ANTIPROTONIC ATOMS AND LONG RANGE HADRONIC INTERACTIONS

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INTRODUCTION

There are several motivations to study if there is any component of the strong interaction with a range larger than the pion Compton wavelength, $\lambda_\pi = \frac{\hbar c}{m_\pi}$.

Indeed several authors$^1$, by exploiting the formal analogy between QED and QCD, suggested that two gluon exchange between color singlets could result in a force falling off as an inverse power of the relative distance, $R$:

$$V_\alpha R^{-N},$$

much in the same way as two photon exchange originates the Van der Waals force between electrically neutral systems.

Also, in schemes of Grand Unified Theories$^2$ one often encounters light particles, $m_\chi \ll m_\pi$, originating from the spontaneous breaking of the large symmetry group of the theory. If these particles do exist, a Yukawa-like potential

$$V = g^2 e^{-m_\chi R/R}$$

superimposed to the exchange of known mesons should be observed in hadron interactions.

Furthermore, evidence for long range (LR) forces in pion-nucleon scattering has been claimed by Sawada$^3$. Although this evidence is not quite clear to us, it is worth investigating if a similar effect shows up in N-N interactions.

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In order to have a clean signature of a hypothetical LR force, a compromise between two opposite criteria must be found: i) the distance between the (groups of) interacting hadrons must be as small as possible in order that the hypothetical LR force can have detectable effects; ii) the interacting particles must be apart enough that the short range (SR) component of the nuclear interaction, which is not well understood, does not hide the (small) effect one is looking for. Antiprotonic atoms, in circular orbits with radius $r \approx 10$ fermi, look a promising tool for this study, as suggested by several authors.

The aim of this paper is to single out the particular antiprotonic atoms and the particular transitions thereof which are best suited to detect a LR interaction if it does exist, or to provide bounds on its strength. Comparison with present bounds will show that experiments on suitably chosen antiprotonic atoms can reach a very significant sensitivity.

**BOUNDS ON LONG RANGE INTERACTIONS**

In principle, any experiment where interactions between hadrons or groups of hadrons are investigated is suitable for the detection of a LR interaction. A discrepancy between prediction of the "standard" theory and experimental results could imply that an "anomalous" interaction is present, whereas agreement sets upper bounds on the "anomalous" coupling constants.

Each experiment is characterized by the value of the average distance between the interacting systems and by the dominant interaction between them. On one extreme one has the Eötvös experiment, concerned with the gravitational interaction of macroscopic bodies at macroscopic distances. On the other side, nuclear physics experiments explore typical distances of the order of 1 fermi, where strong interactions play the main role. In-between, one has atomic and molecular physics, where electromagnetism is the dominant interaction and typical distances are in the range $10^5$ fermi (molecules) - 10 fermi (antiprotonic atoms). Each experiment is best suited for the study of a specific range of masses $m_X$ or exponents $N$. Experiments with large (small) values of $R$ are sensitive to the exchange of light (heavy) particles or small (large) exponents. In addition, hypothetical LR interactions can be best detected when the dominant interaction is weak and well known.

A systematic analysis of the effects of hypothetical LR forces has been performed recently. No positive effect was found. In Figure 1 we summarize the bounds on the coupling constants $g^2$ and $\lambda$ for potentials of the form when $m$ is the nucleon mass, $\sigma_1$ are the nucleon spin operators and $r_0 = 1$ fermi.