White Paper for *Frontiers of Plasma Science Panel*

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Title:	Differential magnetic confinement for mass separation
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Differential magnetic confinement for mass separation

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Research frontier and importance of the scientific challenge

Plasma magnetic confinement has long been recognized as a scientific challenge, and a large amount of work has been dedicated to the study of confinement physics with the objective of improving confinement. An interesting extension for this research field is differential magnetic confinement. Differential effects can in principle arise from various properties, one of them being mass. Differential confinement properties can then be tailored for plasma based mass separation, which could have significant societal benefits. Although differential confinement has commonalities with confinement physics relevant to magnetic fusion, differential confinement as a research field differs in that the focus is no longer on maximizing the overall confinement properties, but rather on maximizing differential effects. This shift of focus calls for revisiting confinement physics with the goal of understanding differential effects. A particular frontier lies in identifying the best configuration for separating elements based on mass at high throughput, with large mass differences (as opposed to isotope separation).

Advancing this frontier will also help improve our understanding of various fundamental plasma physics processes. Among these are particle transport in plasmas and the role of kinetic effects, angular momentum transport in plasmas, and thermodynamics limits associated with the separation of different species.

Approach to advancing the frontier

The approach envisioned to advance this field consists of a combined theoretical and experimental effort. Theoretical efforts will aim at expanding the work already initiated on the differential confinement properties of various rotating plasma configurations[1-4]. Rotating configurations have been favored so far because of the mass differential properties they exhibit through centrifugal forces. These rotating effects can then be combined with electromagnetic forces to maximize differential effects, as well as to make these configurations attractive for mass separation applications. For example, the magnetic field topology can be tailored so that separated species are collected axially along the field lines at different ends of the machine[2,3], simplifying in turn greatly the handling of separated streams.

Future work should include a better understanding of the physics of these devices, in particular the control of rotation through electrode biasing in a non-uniform magnetic field and in moderate to high density plasmas.

Impact of this research on plasma science and related disciplines and any potential for societal benefit

Since differential confinement and rotating plasma physics are strongly connected, the proposed study of differential confinement in plasmas would likely benefit to various other fields in which rotation effects are observed or potentially useful. These not only include fusion (e. g. impurity removal), but space propulsion with Hall thrusters, plasma processing with magnetron discharges or the astrophysics of accretion disks and dynamos.

Only a glimpse of the full potential of plasmas for separating elements has been caught, but different applications for which such techniques could be a game changer have already been identified[5,6,7]. By operating on dissociated molecules, plasmas can in principle be used for processes for which conventional techniques are particularly challenged. For instance, plasmas might be used to discriminate elements of similar chemical properties, but different mass, such as actinides and lanthanides[5,6]. Plasmas are also foreseen to be superior for separating complex feeds, such as typically encountered in nuclear waste cleanup effort[7]. The cost of nuclear waste cleanup effort in the United States is now evaluated to be greater than 250 billion dollars[8]. Millions of gallons of nuclear material have to be processed in order to separate high activity elements from low activity elements, so that high activity elements can eventually be disposed in glass form. For this particular application, a cost analysis shows[7] that plasma based methods could lower this cost by up to 25%.

1. T. Ohkawa, R. L. Miller, Phys. Plasmas 9 (2002) 5116
2. A. J. Fetterman, N. J. Fisch, Phys. Plasmas 18 (2011) 094503
3. R. Gueroult, N. J. Fisch, Phys. Plasmas 19 (2012) 122503
4. R. Gueroult, J.-M. Rax, N. J. Fisch, Phys. Plasmas 21 (2014) 020701
5. R. Gueroult, N. J. Fisch, Plasma Sources Science and Technology 23 (2014) 035002
6. A. V. Timofeev, Physics-Uspekhi 57 (2014) 990
7. R. Gueroult, D. T. Hobbs, N. J. Fisch, Journal of Hazardous Materials 297 (2015) 153
8. G. H. Friedman, Special Report - Management Challenges at the Department of Energy - Fiscal Year 2015, Technical Report DOE/IG-0924, U.S. Department of Energy, Office of Inspector General, Office of Audits and Inspections, 2014.