Enhancement of parity and time invariance violation in radium

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Parity (P) and time (T) invariance violating effects in radium are strongly enhanced due to the large nuclear charge Z, close electronic states of opposite parity, and the collective nature of P,T-odd nuclear moments.

In Ref.[1] the states $7s6d\ ^3\mathrm{D}_2$ with $E = 13993.97\mathrm{cm}^{-1}$ and $7s7p\ ^3\mathrm{P}_1$ with $E = 13999.38\mathrm{cm}^{-1}$ were considered, which are separated by a very small interval $\sim$5 cm^{-1}. Simple estimates showed that the effects of nuclear P- and T-odd moments such as the magnetic quadrupole moment, the Schiff moment and the nuclear P-odd, T-even anapole moment are hugely enhanced.

We now present more accurate calculations of these and other parity and time invariance nonconserving effects in those states of the radium atom where the effects are large. A relatively simple *ab initio* approximation is used to perform the calculations. The approximation is a reasonable compromise between the simplicity of the calculations and the accuracy of the results. It is based on relativistic Hartree-Fock (RHF) and configuration interaction (CI) methods. A minimum number of basis states are used at the CI stage of the calculations. However, important many-body effects, such as polarization of the atomic core by an external field and correlations between core and valence electrons, are included in the calculations of the single-electron matrix elements.

Our calculations show that the contributions of the Schiff and magnetic quadrupole moments to the atomic EDM in the $^3\mathrm{D}_2$ state are of the order of $10^{-19}\eta\ e\cdot$ cm (η is the dimensionless constant of the P,T-odd nucleon-nucleon interaction). This value is about 10^5 times larger than the EDM of the Hg atom which currently gives the best limit on η [2]. We have also performed calculations of the atomic EDM induced by the electron EDM. We found that in radium the electron EDM is enhanced by a factor of 5400 in the $^3D_1$ state. This is many times larger than the enhancement factors for the ground states of Fr (910) and Au (260) [3].

The parity nonconserving (PNC) electric dipole transition amplitude between the ground and $^3\mathrm{D}_1$ even states is about $E1_{PNC} \approx 0.8 \times 10^{-9}(Q_W/N)iea_0$, which is 100 times larger than the measured PNC amplitude in Cs [4] and about 5 times larger than the corresponding value in Fr [5].

The transition amplitude between the ground and $^3\mathrm{D}_2$ even sates induced by the nuclear anapole moment is about $10^{-9}ea_0$, which is more than 10^3 times larger than a similar amplitude in Cs [4].

The calculations show that radium gives P,T-odd effects larger than those in all atoms considered before. This makes radium an excellent candidate for experimental work on P- and T-odd forces by means of atomic physics.

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