Production and Loss of $N_2^+$ Ions during the Decay Period of Plasmas Produced in Helium-Nitrogen Mixtures*

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The time dependence of the number density of $N_2^+$ ions during the decay period of plasmas produced in helium containing 0.05, 0.17 and 0.5 percent nitrogen was studied in the pressure range from about 0.3 to 7 Torr by means of mass spectrometer techniques. During the early part of the afterglow period the time dependence of $N_2^+$ is controlled by ambipolar diffusion loss towards the plasma container walls. The product of the ambipolar diffusion coefficient $D_a$ and the reduced pressure $p_0$ was $D_a p_0 = 900 ± 50 \text{ cm}^2 \text{ Torr/sec}$. The production of $N_2^+$ by collisions between metastable nitrogen molecules determines the temporal behavior of the $N_2^+$ density during the late afterglow for extremely pure discharge conditions. From the data it follows that the metastable molecules involved are de-excited by collisions with ground state helium atoms with a rate constant of $3.4 \times 10^{-15} \text{ cm}^3 \text{ sec}^{-1}$, while the radiative lifetime of these metastable molecules is at least 20 ms. The surface catalytic efficiency for de-excitation upon striking the molybdenum covered plasma container walls was estimated to be smaller than $10^{-3}$. Energy and radiative lifetime requirements suggest that $N_2^+$ is produced during the plasma decay period by the process

$$N_2(a^1 \Sigma_u^+) + N_2(a^1 \Sigma_u^-) \rightarrow N_2^+(X^2 \Sigma_u^+) + N_2(X) + e.$$ 

I. Introduction

Recently, Lund and Oskam$^{1}$ published studies of the time dependence of the $N_2^+$ density during the nitrogen afterglow period. Their data strongly indicated the production of $N_2^+$ during the later part of the plasma decay period by collisions between metastable nitrogen molecules. The explanation of the temporal behavior of the $N_2^+$ density during the early decay period was hampered by the influence of the discharge excitation conditions on the electron energy during the decay period.

The present studies relate to analogous measurements in helium containing small concentrations of nitrogen. It was believed that the

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heating effect of electrons during the decay period by super-elastic collisions with highly vibrationally excited nitrogen molecules in the ground state in these mixtures should be considerably smaller than in pure nitrogen. A better separation of the loss and production processes of $N_2^+$ was therefore expected.

The authors are aware of only one previous study of decaying plasmas produced in helium-nitrogen mixtures. In 1961 Kasner et al.\(^2\) reported a value of the ambipolar diffusion coefficient $D_a$ of $N_2^+$ in helium from measurements of the time dependence of the $N_2^+$ density in helium at pressure varying from 0.5 to 1.7 Torr, containing a fixed partial pressure of 0.006 Torr nitrogen. The fundamental characteristic diffusion length $\Lambda$ of their plasma container was 1.13 cm and $D_a p_0$ was found to be approximately 820 cm\(^2\) Torr sec\(^{-1}\).

II. Measuring System

A block diagram of the measuring system is shown in Fig. 1. It is essentially the same as that used by Sauter et al.\(^3\) and by Lund and Oskam\(^4\). The main difference is that the ion signal, which was previously measured by means of a pulsed ion multiplier, a RC network and an electrometer, is obtained using a multi-channel scaler. The channels of the scaler are open during fixed successive time intervals (minimum length 25 microseconds) during the plasma decay period. The ion-multiplier pulses are counted and stored in the various channels of the scaler. The number of counts in each channel is then representative of the ion signal during a fixed time interval of the decay period. The repetition rate of the discharge pulse was 16 or 33 per second. The magnitude of the ion signal and the desired signal range determine the number of decay periods to be sampled. This detection method is considerably faster than the previous method and has also increased the measurable ion signal range.

The discharge was produced by means of a pulsed 100 MHz rf generator, which was coupled to the discharge region by an external electrode. The gas handling system was an Alpert\(^4\) type high-vacuum system such that helium-nitrogen mixtures could be made. The research grade gases were obtained from the Air Reduction Company and helium was further purified by the cataphoretic segregation process\(^5,\,6\). The