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Does a Heavy Positronium Atom Exist?

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Recently reported observations in e^+e^- collisions suggest the existence of a heavy lepton $L^\pm$ with a mass $\sqrt{s} \sim 2$ GeV. I predict that a heavy prositronium atom exists, which is an L^+L^- bound state. Its detection would confirm the existence of a heavy lepton. A way is suggested to detect this heavy atom by looking for an x-ray signal of a specific energy in e^+e^- collisions.

Some very interesting results have been reported by Perl[1] which suggest that heavy leptons have perhaps been produced at a mass of $\simeq 2$ GeV in e^+e^- collisions at Stanford Linear Accelerator Center. The data may be consistent with a three-body decay mode of a heavy lepton and not all of the events can, at present, be explained by the processes $D \to K^0(\pi^0)l^\pm \nu$ and $D^* \to \mu\bar{\nu}_\mu(e\bar{\nu}_e)$, where D and D^* are "charmed" pseudoscalar and vector mesons, respectively.

If this charged massive lepton exists, then it is natural to suggest that *there is a heavy positronium atom in nature* consisting of an L^+L^- bound state. The Bohr radius of the ground state of this atom would be $a_L = 2/\alpha M_L \simeq 3\times 10^{-12}$ cm for $M_L \simeq 2$ GeV, compared with $a_p \simeq 10^{-8}$ cm for positronium.[2] The Rydberg constant would have the value $R_\infty = M_L\alpha^2/4\pi \simeq 8.5$ keV. The annihilation of the singlet ground state $^1S_0$ into two photons would have a lifetime $\tau \simeq 3.2\times 10^{-14}$ sec. The weak decay rate of a heavy lepton of mass $M_L \simeq 2$ GeV is of order 10^{12} sec^{-1} and thus this process would not compete with the decay of the heavy atom.

It would be very important to conduct a search for this heavy positronium atom in colliding-beam experiments. The discovery of such an atom would confirm the existence of a heavy lepton. Since the width of the heavy atomic state in e^+e^- collisions is $\sim \alpha^5 M_L$, it is futile to look for the bound L^+L^- states in the total cross section. But the γ transition from the 3^3S_1 state to the 2^3P states, followed by a γ transition from the 2^3P states to the 1^3S state, could be used to verify the existence of the heavy atom. The energies of such transitions have unique predicted values given by

$$E_X(n' \to n) = \tfrac{1}{4}M_L\alpha^2(n^{-2} - n'^{-2}). \quad (1)$$

From (1) we find, e.g., $E_X(3 \to 2) = 3.7$ keV and $E_X(2 \to 1) = 19.9$ keV for $M_L = 2$ GeV. I have chosen to consider the $^3S_1$ state, since it can couple to the $J^P = 1^-$ photon in e^+e^- collisions. On the other hand, the annihilation of the heavy positronium atom would go via photon decay and could not be distinguished from the decay of a heavy hadronic pseudoscalar (vector) meson at $\sqrt{s} \sim 4$ GeV. In Fig. 1, the expected γ transitions in the heavy-positronium-atom energy levels are shown schematically.

The success of the proposed experiment depends, of course, upon whether there is a sufficiently high yield of x-ray signal by the heavy atomic states. The cross section can be esti-

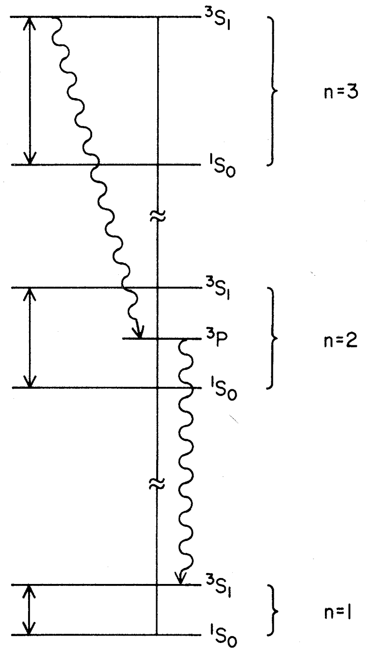

FIG. 1. Heavy positronium energy levels, showing the transition from the 3^3S_1 to the 2^3P states, followed by the transition from the 2^3P states to the 1^3S_1 state.

mated from

$$\sigma = \frac{3\pi\lambda\!\!\!^{-2}\Gamma_{e^+e^-}\Gamma}{(E-E_p)^2+(\frac{1}{2}\Gamma)^2}\left(\frac{\Gamma}{\Delta E}\right), \qquad (2)$$

where $\Gamma_{e^+e^-}$ is the width for decay of the heavy positronium atom into e^+e^- pairs given for $n=3$ by

$$\Gamma_{e^+e^-} = \frac{2}{9}\alpha^5 M_L n^{-3} \sim 3\times10^{-7}\ \text{keV}. \qquad (3)$$

Moreover, Γ is the total width of the atomic state and ΔE is the "energy spread" of the beam. At resonance

$$\sigma = 12\pi\lambda\!\!\!^{-2}(\Gamma_{e^+e^-}/\Delta E) \qquad (4)$$

and for an electron energy of 2 GeV, we find $\sigma \sim 6\times10^{-36}$ cm^2 for $\Delta E \gtrsim 200$ keV. The luminosity at 4 GeV in the Stanford Linear Accelerator Center storage ring is $L = 5\times10^{30}$ cm^{-2} sec^{-1}. Thus, the rate for detecting the x-ray signal is

$$R = \sigma L \sim 3/\text{day}. \qquad (5)$$

If the luminosity L could be increased at 4 GeV, then the count of events would also increase.

Because of the large synchrotron radiation present at 4 GeV, it would probably be best to arrange for the detector device to be perpendicular to the colliding beam, since this radiation is collimated mainly in the beam direction. This would also decrease the amount of Doppler shift of the x ray, which is expected to be a few eV for a momentum resolution ~ 1 MeV.

The idea of doing "high-energy" atomic physics with large storage-ring facilities is an exciting possibility to pursue in the future.

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[1]M. Perl, in Invited Lectures at the McGill Summer School of Physics, June 1975 (to be published); G. Feldman, in Proceedings of the Conference on Lepton and Photon Interactions at High Energies, Stanford Linear Accelerator Center, Stanford, California, 21–25 August 1975 (to be published).

[2]V. W. Hughes, in *Atomic Physics 3*, edited by S. J. Smith and D. K. Walters (Plenum, New York, 1973), p. 1.