DIRECT MEASUREMENT OF A PROTON BEAM PASSING THROUGH A WATER TARGET BY THE INDUCED CHANGE IN THE WATER CONDUCTIVITY*

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ABSTRACT

A water target for use in a neutrino experiment at the Los Alamos Meson Physics Facility was constructed with monitors to measure the transient change in water conductivity induced by the passage of the proton beam. This novel monitoring technique permitted a direct measure of the 800-MeV incident proton beam inside the target and gave a measure of the beam alignment. The conductivity persisted over many milliseconds and exhibited an exponential time decay after the beam pulse ended with a characteristic time constant consistent with the production and recombination of OH^- and H_3O^+ ions in the water. Though the concentration of these ions was observed to increase linearly with the incident proton current, when compared to the formation of ion-pairs by direct energy loss of the incident protons, the process producing the more stable conduction ions observed in this experiment was found to be many orders of magnitude less efficient. The cause of this inefficiency is not understood, but suggests one or more intermediate processes are involved in their production.

THE WATER TARGET AND CONDUCTIVITY MONITORS

The water target, shown in Fig. 1, consisted of a thin-walled stainless steel pipe 100-cm long x 2.54-cm diameter within which de-ionized water flowed in the direction opposite to the incident beam. The physical properties of the target and water are summarized in Table I.

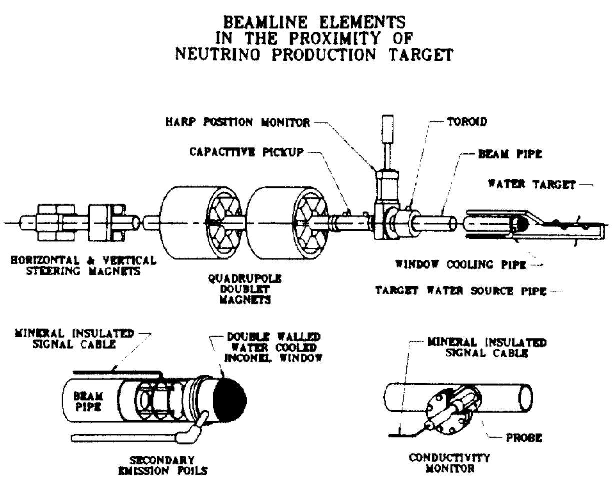

Fig. 1. The end of the neutrino beamline is shown schematically. Details of the conductivity monitors in the water target are shown in the insert.

Three conductivity monitors were placed along the length of the pipe at 46-cm intervals in order to obtain information on the beam location throughout the target. Each monitor consisted of a probe mounted on an insultated feed-thru extending radially into the center of the pipe such that the conductivity was measured between the probe and the target pipe wall. The probes were made of CERAMASEAL high vacuum feed-thrus (cat. no. 804B5230-1). Each had an MHV connector outside and a ceramic insulated pin 0.38-inches long by 0.092-inches diameter on the inside. We soldered a brass rod onto this pin to extend the probe to the center of the water pipe. The feed-thru was welded through a hole in a vacuum blank-off which was sealed using a standard Varian mini-con-flat vacuum flange. The center pin of the MHV connector was soldered to the center conductor of a mineral-insulated coax signal cable, while the braided wire sheath of the cable was grounded to the target pipe wall.

TABLE I

Physical Properties of the Pure Water Target

Target dimensions	100 cm-long x 2.54-cm diameter
Wall thickness (SS 321)	0.025 cm
Water temperature	36^{o} C
Water pressure	185 psi
Water flow rate	0.5 cm/msec
Proton interaction length	67 cm
Average ionization potential	68 eV
Ionic activation energy*	2-3 kcal/mol of H_2O yields 1.004×10^{-7} mol of ions/liter
Ionic recombination rate (k_R)*	1.4×10^{11} liter/mol-s

*For the reaction $2H_2O \rightarrow H_3O^+ + OH^-$, see Ref. 1.

To measure the conductivity, a small DC voltage was applied across the probe through a 50 kOhm resistor placed in parallel with it. The change in the voltage across the resistor was viewed on an oscilloscope. When the beam struck the target, there was a sharp drop in the voltage indicating an increase in water conductivity. This was followed by a more gradual return to the original voltage which we interpreted to be due to the production and subsequent recombination of induced ions in the water. Because of the millisecond time scale over which the signal occurred, the effect could not be due to capacitive charging, etc., in the target.

DATA AND ANALYSIS

Data was taken under different beam conditions to make comparisons and to draw conclusions about the behavior of the conductivity monitors when beam was on the target. A representative oscilloscope trace taken during the experiment is shown in Fig. 2 and our results are summarized in Table II. Note that monitor 1 is at the upstream end of the target.

As can be seen from the oscilloscope trace the monitor measured a progressive increase in water conductivity during the time that the beam struck the target. Just after the beam pulse ended, the conductivity decreased exponentially with a

TABLE II

Measurements Taken with Beam on Target

	Beam Current*	Pulse Width	Water Resis.	Monitor 1 A_1^{+}	t_1^{++}	Monitor 2 A_2	t_2	Monitor 3 A_3	t_3
Run 1	10.0μA	550μs	2.7kOhm	17.5mV	15ms				
Run 2	15.7μA	700μs	2.7kOhm	60.0mV	5ms	50.0mV	4ms	12mV	1.5

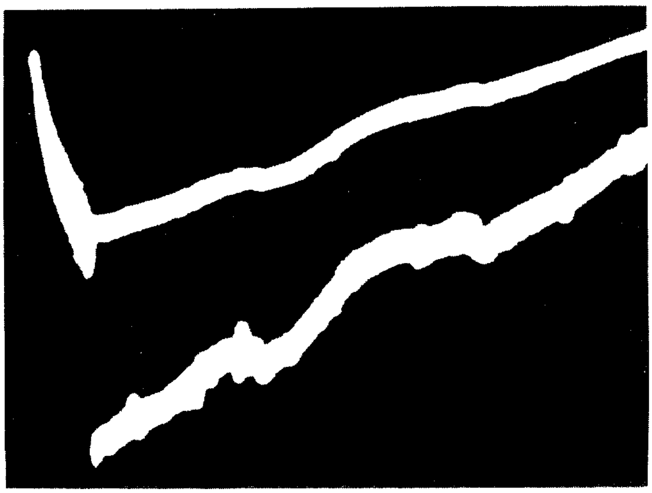

Fig. 2. A sample oscilloscope trace is shown of the response of monitor 1 to the passage of an 800-MeV proton beam through the target. The time scale is 1 ms/cm. The sharp decrease in the trace showing an increase in water conductivity occurs over the beam pulse width and is due to the production of stable ions. The gradual recovery of the trace is due to the recombination of these ions and the characteristic decay time is related to the ionic concentration.

characteristic time constant of about 15 msec. Attributing this behavior to the production of stable ions in the water and their subsequent recombination, the ionic concentration of charge carriers contributing to conductivity was calculated using an expression for the recombination time found in Ref. 1, $t = (2k_R C)^{-1}$. Using the value for the recombination rate (k_R) listed in Table I and the measured value for t, we found $C = 1.5 \times 10^{-9}$ mol/l.

This concentration of ions which produced the conductivity change in the water indicated that the beam created one ion pair for every 20 MeV of energy deposited in the target. This is a surprisingly small concentration considering that it requires on average only 68 eV to ionize the water atoms directly. However, the ion pairs which result from electron emission recombine very rapidly and do not affect the long lifetime conductivity that we observed in this experiment. Our result requires more stable ions such as OH^- and H_3O^+ as charge carriers. Using just the effect of the local heating of the water by the beam we can estimate the concentration of stable ions produced using the thermal activation energy given in Table I. This yields a recombination time larger by only a factor of three from what we measured. Thus the process contributing to the observed conductivity is very inefficient, involves only a small fraction of the energy deposited by the beam, and could be due in part to local heating of the water caused by the beam.

We found that the ionic concentration increases proportionately with an increase in beam current. Furthermore, in Table II we note that the relative amplitudes between the conductivity monitors reflects this effect. We expect the response from the upstream monitor to be greater than the response of the downstream monitors because particle interactions in the target reduce the beam throughout its length. Comparing Monitor 1 with 3 in Table II we see that the amplitude decreased exponentially as expected after taking into account the interaction length along the target (63 cm). However, the response of Monitor 2 did not exhibit quite as dramatic an exponential decrease.

CONCLUSIONS

Our calculations and measurements indicate that the production of the long-lived ions OH^- and H_3O^+ in the target water caused the observed changes in conductivity when the target was struck by the proton beam. We found that the conductivity changed linearly with the amount of beam current striking the target. During the course of the neutrino experiment we used the conductivity monitors in conjunction with other standard beam monitors such as harps and secondary emission foils to align the beam onto the target. We did this by optimizing the amplitude of the responses for+ each conductivity monitor as observed on an oscilloscope. Therefore, the conductivity monitors were an integral component of our monitoring system particularly as they indicated directly the beam position inside the target.

An interesting phenomenon demonstrated by our results was the large difference between the energy deposited in the target by the beam and the small amount of this energy that went into the formation of stable ions. This was even more surprising when compared with the number of ion pairs created by electron emission which was many orders of magnitude larger. This inefficiency in the production of stable ions suggests that there may have been one or more intermediate steps by which the beam created them. This is not unlike a phenomenon observed in bubble chambers where the production of bubbles along a particle track was found to be very inefficient when compared to the amount of energy deposited. Subsequent work on the bubble formation process [2] showed that it proceeded through the secondary interaction of delta rays produced along the particle track.

FOOTNOTES AND REFERENCES

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[2] Ch. Peyrou, in: Bubble and Spark Chambers, vol. I, ed., R.P. Shutt (Academic Press, New York, 1967). Also, T. Dombeck and J. VanHoy, Nucl. Instr. and Meth., 177, 347 (1980).