POSSIBLE EXISTENCE OF 2^3S_1 POSITRONIUM IN MATTER

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The level shift of the hyperfine structure of 2S positronium is described as a function of the field existing between the positronium atom and the medium. An expression is found for the shift of the hyperfine structure levels of 2S positronium as a function of the pressure of the gas surrounding the positronium atom. A method is indicated of preparing concrete substances expected not to interact with a trapped atom. The possibility of existence of such "vacuum" substances is promising for the searches and studies of the properties of metastable states of trapped atoms, particularly 2^3S_1 positronium.

GOL'DANSKIĬ[1] has already noted that searches for 2^3S_1 positronium are now among the most urgent problems in this field. In addition, we have shown[2] that "pure" 2^3S_1 positronium can exist, in principle, at a gas pressure $P < 10^{-3}$ Torr and at a field $E < 0.1$ V/cm between the molecules (atoms) of the medium and the positronium atom. We did not name in[2], however, a single concrete substance where the calculated value of the field can be expected.

To detect 2^3S_1 positronium it is necessary to satisfy two conditions: 1) the presence of a medium that ensures the possibility of production of the 2^3S_1 positronium, and 2) the absence of an internal field between the molecules (atoms) of the given medium and the positronium atom, $E < 0.1$ V/cm.

The trivial possibility for the realization of the condition $E = 0$ is obviously the state of extremely high vacuum, although the first condition is then violated. The purpose of the present communication is to show that the condition $E = 0$ can be easily realized without producing an extremely high vacuum, and to indicate several concrete substances where there is no interaction between the trapped atom and the medium.

It is known[3] that the level shift of the hyperfine structure of the ground state of atomic positronium is determined by the value of the field E and can be expressed as a function of the pressure of the gas surrounding the positronium atom. Let us find an expression for the level shift of the hyperfine structure of 2S positronium as a function of E and of the pressure of the gas surrounding the positronium atom.

Using reasoning and a procedure analogous to those of[3], we obtain for the level shift of the hyperfine structure of 2S positronium in a field E the relation

$$\nu(2S)=\frac{1}{8}\nu_0\left(1-\frac{96a^2E}{e}\right)^3. \qquad (1)$$

Here $h\nu_0$ is the excess of the energy of the triplet over the singlet in vacuum for 1S positronium, 2a is the radius of the first Bohr orbit of the positronium, e is the electron charge, and h is Planck's constant.

By reasoning and calculations analogous to those used for 1S positronium in[3], we obtain an expression for the shift of the hyperfine structure of 2S positronium in a medium as a function of the pressure of the gas surrounding the positronium atom:

$$\nu(2S)={}^1/_8\nu_0(1\pm 16DP), \qquad (2)$$

where D is the fractional pressure shift of the hyperfine-structure levels of the ground state of positronium.

Inasmuch, according to (2), the hyperfine-structure level shift can be either positive or negative, depending on the concrete medium in which the positronium atom is located, it is possible to cancel out the hyperfine level shifts by mixing substances having values of D of opposite signs. It goes without saying that according to (1) we have in such a mixture $\nu(2S) = \nu_0/8$ and $E = 0$. On the other hand, by direct comparison of (1) with expression (12) of[3] we can verify that for 1S positronium we also have $E = 0$ in this case. Taking this into account, we can already indicate a substance with $E = 0$ for 2S positronium and its analogs, without having any experimental data whatever on the hyperfine structure level shift, making use of the data on the hyperfine structure level shift of the 1S state of positronium. Since at present there are only experimental data on the negative level shift of the hyperfine interval of 1S positronium in gaseous argon[4], it follows that, without loss of generality, we can point to several substances satisfying the condition $E = 0$ with respect to the analog of positronium—the atom H^1.

The presence of positive and negative hyperfine-structure level shifts of the ground state of the H^1 atom was established in a number of works[5-8]. The total hyperfine-structure level shift for the gas mixtures is given by[3,9]

$$\delta\nu=\nu_0\sum_{i=1}^{n}D_iP_i. \qquad (3)$$

Here D_i is the value of the parameter D of the H^1 atom in the i-th gas with a partial pressure P_i. Obviously, $\sum_{i=1}^{n} P_i = 1$.

Using (3) with $\sum D_iP_i = 0$, $i = 1, \ldots, n$, and also the numerical values of the parameter D_i for an H^1 atom in the i-th gas, as given in[5], and assuming furthermore for the sake of simplicity that $n = 2$, we find that within the limits of the pressures realized in[5] the following mixtures satisfy the condition $E = 0$ for the atom H^1: 50% He + 50% Ar, 62% Ne + 38% Ar, etc., at T = 318 ± 5°K.

It is interesting to note that whereas the hyperfine structure level shifts of tritium and of H^1 differ appreciably, the compositions of media that satisfy the condition E = 0 are the same for them within the limits of experimental error. The same holds true for deuterium. We can therefore expect gases in the state E = 0 with respect to the H^1 atom at $P > 10^{-3}$ Torr to be of interest for the search for "pure" 2^3S_1 positronium.

Independently of this statement, however, the determination of the composition of a mixture with E = 0 for atomic positronium is trivial once data are obtained on the positive level shift of the hyperfine structure of the positronium atom. Furthermore, substances satisfying the condition E = 0 at $P > 10^{-3}$ Torr are, in addition to all other factors, of interest for the investigation of "pure" pick-off annihilation.

It should be borne in mind that the presence of substances causing no shifts of the hyperfine structure levels of trapped atoms is an established fact. Thus, Arditi and Carver[9] have already noted that the mixtures 75% Ar + 25% Ne, 85% Ar + 15% He, and 70% Ar + 30% N_2 produce at T = 303°K a negligible shift of the hyperfine structure of Cs^{133}. According to the data of Bender, Beaty, and Chi[10], when the temperature deviates by 6 ± 1° from room temperature, the mixture 11.7% Ne + 88.3% Ar produces no shift of the hyperfine structure of Rb^{87}.

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