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The Magneto-Ionic Expander Isotope Separator Applied to Uranium

A short arc in a high vacuum and in a large parallel magnetic field serves as an intense source of ions to a negatively charged surrounding cylinder (*1, 2*). Ion currents as high as 10 amperes were obtained with an arc current of 100 amperes using a uranium anode. Unfortunately electrons are carried out with the ions, even against the opposing electric field in this so-called "ionic centrifuge." The oscillations induced among the ions cause variations of the isotopic constitution to be vanishingly small in the deposits on the cylinder and on the end plates above and below the arc. These oscillations are normal in discharges of this type. [See (*2*), note 6.] As shown by Chew, Goldberger, and Low (*3*), the relative mean motions of electrons and ions in an electric and magnetic field and in the *absence* of particle collisons, as in the ionic centrifuge, may still produce substantial oscillations of various sorts and these will prevent appreciable isotope separation.

The short electric arc may still serve as an intense source of ions (and electrons) to be deposited, not upon a continuous cylinder, but upon a series of separate insulated strips each bearing a different voltage. The side walls which remain nearly bare of deposit during operation, embrace at their short end the arc, aperture L_0 ($\sim$1 in.), and at their long end the insulated slats, making up the aperture L ($\gtrsim$2 ft), and which become well covered with deposit. See Fig. 1. The space is closed above and below the arc in the magnetic field at a suitably great distance by plates which are insulated or are made up of insulated segments.

Between the two guiding side walls a constant electrical potential difference is impressed which is only large enough. The total current drawn through the ionized gas will react with the magnetic field, and if the sign of the potential difference between the guiding side walls is proper, the ionized gas will be driven up the expander tube. Little current is received by the guiding side walls, however. At the negative side wall electrons are repelled into the gas and positive ions are drawn toward the wall. Thus a space charge of positive ions forms next to the wall, taking up a large part of the voltage because of their charge and reducing the electric field behind them to little more than $\mathbf{E} = (1/c)[\mathbf{H} \times \mathbf{v}]$. But being positive ions alone, in the crossed electrostatic and magnetic fields they will not be accelerated into the side wall, but will be driven nearly perpendicularly to both the electrostatic and the magnetic fields and parallel to the side wall surface. They will thus be the total current *up* the tube.

At the positive side wall, positive ions are repelled into the gas, and the electrons make up a negative space charge at the wall. This space charge in the crossed electric and magnetic fields also is driven up the tube. It constitutes a total current of electricity *down* the tube.

The actual total current in the gas must close itself by flowing back through the gas.

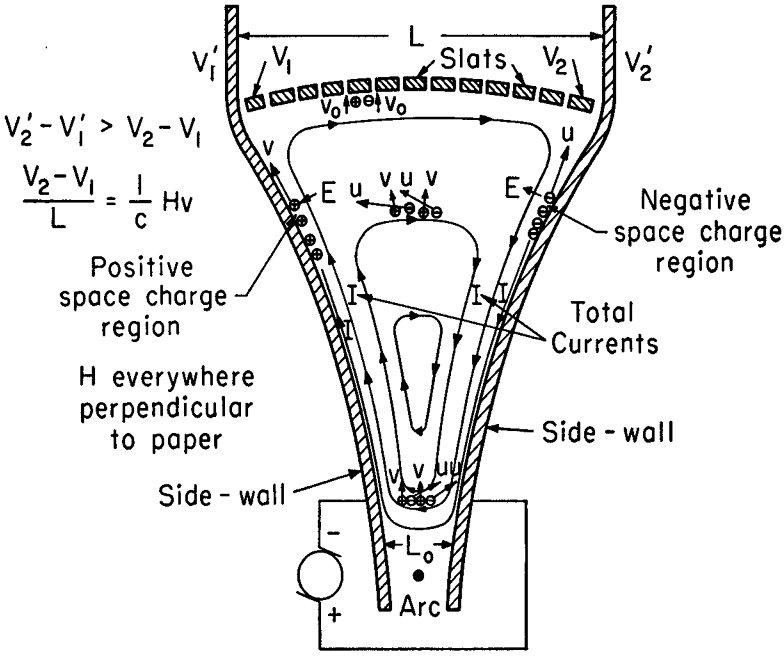

FIG. 1. Magneto-ionic expander.

This is shown in the figure. Thus the total currents induced in the gas by the impressed difference of potential are entirely closed. The insulated slats can receive only zero total current,that is, equal numbers of ions and electrons.

The side walls receive but few ions or electrons. Practically all the ions (with electrons) are precipitated upon the slats. The energy supplied to the gas by the side walls or slats must be zero. The ions (and electrons) must have the same kinetic energy at the slats after passing through the discharge as they did on entering the discharge. The total effect of the discharge upon the ions and electrons must be isentropic; the ions (and electrons) find themselves expanded adiabatically and precipitated upon the slats.

This will be the sole but great difference between the ionic centrifuge and the magneto-ionic expander types of discharge. In the ionic centrifuge the ions encounter the closed total currents in the gas always in the same sense. They, the closed currents, circulate always in the same sense about the arc. They cause the ions which cross them to cut the total currents in the same sense, and the ions precipitate on the cylinder, therefore, with a large value of total current cut.

In the magneto-ionic expander, however, the total currents in the gas are initially of one direction, but the total currents must reverse farther up the expander and must close themselves by flowing in the other direction. Any ion going from the arc to any of the insulated slats will cut the total current first in one sense, but later it must cut the total current in the other sense. The total current cut by the individual ions in their passage to the slats must algebraically be zero.

When crossing the induced total currents at the start, there will be a force in one direction upon moving ions. When crossing the induced total currents farther up the expander, where the induced total currents fall again to zero, the force will be in the opposite direction.

Also there will be a force arising from the pressure tensor produced by the ions (and electrons) moving in the magnetic field (*3*). These forces make the ions avoid the side walls and precipitate upon the slats. They cause the ions to take on at the slats a velocity distribution entirely similar to the velocities of a gas which has expanded adiabatically.

But if the ions are made up of two isotopes, the displacements of the two isotopes will be different for these two forces; the ligher isotope will be brought towards the negative end of the receiving slats, and the heavier isotope will be brought toward the positive end of the receiving slats (*2*).

The relative enrichment of the material found on the two extreme positioned slats will vary approximately as the square of the distance from the arc, and should be enough to give practically pure isotopes in one operation even for uranium.

I have made a rough calculation of the total cost of using the magneto-ionic separator per gram of U^{235}. The cost of the magnet and equipment such as we used was about $150,000. Energizing the magnet at a cost of $0.01 per kilowatt hours would cost about $15,000 per year. For the arc current we have used, 100 amperes, 10 amperes of positive ions, or 6000 grams per year of U^{235} would be obtained. The cost of power for the arc is less than $1.00 per gram of U^{235} and the labor cost per magnet should be about $12,000 per year. These assumptions give $\$1.00 + \$7.00/x$ as the cost per magnet per gram U^{235} with arc current of 100 x amp. Thus, for a 100-amp arc the cost per gram U^{235} should be about $8.00, while for a 1000-amp arc a unit cost of less than $2.00 per gram may be possible. This is to be compared with the value in the AEC 1956 price list of $17.07 per gram of U^{235}, ninety per cent enriched.

The ionic centrifuge has been tested repeatedly for 13 years and gave uniformly negative results in isotope separation. The magneto-ionic expander has been given a preliminary test at a low potential difference between the side walls of only seven volts. Tests at a higher voltage, a few hundred volts, should be made, or the flaw in the above discussion should be exposed.

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Foil Depression Factors for Indium Disk Detectors[1]

Foil detectors have been used for some time as instruments to measure relative thermal neutron fluxes. The foils are thin and usually small in area. It was early realized that the foil itself depresses the thermal flux since it removes neutrons from the surrounding media in order to be activated and, after the capture of the neutron, eliminates the possibility of the neutron's being scattered back to the same point. As the foil thickness approaches

[1] This work was carried out at the School of Nuclear Science and Engineering, Argonne National Laboratory, Lemont, Illinois.