UCRL-3216

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

BERKELEY, CALIFORNIA

UCRL-3216

UNIVERSITY OF CALIFORNIA

Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

ANTIPROTONS

Owen Chamberlain, Emilio Segrè, and Clyde Wiegand

November 29, 1955

Printed for the U.S. Atomic Energy Commission

ANTIPROTONS

Owen Chamberlain, Emilio Segrè, and Clyde Wiegand

Radiation Laboratory and Department of Physics
University of California, Berkeley, California

November 29, 1955

Since the development of Dirac's theory of the electron and the brilliant confirmation of one of its most startling predictions by the discovery of the positron by Anderson, it has been assumed most likely that the proton would also have its charge conjugate, the antiproton. The properties that define the antiproton are: (a) charge equal to the electron charge (also in sign); (b) mass equal to the proton mass; (c) stability against spontaneous decay; (d) ability to annihilate by interaction with a proton or neutron, probably generating pions and releasing in some manner the energy 2 mc^2; (e) generation in pairs with ordinary nucleons; (f) magnetic moment equal but opposite to that of the proton; (g) fermion of spin 1/2. Not all these properties are independent, but all might ultimately be subjected to experiment.

In cosmic rays, where such antiprotons could appear, some events have been observed that could be due to antiprotons, but their interpretation was uncertain.

The absolute lower limit of the energy necessary to generate antiprotons in the laboratory is 2 mc^2 = 1.88 Bev (laboratory system), but the mechanism of the collision and the conservation of momentum influence this lower limit, which becomes 5.6 Bev if the process is a nucleon-nucleon collision or 4.4 Bev if the process is a two-step one with the formation of a pion in a nucleon-nucleon collision followed by a pion-nucleon collision in which the nucleon-antinucleon pair is generated. These thresholds can be lowered appreciably by internal motions of nucleons in the nucleus.

When the Berkeley Bevatron was planned, the goal of 6 Bev was set with the hope that this energy would be sufficient to create antiprotons.

The methods of detection of the antiproton can make use of any of the seven characteristic properties. It seemed that charge, mass, and stability might be the easiest to ascertain. Observation of annihilation would also be highly desirable, whereas generation of pairs, magnetic moment, and spin are at present very difficult to observe.

There are classical methods of measuring charge and mass of a particle, which go back in their origin to J. J. Thomson. They entail the simultaneous measurement on the same particle of any two of the quantities momentum, velocity, or energy, which in turn can be obtained from the observation of electric or magnetic deflections, time of flight, range, scattering in photographic emulsions, etc. As for the charge, it is sufficient to measure its sign and its absolute value in a rough way only, because it is assumed that it is an integral multiple of the electronic charge.

After a detailed discussion it was decided that momentum p and velocity v constituted the most promising combination for ascertaining the mass. The first successful experiment[1] was performed, at the end of September 1955, as follows: The momentum was measured by passing the particles generated by bombardment of a copper target with 6.2-Bev protons through two deflecting magnetic fields and two magnetic lenses. This ensemble let through only particles for which $p = 1.19$ Bev/c if their charge was equal to that of the electron, including sign. The velocity was measured by a time-of-flight measurement between two scintillation counters 40 feet apart. The pulse size in the scintillators showed that the particles were singly charged.

The chief difficulty in the experiment rests with the fact that the antiprotons are accompanied by many pions--44,000 pions per antiproton in the most favorable conditions. For this reason provision must be made for eliminating spurious background effects. One of the most important steps is the insertion in the beam of two Cerenkov counters: one that is activated by particles with $v/c = \beta > 0.79$ and one of a special type that is activated by particles with $0.75 < \beta < 0.78$. Pions with $p = 1.19$ Bev/c have $\beta = 0.99$ while antiprotons of the same p have $\beta = 0.78$ and their respective times of flight for an interval of 40 feet are 40×10^{-9} sec and 51×10^{-9} sec. Particles with β in the interval between 0.75 and 0.78 trigger the sweep of an oscilloscope in which the time of flight between two scintillation counters 40 feet apart is displayed. This time of flight appears as the distance between the two pips due to the traversal of the counters. From this time of flight the mass is determined with an accuracy of 10% for each particle. Up to now about 250 particles have been observed and the average mass is known to about 5%. It is 1840 ± 90 electron masses.

The functioning of the whole apparatus is checked by sending through it positive protons in a separate run. These are obtained from a subsidiary target and their orbits are selected in such a way that they have the same momentum as the antiproton.

The particles are observable after a time of flight of 10^{-7} sec, which rules out particles with a mean life much shorter than 10^{-8} sec, in particular the known hyperons. These measurements are thus in agreement with the charge, mass, and stability mentioned above, and the identification of the new particle with the antiproton is a natural one, although not absolutely established.

There are also some indications on the possibility of annihilation, namely, the terminal process of the particle. Particles selected as antiprotons by the apparatus of Ref. (1) were sent into a block of heavy glass and the Cerenkov radiation generated in it was measured.[2] This radiation does not correspond, of course, to the entirety of the energy released; actually it is only a small part of it. A calibration was performed, however, and from the pulse size the visible energy was estimated. Values up to 800 Mev were found. This is consistent with the expected modes of annihilation for an antiproton and with the energy it would throw into Cerenkov radiation in a detectable form, but it is not sufficient yet for positive identification on that score only.

Another type of observation on the terminal phenomenon accompanying the absorption of the antiproton was also performed[3] with the photographic-plate technique. Particles of selected momentum obtained with an arrangement similar to that described in Ref. (1) were slowed down by a copper absorber and finally stopped in a stack of photographic emulsions. Among a background of many pions one particle was found which has protonic mass, comes to rest, and produces a star containing 6 black tracks, 1 grey proton, 1 pion of 80 Mev, and 1 minimum-ionization track. The visible energy released is more than 800 Mev. The total energy released cannot be known because neutral particles are almost certainly emitted, but this amount of visible energy is also consistent with the annihilation of an antiproton.

Clearly many questions are raised by the new particle. Its identification must be further corroborated; it is important to study in detail its annihilation properties for complex nuclei and, possibly even most interesting, the annihilation with hydrogen and deuterium. In addition, the cross section for nuclear interaction and the mechanism of production are clearly to be investigated.

The existence of the antiproton entails with virtual certainty the existence of the antineutron. Its experimental demonstration is a most interesting problem. Probably the neutron beam of the Berkeley Bevatron contains an appreciable number of them but their disentanglement from the ordinary neutrons appears a formidable task. It is likely that the best approach will be either (a) to transform an antiproton into an antineutron by a collision with a proton or (b) to convert an antineutron into an antiproton by collision with an ordinary neutron and detect either the final antineutron in (a) or the final antiproton in (b).

REFERENCES

1. Chamberlain, Segrè, Wiegand, and Ypsilantis, Phys. Rev., in press.
2. Brabant, Cork, Horwitz, Moyer, Murray, Wallace, and Wenzel, Phys. Rev., in press. Vol. 100 p. 947.
3. Chamberlain, Chupp, Goldhaber, Segrè, and Wiegand, and Amaldi, Baroni, Castagnoli, Franzinetti, and Manfredini, to be published.