micropolyelectron $(e^+e^-)^{n/2}$ with n constituents, contributions from the quadratic

Coulomb interaction add collectively together to give an attractive interaction $-n^2Z^2\alpha^2/R^2$, acting on the micropolyelectron as a whole[6]. When balanced against the repulsive contribution from the spinor interaction, the effective interaction at short distances R becomes[6] $\{-n^2Z^2\alpha^2 + (n^2 + 2n)/4n\}/R^2$. In consequence, the interaction between a micropolyelectron and a nucleus is repulsive when the nuclear charge Z is small, attractive when Z is large, and supercritical when Z is very large. For n = 2, supercritical attraction occurs at $Z_{crit} = 97$, and for n = 4, at $Z_{crit} = 84$. When $Z > Z_{crit}$, the binding energy of a micropolyelectron around a nuclear charge, is greater than that of its rest mass, and the system is unstable against the spontaneous production of the micropolyelectron. As a consequence, a micropolyelectron will be produced in the vicinity of the nuclear charge. The above analysis for the supercritical Z value is obtained for a point nuclear charge. The finite size effect will move these Z_{crit} values to large values but will not prevent the occurrence of the supercritical behavior.

4. Final-State Interactions between a Micropolyelectron and a Nucleus

Our study in the last section is focused on the effective interaction between a micropolyelectron and a nucleus at short distances. As one increases the separation R, the quadratic Coulomb interaction decreases in strength not only because of the R^{-2} dependence, but also because of electronic screening so that the net charge seen by the micropolyelectron decreases. It may therefore occur that for heavy nuclei, the interaction between a micropolyelectron is attractive at short distances but repulsive as the distance R increases. We can explore phenomenologically the consequences of such a final-state interaction between the produced micropolyelectron and a nucleus and can construct the following plausible scenario for the phenomenon of the anomalous positron peaks. We first consider the collision of two nuclei with approximately equal charges. As the two nuclei come to the distance of closest approach to form a system with a large combined nuclear charge such that the single-particle state energy of a micropolyelectron is pulled down below its rest mass due to the strong attraction between the micropolyelectron and the combined nuclear system, micropolyelectrons occupying such a state will lead to a system with a lower energy. Hence, the system is unstable against spontaneous production of the micropolyelectron and a micropolyelectron will be produced. As the two nuclei recede from each other after the collision, the Coulomb field weakens and the binding energy of the micropolyelectron decreases. From the final-state interaction, the micropolyelectron experiences in the beginning an approximately equally attractive force from each of the two receding nuclei. Although it is unstable against pulling to one of the two nuclei, such a tendency is weak for a collision between two approximately equal nuclei. By the time the two nuclei recede to a distance much greater than 1000 fm, the electronic screening of the nuclei begins to be effective and the micropolyelectron experiences repulsive forces from the two nuclei, holding it near the center-of-mass of the system. The repulsive forces weaken as the two nuclei recede, so that the micropolyelectron is held adiabatically to be nearly at rest in the center-of-mass system.

When the charge of one nucleus is much larger than the other colliding nucleus, as in the collision of U on Ta, then the produced micropolyelectron is attracted more to the nucleus with a larger charge when the two nuclei begin to separate from each other. It may therefore be captured into a stationary orbit of the heavier nucleus. At a later stage, when the micropolyelectron decays into an electron and a positron, the electron and the positron share their energies and momenta with the capturing nucleus. The sharing of the energy is inversely proportional to the rest masses so that the sum of the energies of e^- and e^+ can still be very sharp. On the other hand, there is a difference in the Coulomb interaction between a positron or an electron with the nucleus. A positron after the decay gains an energy, while an electron loses an energy due to the Coulomb interaction. In consequence, the energy difference $E(e^+)-E(e^-)$ will shift to a positive quantity. The experimental data[11)] for U + Ta gives an average shift of 250 keV which suggests that the micropolyelectron decays at a distance of approximately 1000 fm from the center of the uranium nucleus. With regard to the momenta of e^+ and e^-, the heavy mass of the capturing nucleus can absorb a large amount of the momenta of e^+ and e^- so that these two particles do not need to be emitted back-to-back; they can have a variable opening angle between them.

5. Conclusions

The experimental characteristics of the phenomenon associated with the anomalous peaks are rather peculiar. Nevertheless, there are elements in the physics of quantum electrodynamics at short distances and intense Coulomb fields which may provide a plausible explanation of this phenomenon. First, the noncentral interaction between an electron and a positron is known to be very strong at short distances when their spins and orbital angular momenta are properly aligned. The attraction may even be supercritical to lead to a system with a very complex spectrum. Second, a small $(e^+e^-)^n$ system is subject to a very strong, attractive interaction from a nucleus with a very large charge. The attraction comes from the quadratic Coulomb interaction. The strong attractive force may lead to the spontaneous production of a micropolyelectron. Finally, the interaction of the spinors $\vec{\alpha}$ of the constituents with the electric field $\vec{E} = -\nabla V$ of the nucleus leads to an effective repulsive interaction. When the receding nuclei are screened by the atomic charges, there may be a net repulsive final-state interaction acting on the produced micropolyelectron at large distances.

The scenario described above may be useful to stimulate further experimental tests using heavy-ion reactions and the bombardment of e^+ on e^-. The search for resonances in the (e^+,e^-) system with the Bhabha scattering experiments are made difficult because of the expected narrow widths from the electron magnetic moment g-2 data. It is also of interest to study the bombardment of e^+ on very heavy targets, to test the concept of the capture of micropolyelectrons by heavy nuclei. In this respect, a recent observation[13)] of an anomaly in e^+ + U and e^+ + Th but no anomaly in e^+ + Ta is worthy of further experimental studies.

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