POLARIZED BEAM MEASUREMENT OF PARITY NONCONSERVATION IN ATOMIC CESIUM

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An improved measurement of parity nonconservation in cesium is being performed. We measured the forbidden electric dipole transition amplitude between 6S and 7S states of cesium. We employed optical pumping technique to produce a spin polarized cesium atomic beam, and achieved five times better signal-to-noise ratio than our 1988 measurement. So far we have reproduced the 1988 result and plan to measure the parity nonconserving amplitude within 0.5%. By studying four different hyperfine transitions between 6S and 7S states we expect to measure the anapole moment of the cesium nucleus as well.

I. INTRODUCTION

Since the proposals by the Bouchiats[1] to measure the parity-nonconserving neutral current interactions in heavy atoms, parity nonconservation (PNC) has been measured in Bi, Tl, Pb and Cs with varying degrees of precision. During the 80's when these experiments measured the PNC within roughly 10%, the main interest was to show the existence of the neutral current interaction at this very low energy scale. Following the 2% measurement on cesium PNC by the Boulder group in 1988[2], however, atomic cesium has become one of the most important systems to precisely study the standard model and look for a new physics beyond it. It should also be emphasized that we need to know atomic wave function with corresponding precision to interpret the experimental result in atomic PNC in terms of more fundamental parameters of the interaction. The groups at Notre Dame[3] and Novosobirsk provided just such calculations for cesium with 1% precision. It is relatively simple structure of cesium atom - one valence electron outside a closed core - that made the calculation tractable and calculation for other heavy atoms with a comparable precision is much more difficult, if not completely impossible.

Since our 1988 measurement we have implemented optical pumping and new detection schemes that gave us a big improvement in the signal-to-noise ratio. Recently we successfully reproduced the 1988 result with only one day of data taking and are currently working to bring the precision down to 0.5%.

II. CESIUM ATOM and PNC MIXING

Heavy atoms are preferred in PNC measurement because size of the PNC is scaling as a cube of an atomic number (Z^3) in addition to relativistic enhancement. For cesium, which is the heaviest stable alkali atom ($Z = 55$), added advantages include relative ease in generating high-density atomic beam, availability of lasers at all the relevant transitions, and the wealth of precise spectroscopic information due to its role in atomic clock.

Ground state cesium is in $6S_{1/2}$ state and Cs^{133} has nuclear spin of 2/7, leading to the hyperfine structure of $F=3$ and 4 (see Fig. 1). The hyperfine separation is 9.2 GHz, the famous clock transition. First excited states consist of fine structure of $6P_{1/2}$ and $6P_{3/2}$. Transitions between 6S and 6P, known as alkali D lines, are electric dipole (E1) allowed and very strong. They are used for optical pumping or cooling and trapping of cesium atoms. In our PNC measurement we are interested in the transition between 6S and 7S states, which is forbidden for El amplitude if the parity is conserved symmetry. Given the parity nonconserving nature of the neutral current interaction between electrons and quarks mediated by Z bosons (Fig. 2) we may rewrite the nS eigenstate as

$$\overline{|nS>} = |nS> + \sum_{n'} \frac{<n'P|H_{PNC}|nS>}{E_{nS}-E_{n'P}} |n'P> \tag{1}$$

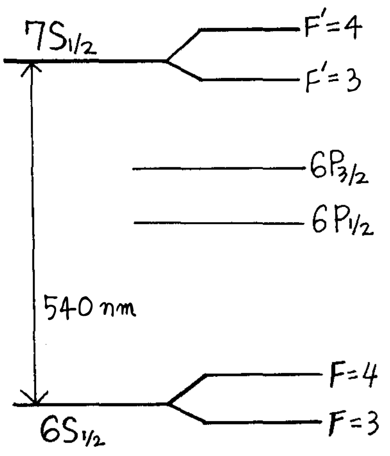

Fig. 1 Cesium Energy Levels

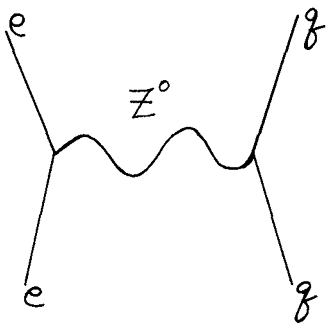

Fig. 2 Diagram for PNC Hamiltonian

III. OUTLINE OF THE EXPERIMENT

Evaluation of the matrix elements in (1) shows that the amplitude of P-state admixture to S is 10^{-11}. This is hopelessly small quantity to measure directly. Instead, we applied dc electric field to produce Stark induced E1 amplitude,

$$A_{E1} = A_{ST} + A_{PNC} \tag{2}$$

which can interfere with each other to produce E1 rate

$$R_{E1} = |A_{ST}|^2 + 2RE\ (A_{ST}^* A_{PNC}) + |A_{PNC}|^2\ . \tag{3}$$

The interference term can be made much larger than the PNC term by applying suitable dc electric field. In the real experimental set up (Fig.3) we have E field normal to the k vector of 540-nm laser photons, and magnetic field is also applied perpendicular to both E and k. We may regard these three vectors as defining our coordinate system. Reversal of any one of E, B or helicity of the photons constitutes a parity transformation and introduces sign change to the interference term. From this point of view we define PNC modulation as

$$dPNC = \frac{R_{E1}(RHC) - R_{E1}(LHC)}{R_{E1}(RHC) + R_{E1}(LHC)}, \qquad (4)$$

where, RHC stands for right handed coordinate system, LHC for left handed coordinate. At typical electric field, E=500V/cm, dPNC is about 6×10^{-6}, which is large enough to be measured precisely.

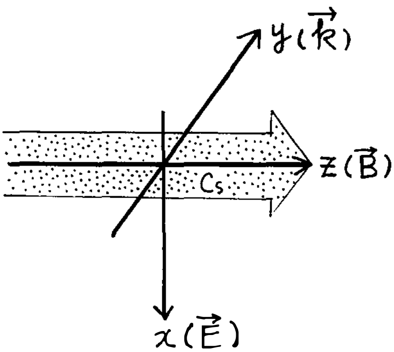

Fig. 3 Experimental Configuration

The interference term in (3) vanishes when averaged over ground state Zeeman levels, and to measure PNC we have to study 6S-7S transition between well defined hyperfine and Zeeman levels. In 1988 experiment we accomplished it by applying large (70 Gauss) magnetic field to resolve transitions between different Zeeman levels. For the present experiment we employed optical pumping technique. We have two diode lasers tuned to cesium D lines to pump almost all the atoms into a single state, e.g. $|6S, F=3, m_F=3\rangle$. This implies 16 fold increase in signal size. Optical pumping also allowed us to use a novel scheme to detect 6S-7S transition.

While optical pumping increased effective atomic beam density, power buildup cavity of 540nm laser beam increased number of photons that interact with atoms. Use of power buildup cavity is not new in Cs PNC experiment, but its improvement helped to increase signal size. Overall, we achieved 25 times larger signal (or 5 times signal-to-noise ratio), and we can measure dPNC to within 10% of its size in less than half an hour.

IV. PRELIMINARY RESULT

The improvement in sensitivity presented us with both opportunity and challenge. We can now measure dPNC to 0.5% precision, which will provide very stringent test on many ideas of new physics. However, higher precision also requires correspondingly better control of various systematics. One class of systematics concerns the issue of calibration. Imperfect optical pumping, presence of nearby unwanted 6S-7S transitions or saturation of the main transition can complicate interpretation of dPNC. Another group of systematics is from those rate terms that can mimic the Stark-PNC interference. Most problematic in this regard is the presence of magnetic dipole transition amplitude and its mixing with the Stark amplitude. Also some type of misalignment in E or B can couple with ambient field to produce PNC-like modulation on 6S-7S transition rate.

After two years of intensive study all of these problems are well understood and we can either measure or control them with enough precision and accuracy. We made a series of runs in October and December of 1993 to measure PNC. Our new result was in good agreement with the 1988 result and presently we are taking care of final loose ends before we further accumulate data.

V. CONCLUSION

So far we have focussed our attention on a single hyperfine transition, namely 6S F=3 to 7S F=4. By simply tuning the lasers to proper transitions we should be able to study all 4 lines between 6S and 7S. PNC measurement on $\Delta F=0$ transitions is new, because application of magnetic field does not remove degeneracy among Zeeman levels when $\Delta F=0$. Comparison among the PNC numbers from different hyperfine transitions are important because they should provide information on parity violating anapole moment of cesium nucleus.

During the last decade there have been revolutionary developments in cooling and trapping atoms. Alkali atoms are the most extensively studied species in this field, and this opens up new experimental possibilities in atomic PNC measurements. High atomic density and pure polarization should give higher signal-to-noise ratio than beam experiment. It will also allow us to make measurements on a string of cesium isotopes. Comparison of PNC among isotopes implies cancellation of atomic matrix element whose uncertainty will soon limit the cesium PNC measurement. We may also measure PNC from francium (Z=87) which has 20 times larger PNC effect than cesium, but does not have a stable isotope.

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