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VACUUM-ARC PLASMA CENTRIFUGE EXPERIMENT

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14. Abstract/Notes

Vacuum-arc plasma centrifuges, for isotope and element enrichment, have been studied to some extent over the last 10 years. This paper describes the vacuum-arc plasma centrifuge developed at INPE. The experiment is characterized by its relative small dimensions. Angular rotation frequencies in the range of 1.9×10^5 rad/s to 3.5×10^5 rad/s, measured with Langmuir probes, are presented for a magnesium plasma. Enrichments of 15% for ^{25}Mg and 26% for ^{26}Mg were measured with a quadrupole mass spectrometer. The dependence of magnesium isotope enrichments upon the magnetic field is also presented.

15. Remarks

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VACUUM-ARC PLASMA CENTRIFUGE EXPERIMENT

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Introduction

The fully ionized vacuum-arc plasma centrifuge was first investigated by Krishnan et al. [1], as a practical element and isotope separation device. In this apparatus the plasma source is a vacuum-arc triggered by a pulsed laser and discharged between a metalic cathode and a grounded mesh anode, in the presence of an externally applied magnetic field. The plasma produced is fully ionized and composed of the cathode material. The ionized particles evaporate from the cathode with large radial and axial velocities. The plasma rotation about the cylinder axis is sustained by the self-consistent radial electric field, produced inside the plasma column, crossed with the externally applied axial magnetic field. The centrifugal force, acting radially outwards, causes a partial separation of the different ion species in the radial direction.

Experimental Apparatus

Figure 1 shows schematically the vacuum-arc centrifuge experiment developed at INPE [2]. The vacuum vessel is a cylindrical stainless-steel tube with a diameter of 0.22m and length of 1.05m, evacuated to a pressure of 6.6×10^{-5}Pa.

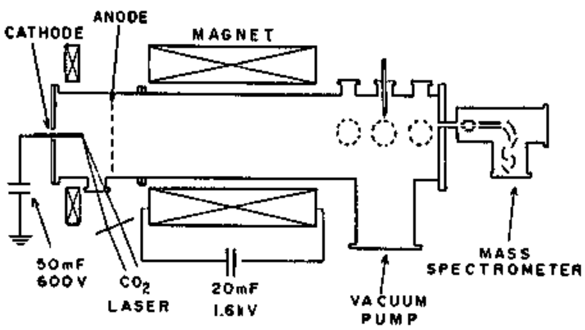

Figure 1. Schematic drawing of the vacuum-arc centrifuge experiment.

A capacitor bank of 20mF and 1.6kV is discharged in a set of eight magnet coils to produce the external axial magnetic field. The obtained peak B-field is about 1T, with a 120ms L/R decay time.

The plasma arc is produced by the discharge of a capacitor bank, of 50mF and 600V, between a cathode and a grounded stainless-steel mesh used as the anode. The arc is triggered by a 4J CO_2 laser focused on the cathode. The current discharge can reach peak values of 1-10kA, depending on the shot conditions. The pulse length of the arc discharge is much shorter than the pulse length of the current in the coils, therefore the magnetic field is practically constant in time during the whole arc discharge.

Plasma Rotation

The plasma floating potential measured by a Langmuir probe inserted in the plasma column shows characteristic periodic fluctuations superimposed on the main signal. These periodic fluctuations disappear in the absence of the magnetic field and lose the periodic pattern for small B-field ($\lesssim$0.03T). These fluctuations are associated with plasma density inhomogeneities. The angular rotation frequency of the plasma column can be obtained from the phase difference between the potential fluctuation signals measured by two Langmuir probes placed 90° apart in azimuth. Figure 2 shows the plasma floating potential measured at R = 0.03m for magnesium plasma, for two shots at the same conditions.

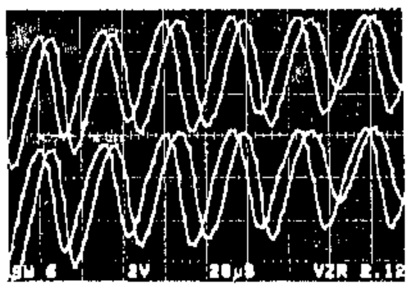

Figure 2. Plasma floating potential measured with two probes 90° apart in azimuth for B = 0.1T. Scales: 2V/div and 20μs/div.

From the two upper signals or two lower ones, which show a time difference of 8μs between a vertical and a horizontal probe, an angular rotation frequency of $\omega = 1.9 \times 10^{5}$rad/s is obtained.

An angular rotation frequency $\omega = 1.9 \times 10^5$ rad/s is also obtained from the period of the fluctuations shown in Figure 2. This value is the same as the one measured by the phase difference technique and the agreement persists for all values of the magnetic field strength. Figure 3 shows the variation of the angular rotation frequency with the magnetic field strength. These results are in agreement with the ones presented by Prasad et al. [3], which were obtained using a spectroscopic diagnostic technique for a maximum B-field of 0.21T. Our results, however, show a saturation of the rotational velocity for magnetic field greater than about 0.2T, probably indicating the existence of a maximum value for the rotational velocity of the plasma column in this type of device.

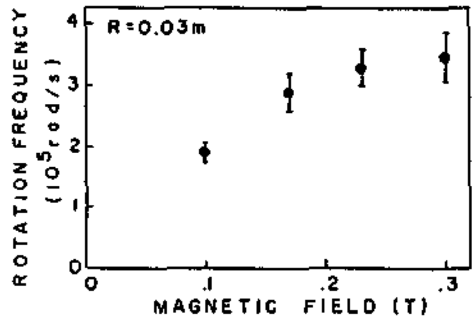

Figure 3. Angular rotation frequency as a function of the applied magnetic field for a magnesium plasma.

Enrichment Measurement

Figure 4 shows a typical magnesium spectrum obtained using the quadrupole mass spectrometer. The spectrum shows the experimental data and the best fit of three Gaussians, obtained with B = 0.1T, at R = 0.04m (I = 1.7kA). In this case the separation factors for the two magnesium isotopes are $\alpha_{25} = 1.15$ and $\alpha_{26} = 1.26$, indicating an enrichment of 15% and 26%, respectively.

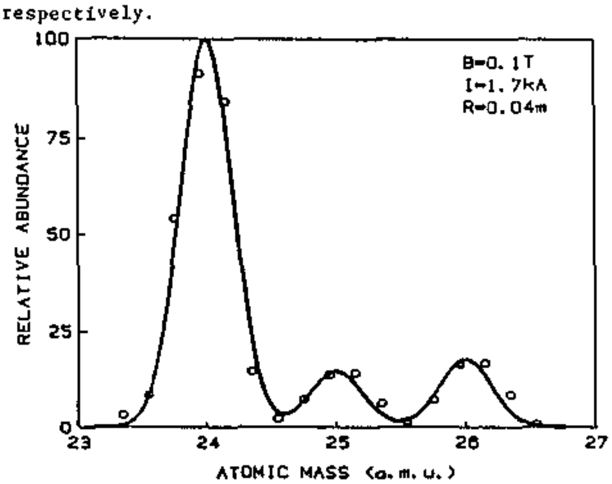

Figure 4. Mass scan of magnesium rotating plasma.

The dependence of the enrichment values for the magnesium isotopes upon the magnetic field strength is presented in Figure 5. Open circles represent enrichment for the ^{25}Mg isotope, while dark circles represent enrichment for the ^{26}Mg isotope. From the data shown in Figure 5 we can observe the existence of a maximum enrichment for magnesium in the B-field range of 0.1T to 0.2T. From the results shown in Figure 3 (measured at R = 0.03m) we could have expected higher rotational velocities at about 0.3T, and therefore higher enrichments. However, the smaller enrichments measured with B = 0.3T, as compared to the measurements at B = 0.15T, shown in Figure 5 (taken at R = 0.04m) are possibly due to the contraction of the plasma column radius caused by the increased B-field, and a nonrigid body rotation at the outer radii of the column.

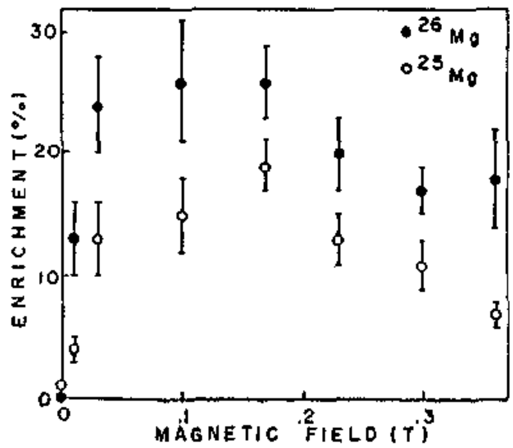

Figure 5. Dependence of the enrichment for ^{25}Mg and for ^{26}Mg upon the magnetic field strength, at R = 0.04m.

Conclusion

The measurements of the angular rotation frequencies and enrichments presented for a magnesium plasma, are in agreement with other results from vacuum-arc plasma experiments. These and other measurements will be used in a multispecies warm fluid model [4], in order to obtain a better understanding of the plasma centrifuge behavior.

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