Paper given at the
IV International Symposium
on Antinucleon-Nucleon Interactions
Syracuse, New York
May 2, 1975

Gamma Spectra from $\bar{p}p$ and $\bar{p}d$ Annihilations at Rest*

D.N. Michael[†]

Syracuse University, Syracuse, New York

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

*Work supported by the National Science Foundation and the Energy Research and Development Agency.

[†]Also at Brookhaven National Laboratory, Upton, New York.

1.

This is a preliminary report on the results of an experiment which was an attempt to observe gamma rays of discrete energy from electromagnetic transitions from possible long-lived antiproton-nucleon bound states. The experiment was largely motivated by the results of the Athens-Syracuse collaboration, in which a large excess had been observed in the rate of gammas from antiproton annihilations at rest in deuterium above that expected from neutral pion decay, assuming charge independence in the annihilation process.⁽¹⁾ The data from this experiment suggested that the spectrum of the excess gammas could be in the form of discrete lines. One possible explanation of this apparent violation of charge independence, then, was that this excess of gammas could be coming from long-lived bound states of the antinucleon-nucleon system. We have attempted to observe gamma lines from these states in a high-statistics experiment, by using a large NaI crystal to detect the gamma spectrum from antiproton annihilations at rest in both hydrogen and deuterium.

The experiment was carried out at the Brookhaven AGS from February to April of this year by a collaboration consisting of D. Lowenstein, A. Nathan, N. Samios, and A. Schwarzschild from Brookhaven National Laboratory, and T. Kalogeropoulos and myself from Syracuse University. Antiprotons were brought to rest in a target filled with either liquid hydrogen or deuterium, by degrading a 750 MeV/c electrostatically separated antiproton beam. An electronic signal for antiprotons stopping in the target, with negligible contamination, was obtained by the usual techniques of time-of-flight and Cerenkov rejection of fast particles in the incident beam, and a requirement for large ionization in a scintillation counter between the degrader and the entrance of the target. Typical antiproton stopping rates in the experiment were of the order of 130 per second.

A section view of the apparatus, as seen by an incoming antiproton, is shown in Fig. 1. The liquid hydrogen or deuterium target was 6 inches

2.

Fig. 1. Section view of apparatus as seen by an incoming antiproton.

3. in diameter by 19 inches in length, and its vacuum box contained a thin mylar window which extended continuously around the upstream end and along both sides beyond the downstream end of the target vessel. The target was surrounded by eight scintillation counters, M_1 through M_8 , which were used to record the approximate charge multiplicity produced with each gamma. The NaI detector consisted of a 10-inch diameter by 10-inch long crystal, surrounded by a large plastic scintillator, all of which was contained in a heavy lead shield. (2) Between the crystal and the target was a 6.8-inch diameter hole in the lead shield, which was covered by a circular scintillation counter, C_0 , used to record whether a charged particle or neutral entered the detector.

An event was recorded each time a pulse greater than 4 MeV was obtained in the NaI crystal which was in coincidence with a stopping anti-proton. Spectra were accumulated in a large multi-channel pulse height analyzer; the memory of the analyzer was apportioned so that 32 separate, 128-channel spectra could be collected concurrently, each according to specific conditions of the various plastic scintillators. Eight separate spectra were obtained according to (1) whether or not a signal was present in C_0 , and (2) if none in C_0 , then the number of multiplicity counters, M_i , which had a signal. In order to improve the energy resolution of the NaI, each of these eight spectra was further subdivided into four, according to the height of the pulse obtained in the large plastic scintillator shield surrounding the NaI crystal. The four different shield-level conditions were as follows:

Shield Level, Y	Minimum Pulse (MeV)	Maximum Pulse (MeV)
0	-	1.1
1	1.1	4.4
2	4.4	7.6
3	7.6	-

4.

An important check of the apparatus was made from time to time during the experiment by changing the stopping beam to negative pions and observing gammas from the reaction $\pi^- p \rightarrow \gamma n$, or $\pi^0 n$. Typical spectra are shown in Fig. 2, for three different shield-level conditions, Y. An energy resolution was obtained for the 129.4 MeV gamma of about 15% FWHM for each of the three shield-level conditions. Also shown in Fig. 2 are spectra obtained from stopping negative pions in deuterium. The gamma line is Fermi-broadened, and the π^0 signal is suppressed in this reaction.

The charged particle spectra obtained in the NaI, that is, the spectra of events in which a signal was present in C_0 , are shown in Fig. 3 from all running in hydrogen and deuterium. The peaks in each spectrum correspond to charged particles which traverse the length of the crystal; the width of the peak is dominated by the ionization statistics in the NaI. This peak provided a continuous monitor of the energy calibration and resolution stability throughout the experiment. Individual runs were read out after several hours of data taking, and small shifts were made in the energy scale of the data in order to correct for long-term drifts in gain.

The observed gamma spectra from antiproton annihilations in the target had very small contamination from background events. The gamma rate obtained when the NaI signal was deliberately delayed to be out of time with the stopping antiproton signal was negligible compared with the in-time rate, indicating that accidentals were not a problem. Background in the in-time gamma spectrum was shown to be small by observing the attenuation of the spectrum by a known amount of lead. Two short runs were taken, each with the same total number of stopped antiprotons in deuterium: one with one radiation length of lead placed between the target and the gamma detector, and one with the lead removed. The upper spectrum shown in Fig. 4 is from the run with no lead, and the lower spectrum is the difference between the two runs; that is, the spectrum of events lost in one radiation length of lead. For gamma energies greater than about 50

5.

Fig. 2. Gamma spectra observed from stopping negative pions. Upper spectra are from hydrogen and lower are from deuterium. Y refers to shield-level selection conditions described in text.

6.

Fig. 3. Charged particle spectra obtained in NaI detector during the experiment.

7.

Fig. 4. Attenuation of the gamma spectrum by lead. Upper spectrum is that obtained during a short run of antiprotons stopping in deuterium. Lower spectrum is for those events lost in one radiation length of lead.

8.

MeV, the spectrum was attenuated by approximately the correct amount, indicating that the contamination from neutrons was low. Most of the excess of events below 50 MeV is believed to be from higher energy gammas which have scattered along the surface of the lead collimator.

The gamma spectra obtained in the experiment from hydrogen are shown in Fig. 5, and those from deuterium are shown in Fig. 6. The four spectra shown in each figure are those obtained with the four different shield-level requirements. For both hydrogen and deuterium, the highest shield level, $Y = 3$ (which has no upper limit on the size of the pulse in the shield) shows a peak centered near 130 MeV from a small fraction of charged particles which were not detected in C_0 . From the lowest three shield levels, some 475,000 events have been accumulated from hydrogen, and 573,000 from deuterium. There is clearly no large structure in the spectra.

Linear plots of the data with the second shield-level requirement, $Y = 1$, are shown in Fig. 7. In the top spectrum are some 203,000 events from hydrogen, and in the middle are some 250,000 events from deuterium. The bottom spectrum is shown to demonstrate the appearance of a known gamma line: one of the spectra obtained from a stopping negative pion run has been added to the deuterium spectrum. The pion spectrum has been normalized such that the number of events in the 129 MeV gamma line is 1% of the total in the deuterium spectrum. It is thus seen that a line intensity of 1% shows a clear effect. From this, we give a preliminary estimate of 0.5% as the upper limit on the intensity of any lines with spacing of the order or greater than our 15% resolution.

No clear structure is seen in the above data when they are subdivided into spectra associated with specific charged multiplicity detected by the multiplicity counters M_i . For example, the spectra with even multiplicities, $M = 0$ through $M = 6$

9.

Fig. 5. Gamma spectra obtained in the experiment from hydrogen. Spectra obtained with the four different shield-level requirements, Y , are shown. Absolute scales of the four spectra have been displaced relative to each other by factors of ten.

10.

Fig. 6. Gamma spectra obtained in the experiment from deuterium.

11.

Fig. 7. Gamma spectra obtained in the experiment with shield-level requirement, $Y = 1$. Upper spectrum is from hydrogen, middle spectrum is from deuterium, and lower is deuterium spectrum with a 1% intensity gamma line added.

12.

are given in Figs. 8 through 11. A possible hint of a line near 130 MeV can be seen in the deuterium data with $M = 0$, and 4. It is expected that this line should be present in the data when a small fraction of negative pions from the annihilation stop in the target and give the gamma line from $\pi d \rightarrow \gamma nn$.

To summarize:

- (i) The experiment has accumulated spectra with more than half a million gammas from anti-proton annihilations in both hydrogen and deuterium;
- (ii) the energy resolution is about 15% FWHM; and
- (iii) no gamma lines are seen whose intensity are greater than 0.5% of the total.

REFERENCES

- 1. T.E. Kalogeropoulos, A. Vayaki, G. Grammatikakis, T. Tsilimigras, and E. Simopoulou, Phys. Rev. Letters 33, 1635 (1974); also see the paper presented to this conference by A. Vayaki.
- 2. A similar detector system is described in E.M. Diener, J.F. Amann, S.L. Blatt, and P. Paul, Nucl. Inst. and Methods 83, 115 (1970).

13.

Fig. 8. Gamma spectra from hydrogen and deuterium associated with charged multiplicity zero.

14.

Fig. 9. Gamma spectra from hydrogen and deuterium associated with charged multiplicity two.

15.

Fig. 10. Gamma spectra from hydrogen and deuterium associated with charged multiplicity four.

16.

Fig. 11. Gamma spectra from hydrogen and deuterium associated with charged multiplicity six.