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HEAVY ION SOURCE SUPPORT GAS MIXING EXPERIMENTS

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Summary

Experiments on mixing an easily ionized support gas with the primary ion source gas have produced large beam enhancements for high charge state light ions (masses ≤ 20). In the Oak Ridge Isochronous Cyclotron (ORIC), the beam increase has been a factor of 5 or greater, depending on ion species and charge state. Approximately 0.1 cc/min of the easily ionized support gas (argon, krypton, or xenon) is supplied to the ion source through a separate gas line and the primary gas flow is reduced by ≃ 30%. The proposed mechanism for increased intensity is as follows: The heavier support gas ionizes readily to a higher charge state, providing increased cathode heating. The increased heating permits a reduction in primary gas flow (lower pressure) and the subsequent beam increase.

Introduction

Improvements in the performance characteristics of heavy ion sources have a direct impact upon the performance of heavy ion accelerators. Therefore, a large effort on positive ion source improvement has been carried out at ORNL in connection with the Oak Ridge Isochronous Cyclotron. In the past, mixing gases in the ion source had been viewed as resulting in poorer source performance, since the proportion of ions available for ionization would be diluted by the mixing ratio. In particular, this effect is obviously seen in enriched isotope gases (e.g., the intensity of ^{18}O versus enrichment factor).

Another observation is that the quantity of gas needed to support the arc varies with the element being ionized, namely, for protons the source requires a large gas flow, whereas for xenon the source requires a small gas flow. Assuming that the energy (E) to heat the cold cathodes to the thermionic emission limit is the same for all gases, then the following relation can be written:

$$E \propto n_i \hat{q} V, \qquad (1)$$

where n_i is the number of ions required for the cathodes to reach the thermionic emission limit and is related to the source gas flow, $\hat{q}$ is the average charge in the plasma, and V is the arc voltage (the potential the ions fall through in bombarding the cathodes). For hydrogen, $\hat{q}$ can be only ≤ 1. As the ion source gas mass increases, the $\hat{q}$ charge increases since the ionization energy decreases for ions of the same charge state.[1]

Effects in the source and near the cyclotron central region that are pressure dependent may then vary as different gases are used, since less gas flow is needed for the heavy mass gases.

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Another ion source characteristic that is known but not understood is that different cold cathode ion source geometries require different amounts of gas flow for source operation. For example, the present ion source of Oak Ridge[2] requires ≃ 3-4 cc/min gas flow for normal operation, whereas the ion source of Michigan State University and some other laboratories require a flow of 0.5 - 1 cc/min.[3] One would then expect central region pressure effects and ion source gas usage effects would be more readily detectable in the large gas flow source of Oak Ridge.

Gas Mixing Experiments

Gas mixing experiments have been performed and large beam enhancements have been detected at ORIC. The experimental arrangement for gas mixing is schematically shown in Figure 1. The gases are fed to the ion source through separate gas lines and are mixed in the plasma chamber. Experiments of mixing the gases external to the ion source and feeding

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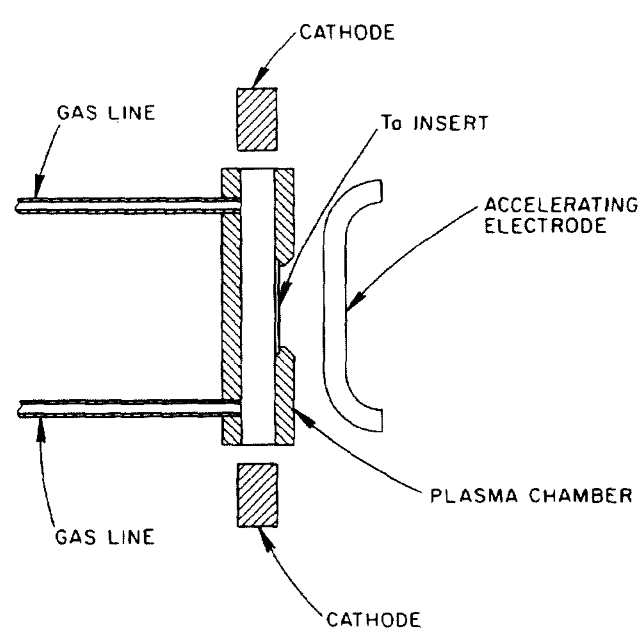

Fig. 1. A schematic view of the cold cathode ion source showing the gas inlet lines. In the gas mixing mode the primary arc gas is fed through one line and the support gas through the other. In mixing xenon with neon, visible observation of the arc through the extraction slit shows a two-colored arc, one side green (xenon) and the other side pink (neon).

through one gas line have produced substantially the same results. Gas mixing of krypton with neon for an extracted beam of $^{20}Ne^{6+}$ at 163 MeV is shown in Fig. 2.

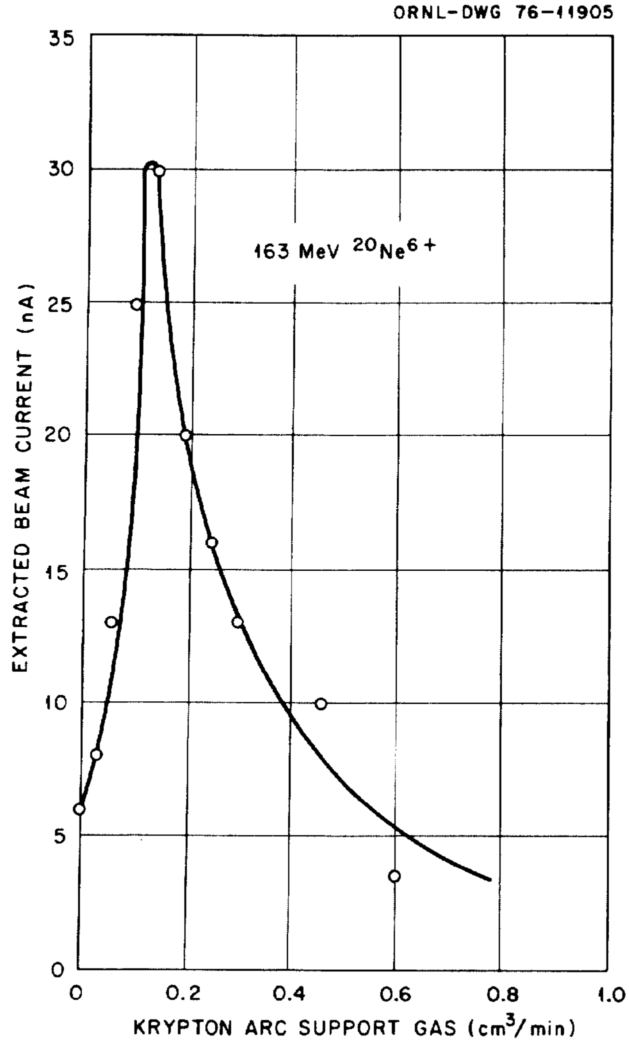

Fig. 2. The $^{20}Ne^{6+}$ extracted beam intensity versus the support gas flow (krypton). For each point a small amount of krypton was supplied to the arc then the primary gas (neon) was decreased until the arc voltage started to increase, an indication that the arc was about to drop out. A maximum beam enhancement occurred at 0.15 cc/min. of krypton.

As krypton gas was added to the ion source, the neon gas flow was decreased until the arc voltage started to rise. The neon beam intensity increased by approximately a factor of five for a krypton gas flow of 0.15 cc/min. A further increase in krypton flow resulted in a decrease in the neon beam intensity. In Fig. 3 the cyclotron internal beam intensity with radius^2 of a $^{14}N^{5+}$ beam is shown for xenon gas mixing. The internal beam attenuation slope for gas mixing and without gas mixing is the same, and indicates that the internal pressure in the cyclotron is the same and does not account for the increase in beam intensity that occurs with gas mixing. In Fig. 4 the internal cyclotron beam attenuation is shown for a $^{20}Ne^{6+}$ beam. The large step in the beam attenuation at 63 cm is due to the 3rd harmonic beam of $^{20}Ne^{2+}$ falling out of phase with the 1st harmonic $^{20}Ne^{6+}$ beam.

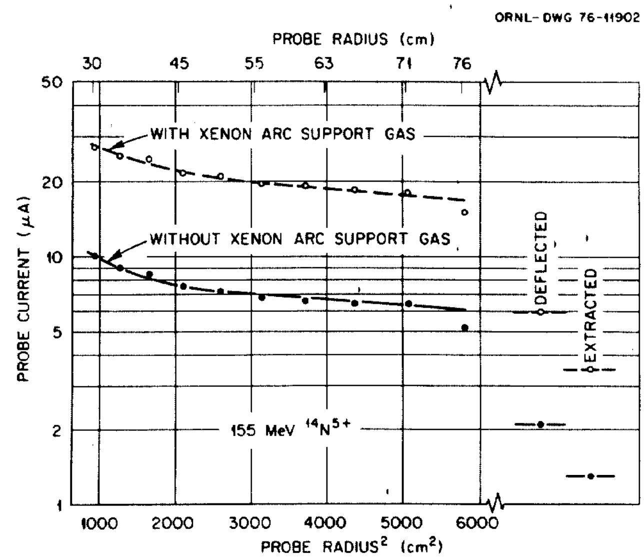

Fig. 3. The $^{14}N^{5+}$ beam attenuation with radius as measured on a cyclotron probe, with and without xenon support gas. The slopes of the curves are equal, indicating equal pressure attenuation in the cyclotron.

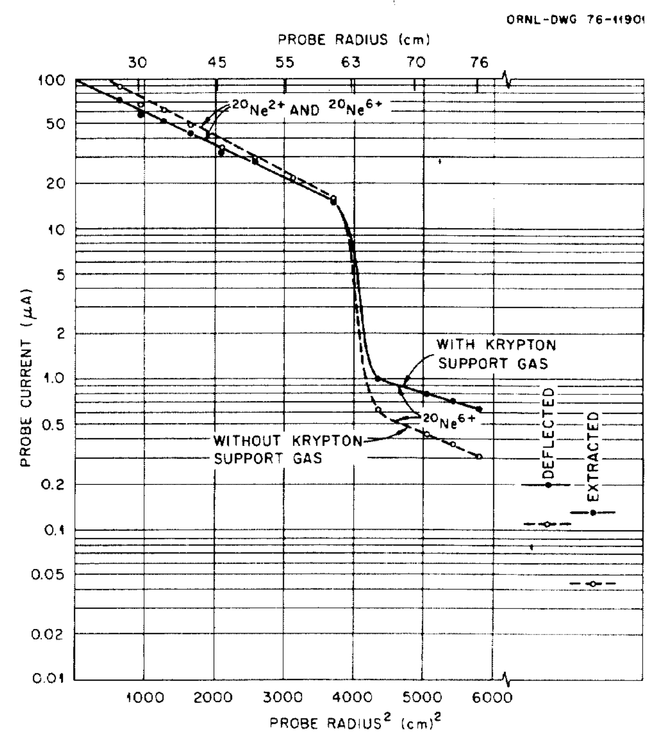

Fig. 4. The beam attenuation obtained for a $^{20}Ne^{6+}$ extracted beam, with and without krypton support gas. The step at 63 cm is due to the acceleration of the $^{20}Ne^{2+}$ harmonic beam. The intensity of the $^{20}Ne^{2+}$ decreases with krypton support gas, and if the pressure were improving it would be expected to increase.

The intensity of the $^{20}Ne^{6+}$ beam with gas mixing and and without gas mixing indicates that the charge distribution in the source plasma is shifting to the higher charge states, since a decrease in pressure[4] would be expected to produce less attenuation of the $^{20}Ne^{2+}$ beam.

The effects of different support gases (argon, krypton, and xenon) are shown in Fig. 5. The maximum beam improvement obtained is about the same for the three gases; the $\hat{q}$ of these gases are approximately equal.[5] Xenon and krypton gas mixing experiments with an $^{40}Ar^{8+}$ beam has not shown an increase in intensity with gas mixing.

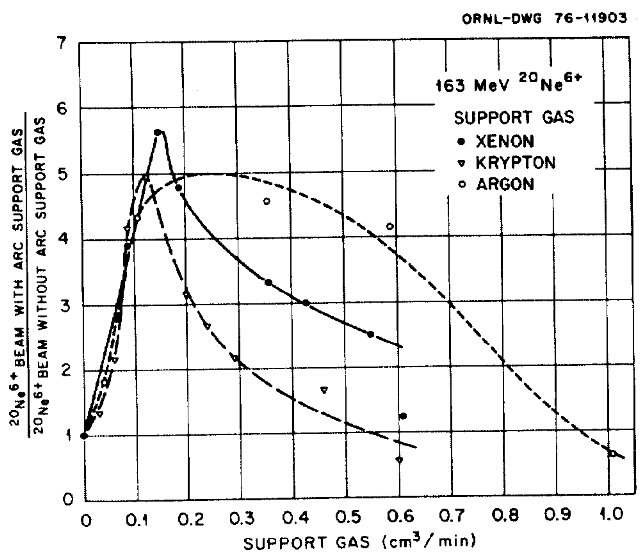

Fig. 5. The normalized beam enhancement of $^{20}Ne^{6+}$ for different support gases (xenon, krypton, and argon). The maximum enhancement appears to be approximately the same for all gases.

In Fig. 6, the extracted beam intensity of an $^{16}O^{5+}$ beam is recorded as a function of time with and without mixing. The increase in the beam intensity at 40 minutes was obtained by adjusting the xenon gas flow. The data indicate the large beam intensity for the oxygen beam is obtained from the beginning of the ion source lifetime. An important side effect is that the xenon gas mixing improves markedly the stability of the oxygen beam performance of the ion source.

Gas mixing is now routinely used at ORIC. Gas mixing enhancement has also been observed with an $^{16}O^{6+}$ beam at Michigan State. Additional gas mixing experiments are in progress.

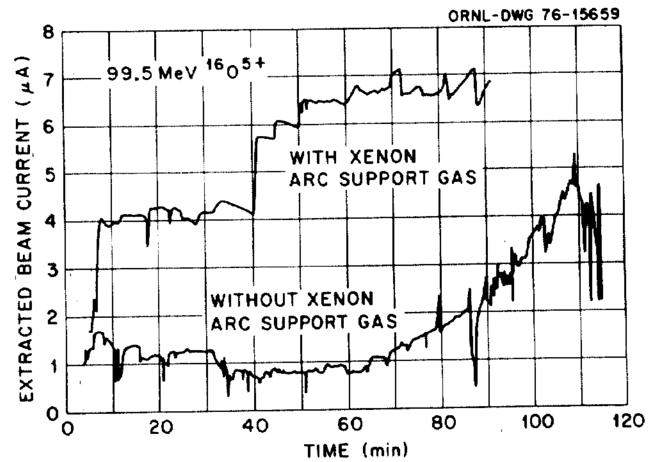

Fig. 6. The extracted beam intensity for an $^{16}O^{5+}$ beam versus time. The intensity of oxygen without support gas tends to increase slowly over a period of hours. The beam intensity with xenon support gas reaches even a higher level in a few minutes, and is more stable.

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