SOME APPLICATIONS OF THE EINDHOVEN A.V.F.CYCLOTRON

On the use of radioactive tracers for the study of transport phenomena in gasdischarges

L.C.J. Baghuis, A.M.W. Duys, H.L. Hagedoorn and M. Prins
Eindhoven University of Technology, Eindhoven, Netherlands

ABSTRACT

Short-living isotopes are produced with the cyclotron. The isotopes are injected as tracers into a discharge and will follow the flow lines. In this way the transport processes inside the discharge tube are studied. In our experiments we use the reaction $^{20}Ne(p,n)^{20}Na$ for the study of Neon Sodium discharges. The Na atoms produced can be detected by counting the emitted positrons or by a resonance fluorescence method. The latter shows a theoretical detection sensitivity of a few thousand Na atoms per cm^3. This method of detecting isotopes in gastargets can also be used to investigate chemical reactions in gases and atomic processes as recombination and (ambipolar) diffusion.

I INTRODUCTION

Radioactive tracers can be used fruitfully for the investigation of transport phenomena in gases and liquids or in plasmas of gasdischarges. This paper reports on the use of ^{20}Na ions for the study of neon gasdischarges. ^{20}Na has a rather simple decay scheme [1], which shows a lifetime of 0.45 s and a positron emission with a maximum positron energy of 11.25 MeV. These properties are especially suited for our purposes since, first, the short lifetime is of the same order of magnitude as the relevant transport times (10^{-3} to 10^{-1} sec.), secondly one is able to repeat the experiment many times and thirdly the high positron energy and the simple decay scheme give rise to relatively simple detection methods [2].

The ^{20}Na isotope is produced via the $^{20}Ne(p,n)^{20}Na$ reaction using 20 MeV protons accelerated by the Eindhoven A.V.F.cyclotron [3]. For this proton energy the experimentally determined cross-section of the reaction which leads to the formation of ^{20}Na in the ground-state is about 25 mbarn [2]. The reaction takes place in a neon gas target or in a neon gasdischarge with gas pressures between 50 and 760 torr. The cyclotron beam is always pulsed in such a way that e.g. the beam is on during 150 msec and off during a few seconds.

After this time the tracers have disappeared owing to their radioactive decay to natural ^{20}Ne; thus a new measuring cycle can start. In the off period the transport phenomena are studied. If a proton beam of 10 μA is used, 7.5 10^5 ^{20}Na atoms are produced per cm path length in 100 torr neon gas during the 150 msec pulse. This is a sufficient number of tracers for the study of the transport phenomena.

The experimental set-up will be given in section II, some results on transport phenomena in section III, and some concluding remarks in section IV.

II THE EXPERIMENTAL SET-UP

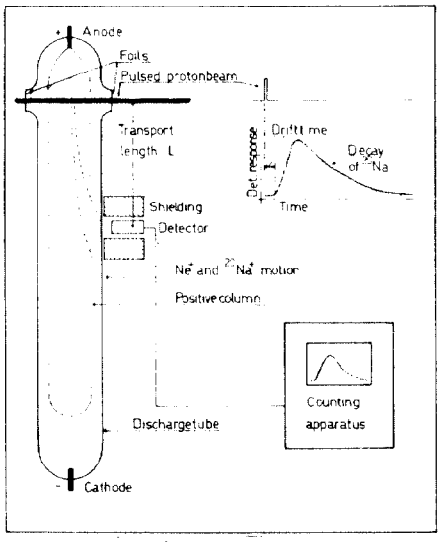

fig. 1

Simplified scheme of the tracer experiment

(a) The discharge

A neon gasdischarge in maintained in a pyrex tube with an inner diameter of 6.5 cm and two tantalum electrodes (see fig. 1). The neon gas pressure is varied between 50 and 300 torr, the discharge current between 10 - 300 mA. For most conditions a homogeneous positive column fills the discharge tube. For the higher pressures and currents, however, contraction of the column is observed [4]).

In the anode region two tantalum foils of 20 μm thickness are positioned in the tube wall. The proton beam enters and leaves the discharge through these foils. The diameter of the foils is 20 mm. They are placed so far away from the discharge that they have no significant influence on the discharge properties.

The position of the proton beam is measured by two beamscanners. The beam intensity is measured by a concrete shielded stop target.

(b) The detection of ^{20}Na (see fig. 1)

The positrons emitted by ^{20}Na are detected by a telescope consisting of two Si detectors or by one single Si detector.

After their production, the ^{20}Na ions drift from the anode to the cathode. The ions follow the flow lines in the discharge. These lines slightly bend away from the discharge axis to the tube wall owing to an axial field generated by the phenomenon of ambipolar

diffusion [5]). Two effects can now be measured: (1) the deposit of ^{20}Na ions on the tube wall, supplying knowledge about the ambipolar diffusion; (2) the time of arrival of the Na ions at a certain place in the column or at the cathode. From this, data on the mobility of ^{20}Na ions can be acquired.

To measure the above mentioned quantities the beta telescope can be moved along the tube wall. The ^{20}Na ions deposited on the tube wall can be measured as a function of the axial position. As the positrons have to pass the pyrex tube wall of 2 mm thickness, one is very sure that other ions (e.g. $^{19}Ne^{+}$ and $^{22}Na^{+}$) which have lower maximum beta energies than 2 MeV, will not be detected.

For the measurement of the time arrival use is made of a 400 channel analyser in its multiscale mode (Laben spectrascope 400).

(c) The measuring cycle (see fig. 1)

In the measuring cycle two different phases are distinguished: (1) The production phase which must be short compared with the transport time of the ions from the anode to the cathode. In our first experiments the production time was 150 msec with a transport time of the same order of length. The production phase will be decreased to about 1 msec in the near future. This then will be sufficient to reveal the transport time in a proper way.
(2) The analysing phase, which must be large compared with the mean life of the ^{20}Na isotope. In our case we took about 2 sec for this phase which equals 3.5 times the mean life time.

The beam intensity in the production phase may reach values in the region of 50 μA. For this purpose the ion source is modulated by a periodically pulsed signal. In the analysing phase, however, a very small beam intensity of several nA still exists yielding a disturbing background signal in this phase. To avoid this signal an electromechanical beam shutter in correlation with the modulation of the ion source is used.

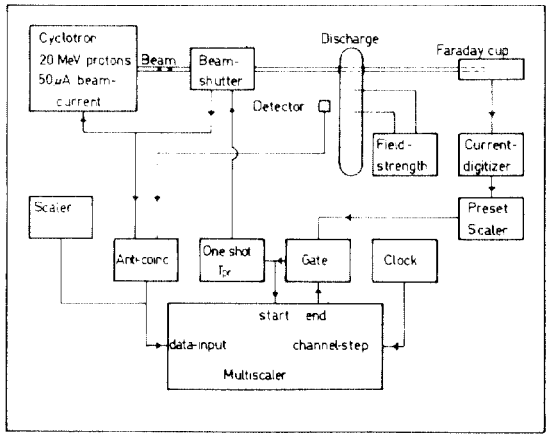

fig. 2

Block-scheme of the electronic system

A block-scheme of the electronic system is shown in fig. 2. The measurements are performed in the following way. A manual start of the multiscaler generates a pulse which activates the beam shutter. When the shutter has opened the beam pipe, the cyclotron ion source is intensified. The beam shutter remains open during an adjustable time interval T_{pr}. After this interval the shutter is closed and the ion source is switched off. If all channels of the multiscaler have been in operation, the analyser automatically starts a new production phase. The process is repeated until the cyclotron beam has transported a preset amount of charge to the stop target.

III EXPERIMENTAL RESULTS

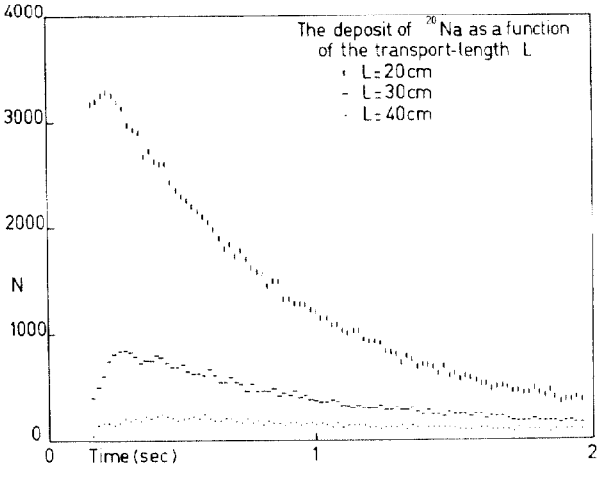

fig. 3

The response of the detector at different positions along the discharge tube

Three plots of the multichannel analyser in its multiscaling mode are shown in fig. 3. All plots are represented with 100 channels. Each channel has a duration of 20 msec. In the first seven channels the counting has been inhibited as these channels lie in the production phase. Then an increase in the counting rate is observed owing to the arrival of the tracer ions until a maximum is reached. After the maximum the radioactive decay of ^{20}Na is visible. Three different processes can now be distinguished:

(1) The time of arrival of the first tracer ions yielding the mobility of the Na ions in the neon discharge. The mobility will be better determined if in the near future the production phase is decreased to less than one msec.

(2) The spread of the arrival times which is caused by the duration of the production phase and by the axial diffusion of the ions in the discharge. The spread may be enhanced considerably if recombination takes place in the discharge. The tracers can then remain a rather

long time in the discharge as neutral particles. When ionized again, they start to drift towards the cathode. The enhanced spread especially happens if impurities are present in the discharge.
(3) The decrease in the total number of counts due to an increase in the distance between the place of production of ^{20}Na and the detector position (transport length L). The tracer ions are deposited on the tube wall by the drift motion in the radial ambipolar field, and are lost for further transport. In this way the ^{20}Na deposit in the region of the detector is decreased for increasing values of L.

From this decrease, knowledge can be gathered about the bent flow lines, which are determined by the axial and outward pointed radial electrical fields.

IV CONCLUDING REMARKS

The presented method with radioactive tracers gives a diagnostic technique for gasdischarges. The obtainable information is additional to that acquired with other techniques. The big advantage here is that the transport phenomena can be studied in the discharge without any noticeable perturbation.

The tracers produced can be transported with reasonable efficiency over distances of approx. one metre. This may be of importance for the study of short-living isotopes produced in gastargets. The Na isotopes produced can be detected in a different way with the aid of resonance fluorescence [6]. The advantage of the latter method is caused by the fact that a Na nuclide in the ground-state, e.g. ^{20}Na or ^{22}Na, can emit many photons during its lifetime, against only one β or γ event. Owing to several effects such as diffusion outwards of the production and detection area, and the ionized state directly after production, it is difficult to detect ^{20}Na during its lifetime. The much longer living isotope ^{22}Na ($T_{\frac{1}{2}}$ = 2.7 y produced via ^{22}Ne(p,n)^{22}Na) can diffuse back into the detector area after recombination. The ^{22}Na production is measured with a threshold of approx. 10^3 Na atoms cm^{-3}.

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