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Negative Ions and Charge Neutralization in the Cyclotron

E. J. Lofgren

November 13, 1950

Berkeley, California

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Negative Ions and Charge Neutralization in the Cyclotron

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November 13, 1950

Abstract

Evidence is given for the presence of negative hydrogen ions in the synchro-cyclotron. They are lost by charge neutralization before they reach an energy of about 3 Mev. Protons have been made to circulate in the cyclotron without acceleration after they have reached an energy of 5 to 22 Mev and are found to be lost with a half-life of 1/3 to 2 seconds.

Negative Ions and Charge Neutralization in the Cyclotron

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In some of the early experiments with nuclear emulsions exposed inside the 184-inch synchrocyclotron a portion of the background of the plates was found to be due to short range particles coming from the center of the machine. Apparently ions were capturing electrons near the source and flying tangentially from small radius orbits. This process is most probable when the speeds of the ions are comparable with the speeds of the outer orbital electrons in the residual gas. Luis W. Alvarez pointed out that in the bevatron (proton synchrotron) then being designed at this laboratory the ions will spend relatively long times at low velocities and a disasterously large fraction of the injected ions might be lost by this mechanism. Accordingly some simple experiments were carried out to identify these particles and to estimate the rate at which beam is lost by charge neutralization.

To define the origin of the neutral particles some Eastman NTA plates were exposed at an angle of 5° to the horizontal in the median plane of the cyclotron[1] behind a 1/32 inch wide slit in a box made of 1/4 inch thick brass. A beam of the neutral particles defined by the slit would graze the emulsion giving a pattern which could be projected back to the origin of the particles. The geometrical arrangement is shown in Figure 1. These plates showed that there were two bands, one projecting back to each side of the center of the cyclotron. A

[1] The operating characteristics of the 184-inch cyclotron are summarized in a paper by Henrich, Sewell and Vale, R.S.I. 20, 887 (1949)

print of one of the plates is shown in Figure 2. The denser band projects to the side of the source where the protons are receding from an observer at the photographic plate, hence must have come from counter rotating ions. The outer edge of this band is very sharp and permits fixing the extreme radius of the counter rotating ions to an accuracy of about 1/2 inch. When similar exposures were made with a 0.00014 inch aluminum foil covering the defining slit the neutral particles were stripped of an electron resulting in a curved band from which the upper limit of $H\rho$ could be determined. In one set of exposures the band obtained without foil projected to a 6-1/2 inch radius where the counter rotating ions would have an $H\rho$ of 2.5×10^5 gauss cm. The measured curvature on the plate exposed with a foil covering the slit corresponded to positive ions with an $H\rho$ of 2.6×10^5 gauss cm. In addition the range of the individual tracks could be measured on lightly exposed plates and the upper limit was found to be about 80 microns, which corresponds to protons of 3 Mev or $H\rho$ 2.5×10^5 gauss cm. It seems certain then that the neutral particles in the heavy band are hydrogen atoms and that they come from negative ions formed in the ion source and accelerated to not over about 3 Mev, before they are neutralized. Negative hydrogen ions are known to occur in arcs and to have a binding energy of 0.7 ev.[2]

The question remained as to whether the very sharp outer limit of the negative band was due to a very rapid neutralization beyond a certain velocity or due to some property of the cyclotron. The latter was shown to be the case since the angle of the outer edge of the band could be changed by varying some of the operating parameters of the cyclotron. In one sequence of exposures the radius of the cyclotron orbit to which the band projected was 9-3/4 inches when the cyclotron dee voltage was 18 kv and the modulation rate was 60 cycles per second. Changing the dee voltage to 22 kv, with every other variable unchanged,

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[2] See Negative Ions by H. S. W. Massey, Cambridge Press, 1938

increased the radius to 10.3 inches. Changing only the modulation rate to 50 cycles per second decreased the radius to 7 inches. The most likely explanation seems to be that the sharp edge of the band is connected with the radial motion accompanying the phase oscillations, the radius corresponding to the outer edge of the band being the extreme radial excursion during one phase oscillation and that before the next phase cycle would have carried the negative ions to a greater radius they are all lost. This explanation is consistent with the observed increase of radius with accelerating voltage and modulation rate.

No measurement of the number of neutral particles was made. However in lightly exposed plates it was possible to compare the number of particles in the two bands by counting tracks. The band coming from the negative ions was the greater by a factor of about eleven.

The weaker band is due to neutralizations of protons and is the one of consequence to the operation of a proton synchrotron. It has no sharp boundary like the negative band but it can be projected back to a zone inside the 15 inch radius where the energy of the protons is 16 Mev or less.

Because it was not easy to make a count of the total number of protons lost by neutralization an experiment was devised to measure the survival of ions directly. A scintillation counter telescope was attached to the cyclotron tank by a sylphon bellows and pivot so that it could swing in the median plane and intercept particles coming from any radius up to 60 inches. The telescope consisted of 66 inches of 2 inch diameter pipe with an anthracene crystal at one end adjacent to a lucite window through which the light reached a photo tube. The resolution of the telescope was $\pm$ 4 inches at the center of the cyclotron. Figure 1 shows the relation of the telescope to the cyclotron. Provision was made to pulse the oscillator off at a predetemined time after the arc pulse at the beginning of the modulation cycle. The ions would then presumably circulate at a constant radius until lost by scattering or charge neutralization.

The later particles could be picked up by the counter when its axis was tangent to the zone in which the ions were rotating and would permit a measurement of the decay of the circulating beam. It was found that with the axis of the counter pointed to a zone varying from 8 inches to 18 inches which corresponds to protons of 5 to 22 Mev, and with the oscillator pulsed off after an interval of 300 to 500 microseconds the counts per cyclotron pulse were in the range 500 to 2500. The longer times giving fewer counts. If the oscillator ran through its full cycle there were only 1 to 15 counts per pulse. The background with the crystal shielded by 3/8 inch of brass was also always below 15 counts per pulse. With the telescope position constant the oscillator off time was varied to give a maximum number of counts per pulse. A Brush moving tape recorder was then connected to the output of a scaler and the rate of decay of the circulating ions could be measured. One such decay curve is shown in Figure 3 in which the counts occurring after a time interval are plotted against the interval, indicating a half-life of 0.35 second. The measured half-lives of the circulating ions were not reproducible from run to run to better than a factor of 2 to 3, but in the range of 300 to 500 microseconds the half-life varied from 1/3 to 2 seconds and in any given run the half-life always increased with increasing oscillator pulse length. Beyond 500 microseconds the number of counts per pulse were too few to determine a half-life by the counting method used. The proof that ions could circulate in a cyclotron for times of the order of a second favorably settled the question which started the inquiry since in the bevatron the injection energy was to be 10 Mev and the rate of increase of the magnetic field was such that in 0.1 second the protons would be well past the range where charge loss in positive ions is important.

The variation of half-life with pressure in the cyclotron was determined in one run with the counter directed at the eight inch orbit and the oscillator pulsed off at 400 microseconds after the arc pulse. The results are given in

Figure 4. The half-lives are based on 900 to 1500 counts each.

Thanks are due to Dr. Hugh Bradner who assisted in the photographic plate work and to Mr. Norman Knable who assisted in the counter work.

The work described in this paper was performed under the auspices of the Atomic Energy Commission.

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Figure Captions

Figure 1. Diagram of the 184-inch synchrocyclotron showing photographic and counter methods of detecting positive and negative ions neutralized in the central region.

Figure 2. Plate exposed to neutralized ions from the cyclotron. The denser band projects to counter rotating ions. (The plate was turned over in printing to give a sharper picture.)

Figure 3. A decay curve of protons circulating at 8 ± 4 inches with the oscillator cut off at 325 microseconds.

Figure 4. The half-life of protons circulating at a radius of 8 ± 4 inches in the cyclotron as a function of tank pressure. The oscillator was cut off at 400 microseconds.

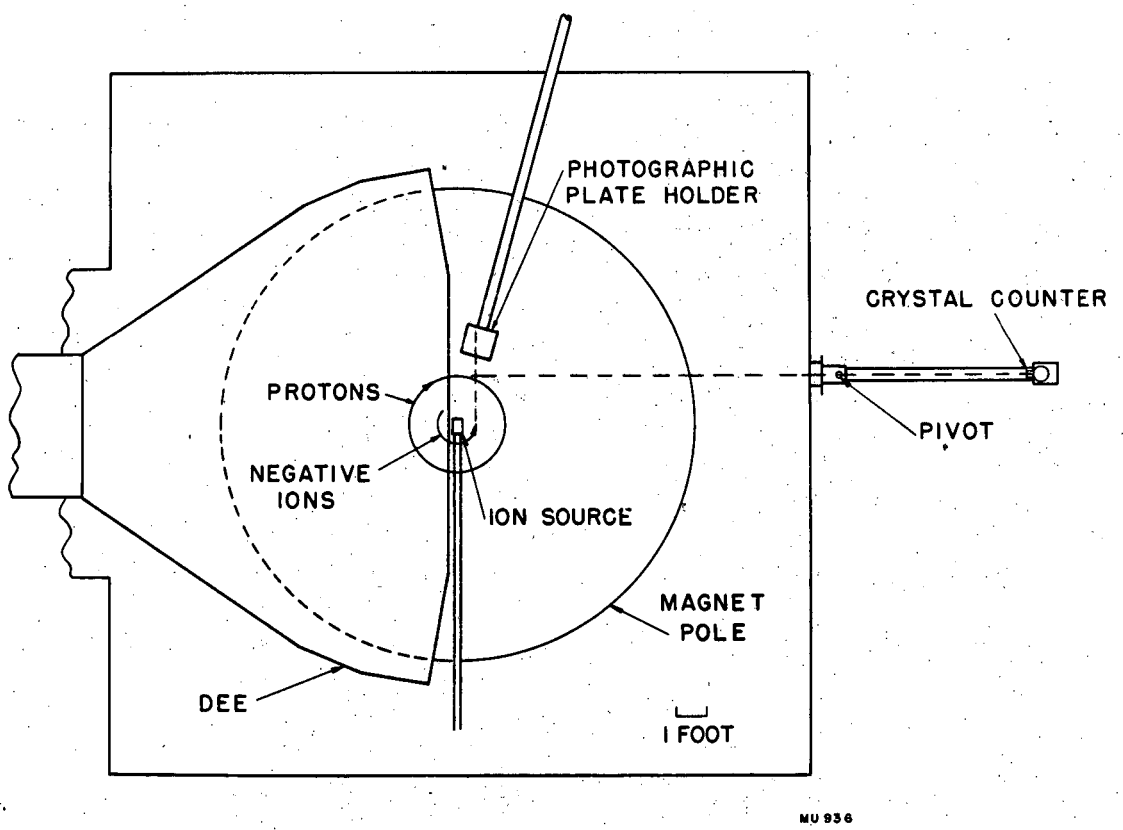
PHOTOGRAPHIC
PLATE HOLDER
CRYSTAL COUNTER
PROTONS
PIVOT
NEGATIVE
IONS
ION SOURCE
MAGNET
POLE
DEE
1 FOOT
MU 936

Fig. 1

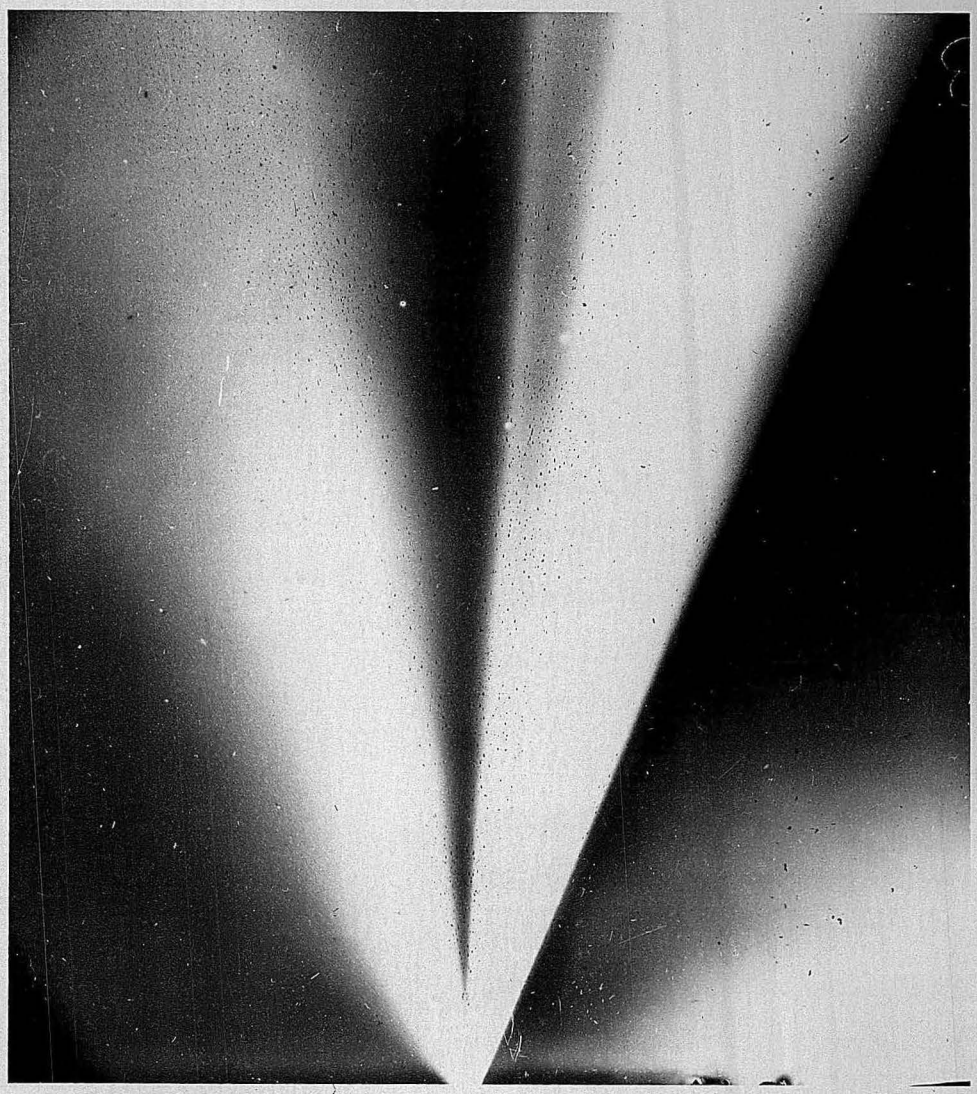

FIG. 2

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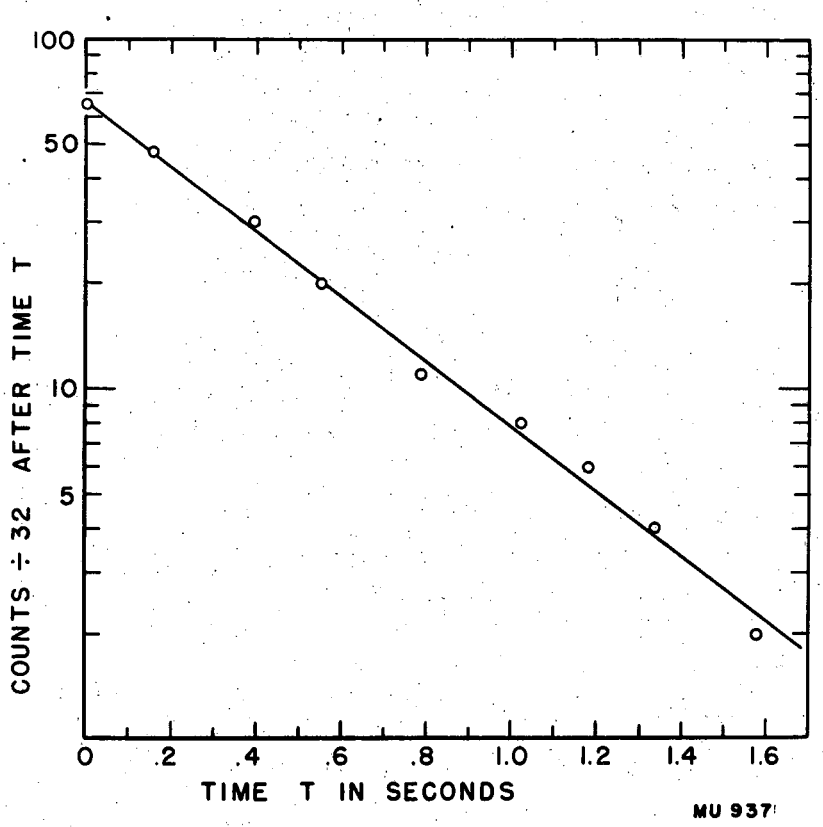
100
50
10
5
COUNTS ÷ 32 AFTER TIME T
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
TIME T IN SECONDS
MU 937

Fig. 3

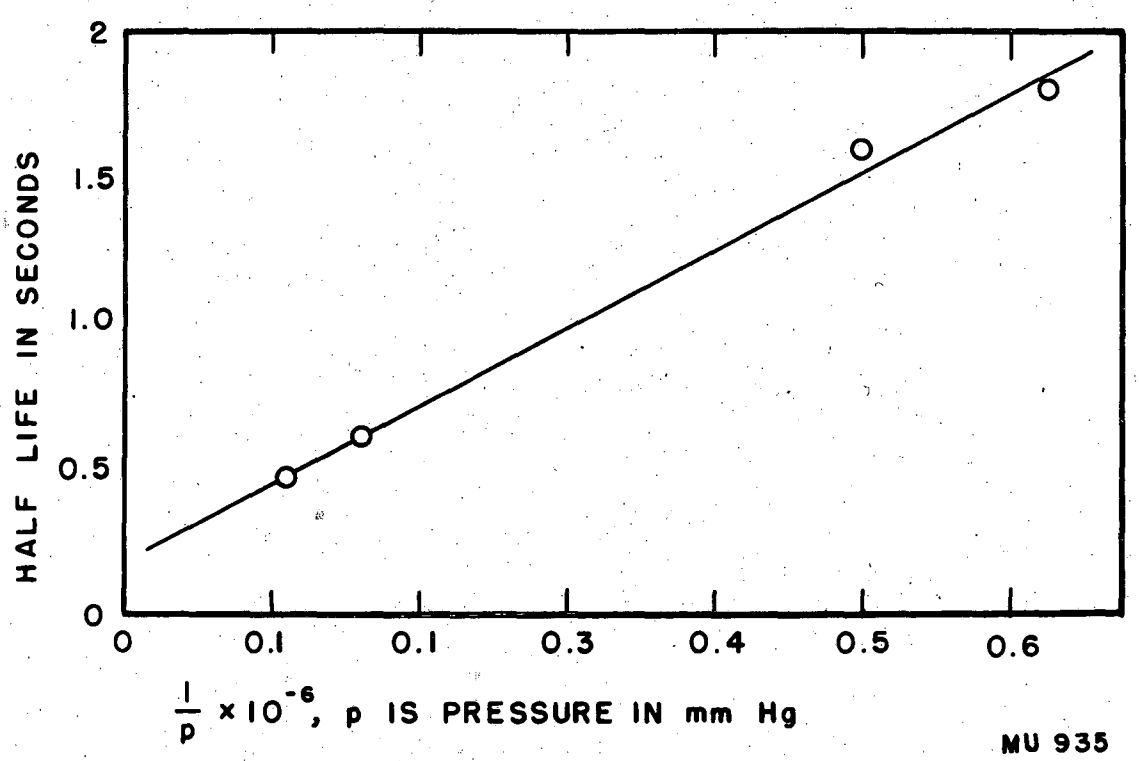
2
1.5
1.0
0.5
0
HALF LIFE IN SECONDS
0
0.1
0.1
0.3
0.4
0.5
0.6
$\frac{1}{p} \times 10^{-6}$, p IS PRESSURE IN mm Hg
MU 935

Fig. 4