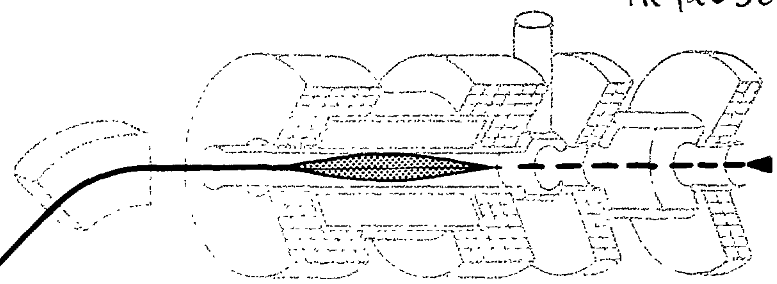
Université Joseph Fourier
IN2P3 - CNRS



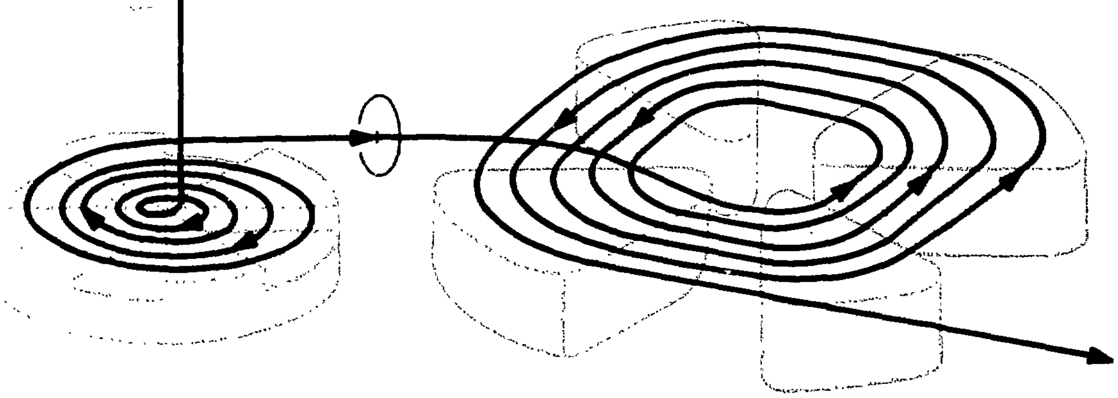
ISN 90.59

SOME OPEN ISSUES IN NUCLEON–ANTINUCLEON INTERACTION

Jean–Marc RICHARD
Institut des Sciences Nucléaires
Université Joseph Fourier—IN2P3—CNRS
53, avenue des Martyrs
F–38026 GRENOBLE Cedex, France

August 5, 1990

Talk given at the Workshop on Science at the KAON Factory, Vancouver, B.C., Canada, 23-28 July 1990



SOME OPEN ISSUES IN NUCLEON–ANTINUCLEON INTERACTION *

Jean–Marc RICHARD
Institut des Sciences Nucléaires
Université Joseph Fourier—IN2P3—CNRS
53, avenue des Martyrs
F–38026 GRENOBLE Cedex, France

August 5, 1990

1 Introduction

The conventional picture of the $N\bar{N}$ interaction at low energy relies on the superposition of a long–range elastic potential and a short–range absorption. In the meson–exchange model, the long–range $N\bar{N}$ potential is deduced from the NN one by a G–parity transformation. It is supplemented by a short–range, complex potential which simulates the effect of annihilation. This simple optical–potential picture is sometimes replaced by a coupled–channel formalism where a few two–body channels with various masses simulate the effect of the numerous mesonic final states.

This approach has been successful in the period running from the discovery of the antiproton to the opening of LEAR. As emphasized by Shapiro [1], the large inelastic cross–section ($\sigma_{inel} > \sigma_{el}$) is due to the conspiracy of the long–range and short–range forces. The former focuses the wave–function towards the annihilation region where the latter can work. The optical model also explains why the charge–exchange ($p\bar{p} \to n\bar{n}$) cross–section is so small, due to a cancellation of the two isospin amplitudes $\mathcal{M}(I=0)$ and $\mathcal{M}(I=1)$, which is effective enough, provided annihilation acts up to around 1 fm.

Unfortunately, this simple optical model approach is not likely to survive the LEAR–ACOL era. Recent data on spin observables [2] contradict the predictions of potential models, and the *postdictions*, obtained at the expense of additional parameters and laborious fine tuning, do not appear as very convincing, so far. The situation is, however, better for the $p\bar{p} \to \Lambda\bar{\Lambda}$ reaction [3].

*Talk given at the Workshop on Science at the KAON Factory, Vancouver, B.C., Canada, July 1990.

2 Annihilation

There have been several debates on the *range* of annihilation, starting with the analysis following the first measurements of antiproton cross–sections. One should first point out that the range is not clearly read off from optical models. The imaginary part of the potential usually exhibits a larger range than the transition potentials in the equivalent coupled–channel formalism. More relevant than the potential itself are the radial densities of annihilation [4] $\varrho(r) = -|u^2_{n,l,S,J}|W$ where u is the radial wave–function and W the imaginary potential.

It remains that a naive analogy with e^+e^- annihilation in QED would lead to a very short range $r_A \simeq 0.1$ fm which would never allows one to reproduce the observed cross–sections. In fact, since the nucleon and the antinucleon are composite, annihilation looks more like a molecular rearrangement [4]. The range is essentially given by the size of the mesons, *i.e.* their ability to pick up a quark in N and an antiquark in $\bar{N}$ [5]. Noticeable exceptions are annihilations like $p\bar{p} \to \phi\phi$ where all incoming quarks have to disappear. This is a short range process, and it has already been speculated that it should propagate in nuclei more deeply than other elementary reactions, in line with the fashionable ideas of "colour transparency" [6].

Even more difficult are the problems related to the annihilation *mechanisms*. First, it is almost impossible to disantangle the selection rules due to the genuine quark dynamics from the effects induced by the initial state interaction and its strong spin and isospin dependence which will be discussed in the next section. If one compares only branching ratios corresponding to the same initial states, one is left with only a few comparisons such as that of $\pi^0\pi^0$ and $\eta\eta$ which involves rather different momenta, *i.e.* probes different regions of the initial wave–function. Another strategy was attempted recently by Klempt [7], who compared channels such as $\pi\rho$ and $\pi\omega$ with different quantum numbers but same kinematics. Klempt's study reinforces the warning that initial state interactions can be dramatically important in annihilation from protonium states.

Branching ratios have been computed by many authors [8]. They use rearrangement diagrams or annihilation diagrams or some superpositions with *ad–hoc* weights. Unfortunately, no clear conclusion has yet emerged. In these calculations, one is perhaps pushing too far the constituent quark model and the ${}^3P_0$–types of models for creation or annihilation of pairs of quarks. These effective operators have been designed for studying the decay of baryon resonances, with only one additional $q\bar{q}$ pair in the final state and a small energy release. In $N\bar{N}$ annihilation, several pairs of high momentum are created or destroyed and many intermediate states contribute.

In summary, many data have been accumulated on annihilation at rest [9]. This is a fascinating process, where matter undergoes a phase transition from its baryonic phase to the mesonic one. However, the dynamics of this transition is still poorly understood.

3 Long–range forces

The meson–exchange model of nuclear forces is likely to be an effective theory, whose intimate connection with QCD is not yet very well elucidated. As a consequence, the G–parity transformation of the NN potential, leading to a long–range $N\bar{N}$ potential, though technically correct, may well neglect important aspects of the $N\bar{N}$ elastic forces.

Consider, for instance, the interaction between two hydrogen atoms. In the conventional approach, a proper antisymmetrization of the electronic wave–function and resummation of the leading diagrams leads to an adiabatic potential which acts between the two protons and governs the ground–state and the first excitations. Now, a C–conjugation of this potential, if by any means possible, would not be too adequate for a hydrogen–antihydrogen system, even if one forgets about annihilation. In this system, the configurations of protonium–positronium type plays an important role, the hierarchy of the excitation energies is modified and new approximation schemes should be implemented. Similarly, the dynamics of $N\bar{N}$ interaction involves important contributions from $q^2\bar{q}^2$ intermediate state which are not well accounted for in optical models.

There are obvious experimental difficulties for measuring the $N\bar{N}$ long–range forces in presence of a very strong annihilation. Obviously, differential distributions and spin observables are required. In fact, polarization does not suffice, since tensor forces, which are likely to be very strong, manifests themselves more clearly in spin transfert or spin correlation parameters [2].

Recent studies have shown that the phenomelogical analysis of $N\bar{N}$ data is not an easy task. Typically, one wishes to compare channels where the forces are attractive to channels where they are repulsive. This could be, for instance, the isospin partners ${}^{2I+1,2S+1}L_J = {}^{1,3}P_0$ and ${}^{3,3}P_0$ of protonium states [4,7] or the various P states in scattering situations. In each case, one wishes to compare simple models where only the pion–exchange tail is included beside annihilation, and more refined models where sophisticated ρ, ω, two–pion, ...exchanges are also included. When pion exchange is repulsive, the wave–function is not too much further suppressed by other exchanges. When pion exchange is attractive, it enhances the wave–function. Further attraction does not increase $|u^2(r)|$. It produces an oscillation, which is reminiscent of the Sturm–Liouville node one gets near or above the threshold with a potential which is attractive enough to support one bound state. As a consequence, the averaged $|u^2(r)|$ do not differ much when going from the simple to the sophisticated model [10].

To test the coherent attraction which is predicted in some partial waves by the meson–exchange model [11], it seems preferable to rely on direct consequences, namely the existence of quasi–bound states.

4 Baryonium

The $AX(1565)$ state was reported by the ASTERIX collaboration and confirmed by the Crystal Barrel group [9]. A possible interpretation of this new meson resonance is an $N\bar{N}$ quasi–bound state, in the coupled partial waves ${}^3P_2 - {}^3F_2$ with isospin $I = 0$. The tensor potential is expected to be very strong in this $I = 0$, natural parity states. As a consequence, the orbital basis $|l = J - 1\rangle$, $|l = J + 1\rangle$ is not appropriate. One should instead form the combinations which diagonalize the tensor operator S_{12} [11]. This simple exercise leads to a channel where the central and tensor potential acts coherently, as $V_C - 4V_T$, with an effective orbital barrier $(J^2 + J + 2)/mr^2$. One predicts a sequence a states ordered according to J rather than to the orbital momentum l. If the AX is the $J = 2$ member, one expects the $J = 1$ and $J = 0$ partners below, with a spacing of around 300 MeV. The width of these low lying states is rather large if computed from the same imaginary potential W, since the N and the $\bar{N}$ are less efficiently separated by the centrifugal barrier. However, in any microscopic model [8], the strength of W decreases when one goes below threshold, since more and more channels involving vector mesons become energetically forbidden. So the width of those $J = 1$ and $J = 0$ states could be comparable to that of the AX.

This confirms that there are still exciting discoveries to be made with low–energy antiprotons.

Acknowledgments. I am pleased to thank the organizers and the conveners for the stimulating atmosphere of this Workshop, the members of the Nuclear Theory Group at the University of Washington for their hospitality at Seattle where this contribution was written, and, in particular, G.A. Miller for comments on the manuscript.

References

[1] I.S. Shapiro, *Phys. Rep.* **35C**, 129 (1968).

[2] C. Lechanoine–Leluc, Contribution to this Workshop.

[3] M. Alberg, contribution to the LEAP 90 conference, Stockholm, 1990, to be published, and private communication.

[4] J. Carbonell, G. Ihle and J.-M. Richard, *Z. Phys. A* **334**, 329 (1989).

[5] A.M. Green, J.A. Niskanen and J.-M. Richard, *Phys. Lett.* **B121** , 101 (1983).

[6] See, e.g., the contributions by S. Brodsky, I.S. Shapiro and G.A. Smith, in Proc. Int. School of Physics with Low Energy Antiprotons, Erice, June 1988, ed. F. Bradamante *et al*, Plenum, N.Y., 1990.

[7] E. Klempt, *Phys. Lett.* **B**, *in press.*

[8] A.M. Green, Proc. Erice School, *loc. cit.*

[9] See the contributions by C. Amsler and by R. Landua at this Workshop.

[10] J. Carbonell, C.B. Dover and J.M. Richard, in preparation.

[11] C.B. Dover and J.M. Richard, *Phys. Rev.* **D17**, 1770 (1978).