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MEASUREMENT OF CARBON ARC DENSITY

M. L. Halbert
C. E. Hunting
A. Zucker

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MEASUREMENT OF CARBON ARC DENSITY

M. L. Halbert, C. E. Hunting, A. Zucker

Oak Ridge National Laboratory

Oak Ridge, Tennessee

Considerable interest has been evidenced in the density of the carbon arc used to dissociate molecular hydrogen ions, H_2^+ , into atomic hydrogen ions, H^+ . It was decided to attempt a measurement of the density of the arc by elastic scattering of ~ 28 -Mev nitrogen ions from the ORNL 63-Inch Cyclotron.

Experimental Method

The solenoid described by Barnett, Mackin, and Ray (ORNL-2420) was modified, installed at the exit port of the cyclotron, and a carbon arc was run through the solenoid. The solenoid magnetic field was produced by passing about 240 amperes through the windings to give a magnetic field of 1,800 gauss. The arc current was 250 ± 10 amperes and the arc voltage about 70 volts. The anode was grounded. By moving the cathode the arc was positioned to run down the axis of the vacuum chamber.

The solenoid was interrupted at the middle by a cylindrical reaction chamber about 2 in. long, in the direction of the magnetic field. The surface of the anode was $8 \frac{1}{4}$ in. from the plane of symmetry of the chamber. The cyclotron beam entered this chamber at right angles to the arc and diverged to about $\frac{1}{2}$ in. in diameter at the arc. On the periphery of the scattering chamber were affixed (a) a stationary scintillation counter at 60 deg to the incident beam, (b) a movable scintillation counter which could be positioned so that in an elastic nitrogen-carbon collision it would count the nitrogen ion while the 60 deg counter would count the recoil carbon ion, (c)

a vacuum lock through which one could insert probes into the reacting volume. Fig. 1 is a diagram of the scattering chamber. Fig. 2 is a photograph of the apparatus.

The scintillation counters used half-inch diameter 0.005 in. thick CsI(Tl) crystals mounted on a lucite light pipe 0.5 in. high. DuMont 6291 photomultiplier tubes were used, they were well shielded from the fringing magnetic field of the solenoid. The response of CsI(Tl) to nitrogen ions had been measured previously¹. A 1-cm-dia collimator placed about 17 cm

1. M. L. Halbert, Phys. Rev. 107, 647 (1957).

from the reacting volume defined the solid angle of each counter. In the course of the experiment it was found necessary to place an antiscattering aperture in front of the movable counter about 4 cm from the reacting volume. Thin nickel foils (0.6 mg/cm^2) were placed in front of the scintillation counters to prevent light from the arc from reaching the photomultipliers. Aluminum foils, even though free of pinholes, were transparent to some radiation from the arc and could not be used as light shields.

The angular acceptance of each counter was ± 1.6 deg. The beam spread was ± 1 deg. The effect of the magnetic field of the solenoid is not simple to estimate. Its effect on the fast N ion is negligible. However the total deflection of a 7-Mev C^{4+} ion is 3.2 deg, and for C^{5+} it is 4.0 deg. One must bear in mind that the ions describe a sort of S curve, first in the field of the solenoid then in the reversed return field. The return flux was concentrated by a 1/4-in. iron shield placed concentrically about 1/2 in. outside the solenoid windings. The function of this iron was to shield the region inside the solenoid from the stray field of the cyclotron.

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Fig. 1. Schematic diagram of scattering chamber.

Fig. 2. Photograph of apparatus installed at the cyclotron. The nitrogen beam enters from below. Two scintillation counters in their magnetic shields are shown in place. The nearer one is movable.

First the arc and the cyclotron beam were aligned so that they crossed in the center of the chamber where both counters could see them. This was done by burning patterns with the arc on a flat graphite dummy anode inserted on a probe through the vacuum lock. The beam position was obtained by burning spots on paper tape affixed to the same probe. When these spots coincided with the intersection of the solid angles of both counters the system was considered aligned. Checks on alignment were made several times during a run to ascertain that erosion of the electrodes did not shift the position of the arc.

A thin uranium plating was placed near the counters to check the fact that they (a) operated properly and (b) that the pulse height response did not change when the arc was turned on. It was found that the counters indeed operated properly and were not affected by the arc. In later runs the uranium was removed to avoid introduction of accidental coincidences. The single counting rate in each counter was measured and found to be a negligible factor in causing accidental coincidences.

The incident nitrogen beam was measured and integrated by passing it through a 0.15 mg/cm^2 Al foil. The foil was insulated and connected to the d-c amplifier commonly used on the cyclotron for beam measurement. A negative current was obtained due to the electrons stripped off the N^{3+} ions as they passed through the foil. This beam monitoring device was used in all runs, and provided a method of normalization between various types of runs. The incident N^{3+} beam was usually about 0.1 to 0.3 microamperes. When the arc was on, a spurious pick-up of about 0.02 μa negative was measured on the foil. This was subtracted in the final calculations.

To calibrate the apparatus a thin foil of carbon ($0.28 \pm 0.03 \text{ mg/cm}^2$) was bombarded and the coincidence rate was determined as a function of the angle of the movable counter. The experiment consisted of essentially three measurements (1) the coincidence rate with the carbon foil, (2) the coincidence rate in vacuo, (3) the coincidence rate with the arc. In addition the coincidence rate due to about 1μ of benzene vapor in the reacting volume was measured. This was done to see whether the equilibrium charge effects or multiple scattering and energy loss in the solid target could introduce important systematic errors.

The electronic circuits for the experiments were standard. The pulses from the photomultipliers were fed into separate cathode followers and then into A-1 amplifiers. The EPHS pulse from the carbon counter was used to gate a 20-channel analyzer and the latter, when the gate was open, accepted pulses from the nitrogen counter. The resolving time of the coincidence circuit was $2.3 \mu\text{sec}$. The carbon counter pulse height selector was set such that a small change in the setting would not affect the coincidence counting rate. Plateaus were run on the EPHS setting for every solid carbon bombardment.

Results and Discussion

The solid target, placed at 20° to the incident beam to reduce the thickness for the low energy carbon ions leaving the foil, presented a surface density of $1.5 \times 10^{19} \text{ atoms/cm}^2$ to the beam. Fig. 3 shows the number of coincidences as a function of the angle of the movable counter. The peak was expected at 27.5° . At these angles the energy of the nitrogen is about 21 Mev and of the carbon about 7 Mev, not counting the energy loss in the carbon target. The latter amounts to about 2 Mev on the average for each particle. The particles further lose a little over 2 Mev

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Fig. 3. Angular setting of nitrogen detector (degrees)

each in the nickel foils placed over the scintillators. The coincidence counting rate with the thin carbon target was 500 coinc/integrator count (one integrator count = 7.0×10^{11} incident particles).

Benzene vapor was also introduced into the reacting volume as a separate experiment for reasons stated previously. The pressure of benzene was estimated to be about 1μ . The resulting coincidence rate was 2.9×10^{-2} coinc/integrator count. If one takes into account that the active volume for this experiment was about 3.3 cm long the results are in agreement with the solid target results to within 25%. This is surprisingly good because the statistical errors due to the low counting rate are themselves $\pm 25\%$, and the accuracy with which we were able to measure the pressure is probably no better than $\pm 50\%$. The C_6H_6 formula for benzene was taken into account in these calculations. It was therefore apparent that a change from the dense solid target to the very rare benzene target did not effect a change in the kinematics, nor could it play a significant role in the experiments.

Runs were made with arc-off and arc-on conditions at various angles. The average counting rate was 2 coinc/400 integrator counts at 25 deg and 28 deg, regardless of whether the arc was on or off. In the run at the 30-deg position 5 coincidences were observed for 400 integrator counts. Two possibilities arise: either the excess of 3 counts above background was real, or some of the excess may have been caused by noise. If the first hypothesis is true the most probable density of the arc is 1.1×10^{14} atoms/cm³, using the solid-target data and assuming that the arc is 2 cm thick where the beam traverses it. Applying a Poisson distribution in this case we find that the probability of 3 coincidences as a function of density is as follows:

<u>Arc Density</u>	<u>Probability of 3 counts</u>
10^{12} atoms/cm ³	3.4×10^{-6}
10^{13}	0.0026
2×10^{13}	0.016
4×10^{13}	0.074
6×10^{13}	0.14
8×10^{13}	0.20
10^{14}	0.22
2×10^{14}	0.11
4×10^{14}	0.0037
6×10^{14}	0.000052

It is quite possible that some or even all of the coincidences at the 30-deg position are accidentals due to cyclotron sparking or other noise in the electronic circuits. In this case we can give only an upper limit to the density. As before we express this upper limit as a probability that three or fewer coincidences were observed for various values of the arc density.

<u>Arc Density</u>	<u>Probability of ≤ 3 counts</u>
10^{12} atoms/cm ³	0.99999
10^{13}	0.99978
2×10^{13}	0.998
4×10^{13}	0.97
6×10^{13}	0.91
8×10^{13}	0.82
10^{14}	0.70
2×10^{14}	0.20

<u>Arc Density</u>	<u>Probability of ≤ 3 counts</u>
4×10^{14}	0.050
6×10^{14}	0.000062

Conclusions

It can be seen from the results presented that the experiment is not well suited to measuring densities of the order of 10^{14} atoms/cm³ or lower. In order to do that a new experiment would have to be designed with an increase in beam intensity as well as increase in the angular acceptance of the scintillation detectors.

The results given above depend on the assumption that the material in the arc is distributed throughout its volume. If the material were concentrated at the periphery of the arc the experiment would give too low a value of the density because the off-center geometry would not give coincidences at the proper angles.

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