Magnetic propulsion experiment

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Abstract

Magnetic propulsion represents a mechanism for driving intense plasma facing lithium streams in a strong magnetic field of tokamaks. If developed, the technology of intense lithium streams would give a new way of solving the problem of power extraction and particle control in tokamak reactors.

While well understood theoretically, propusion was not yet demonstrated experimentally. Now, we report the very first experiments which show the existence of this effect using a simplest magnetic propulsion cell.

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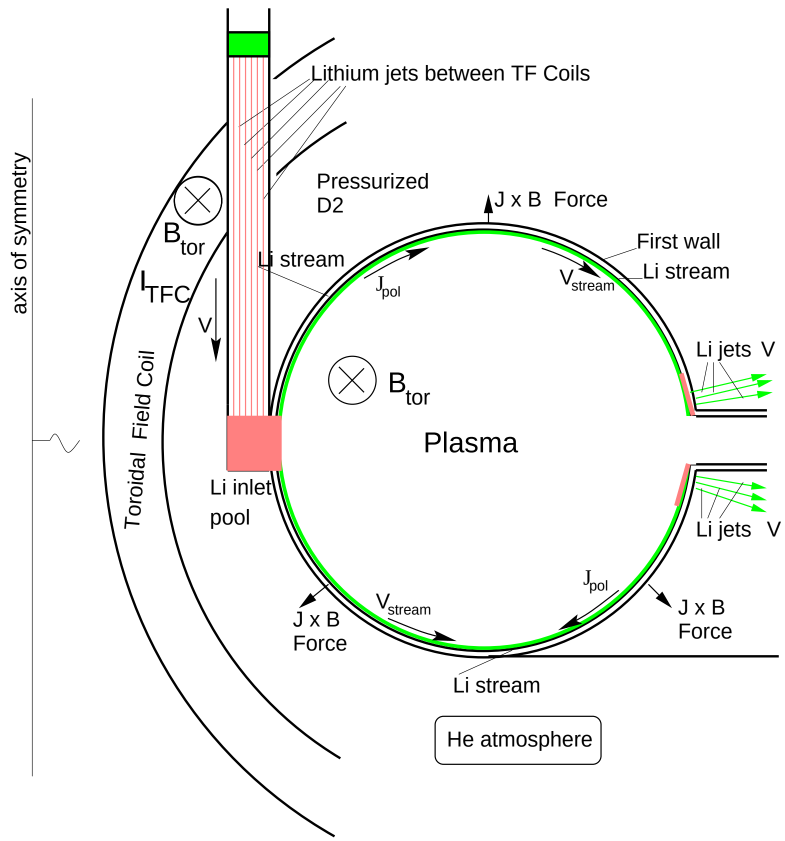
1 Magnetic propulsion of liquid lithium

Magnetic propulsion opens the possibility for intense plasma facing lithium streams in tokamaks

$$p_{j\times B}|_{inlet} - p_{j\times B}|_{outlet} \simeq 1.5 - 3\ [atm], \quad p_{j\times B}|_{outlet} > 1\ atm$$



- Magnetic Reynolds numbers

$$\Re_1 \equiv \mu_0 \sigma h V \simeq 0.8, \quad \Re_2 \simeq 0.0015$$

- Driving electro-magnetic pressure

$$p_{j\times B}|_{inlet} - p_{j\times B}|_{outlet} \gg \Re_2 \frac{B_{tor}^2}{2\mu_0}$$

- Flow parameters

$$V \simeq 20\ m/sec, \quad h \simeq 0.01\ m$$

- Stream are robustly stable due to centrifugal force, if

$$\rho \frac{\langle V^2 \rangle}{2} > \frac{a}{2R} p_{wall} n_r$$

Intense lithium streams have reactor relevant power extraction capabilities

$$\Delta T_{max} = q_{wall}\sqrt{\frac{4t_{transit}}{\pi\kappa\rho c_p}}, \quad d_{skin} \equiv \sqrt{\frac{\kappa t_{transit}}{\rho c_p}}$$

$$R = 6\ m, \quad a = 1.6\ m, \quad q_{wall} \simeq 3.5\ \frac{MW}{m^2}$$

$$P_{wall} = 4\pi^2 R a q_{wall} \simeq 1.3 GW$$

even with no mixing on the surface lithium layer.

Intense lithium streams can keep wall temperature low (250-300^o C) at the neutron wall loading $> 10\ MW/m^2$.

3 Simplest propulsion cell

For tokamak-like propulsion it is necessary to have the magnetic field

$$B_{tor} \propto \frac{1}{r} \qquad (3.1)$$

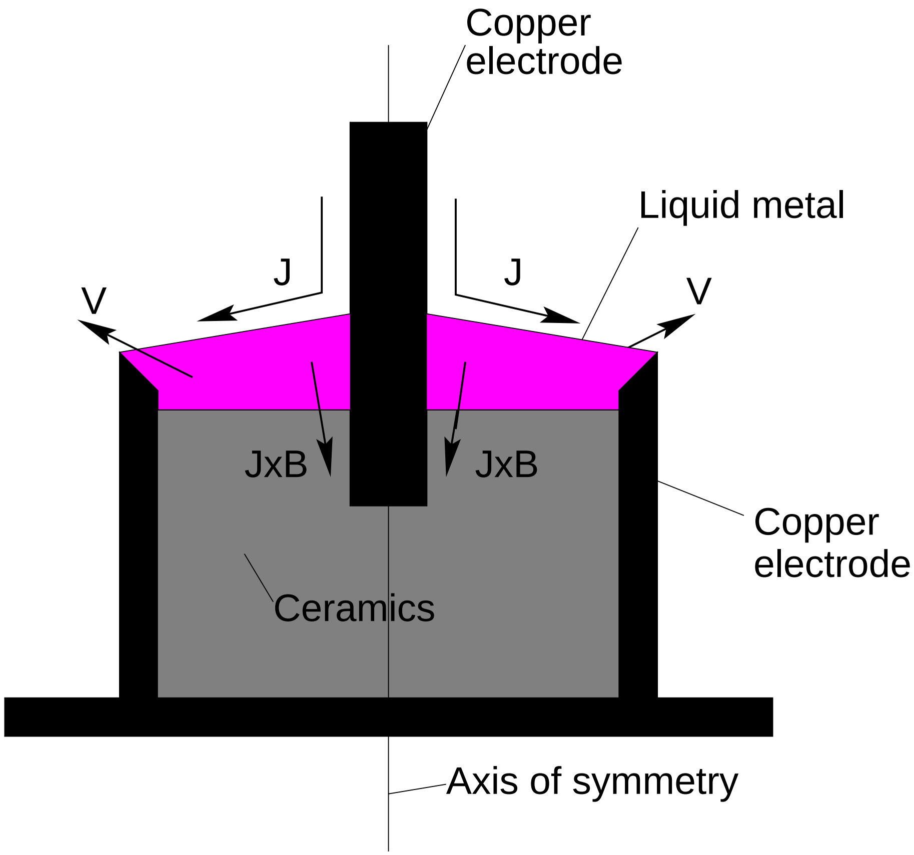
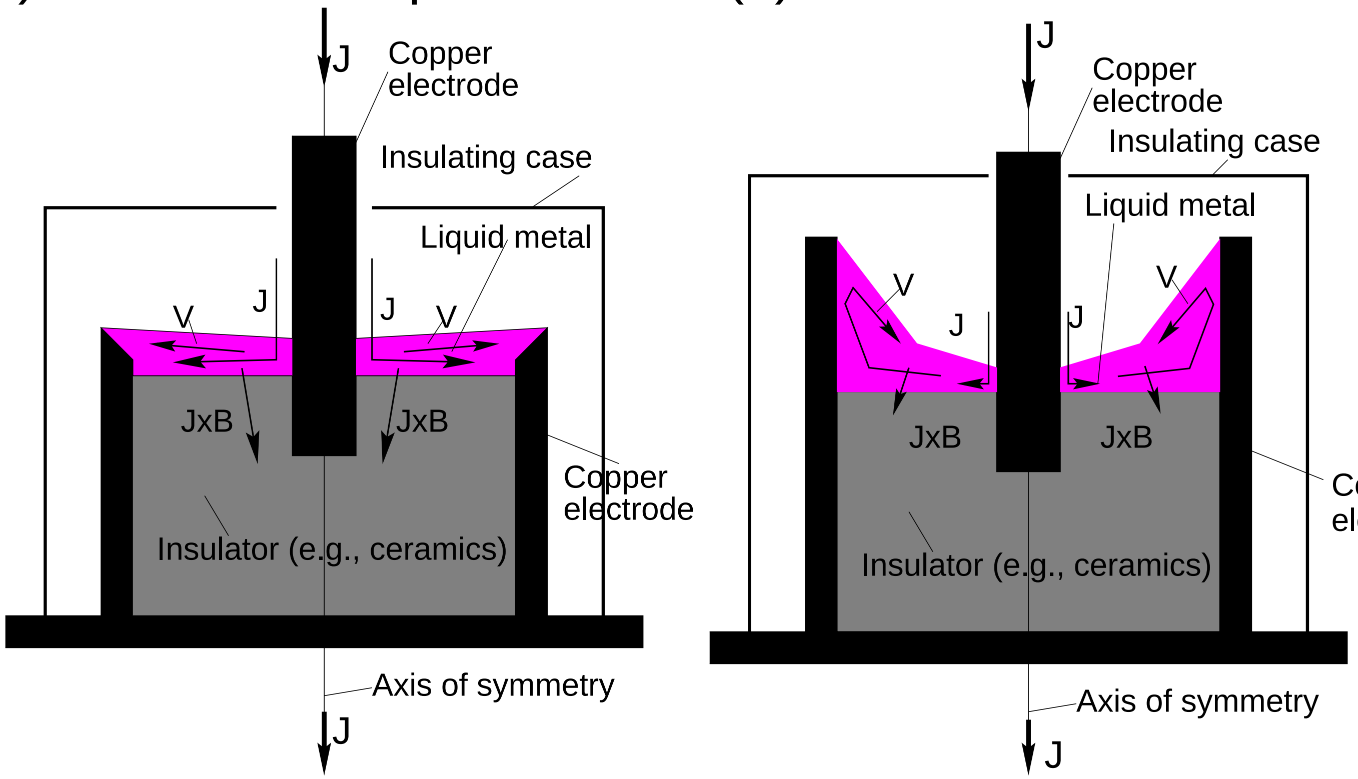


Fig.1. Cross-section of a simplest propulsion cell

(a) Current interrupter device (b) Current limiter device



In the interruption case the metal is expelled from the contact area by the electromagnetic force. In the current limiting case, the electromagnetic force creates a convection inside the metal and enhances the resistance at higher current.

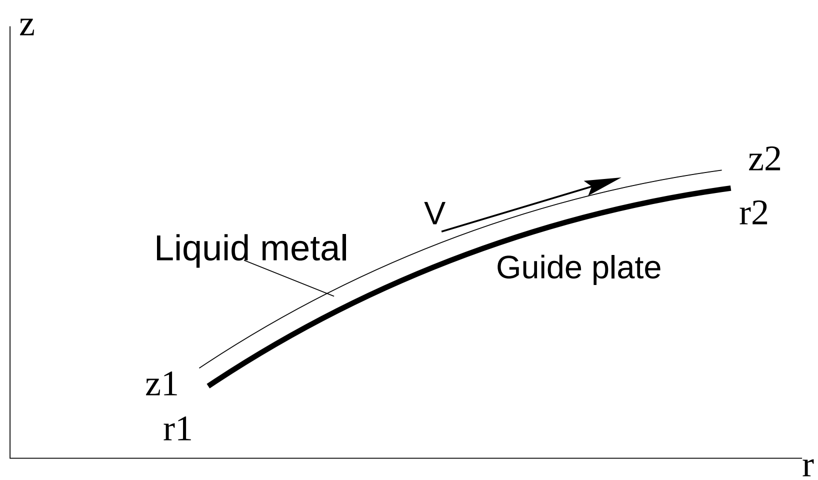
4 Size of the propulsion cell

From MHD equation of motion (with gravity)

$$\frac{B^2}{2\mu_0} + \pi z + \rho\frac{V^2}{2} = const, \quad \frac{B_2^2}{2\mu_0}\frac{r_2^2}{r^2} + \pi z + \rho\frac{V^2}{2} = const \qquad (4.1)$$

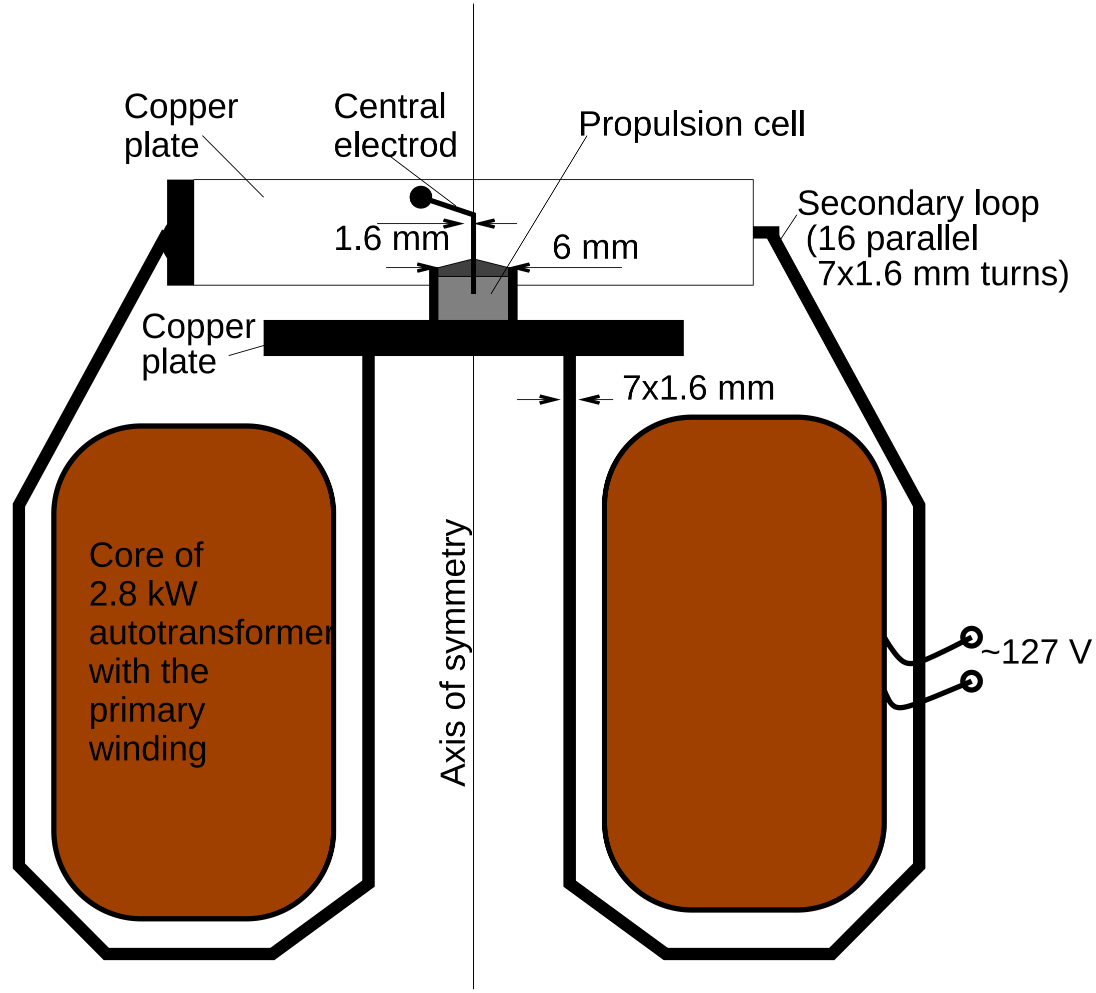
For Gallium

$$\rho = 6.1\,\frac{g}{cm^3}, \quad 1\,atm \rightarrow 164\,cm \qquad (4.2)$$

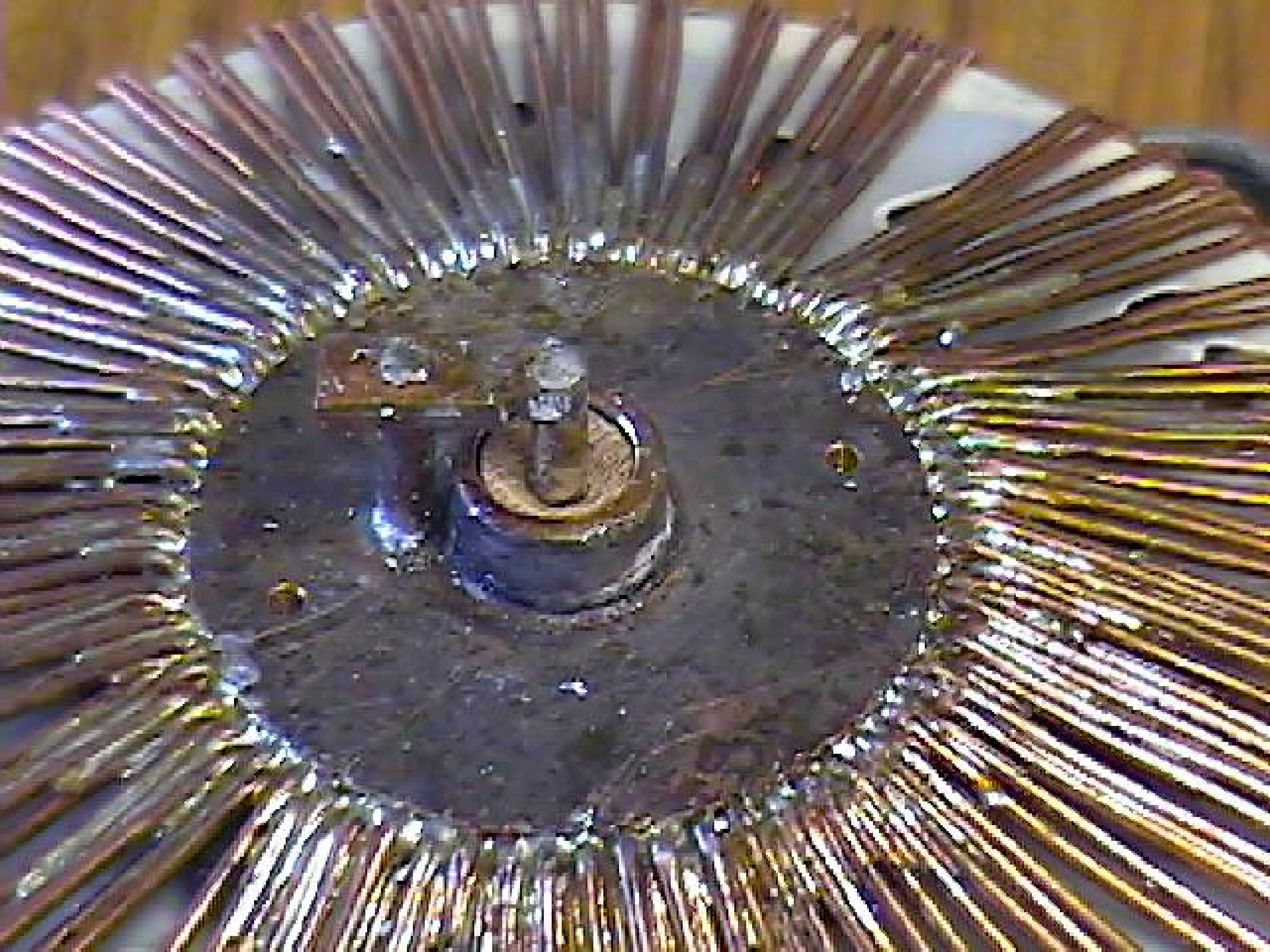


$$B\,[T] = 0.2\frac{I\,[kA]}{r\,[mm]}, \quad z\,[mm] \simeq 260\frac{I^2\,[kA^2]}{r^2\,[mm^2]} \qquad (4.3)$$

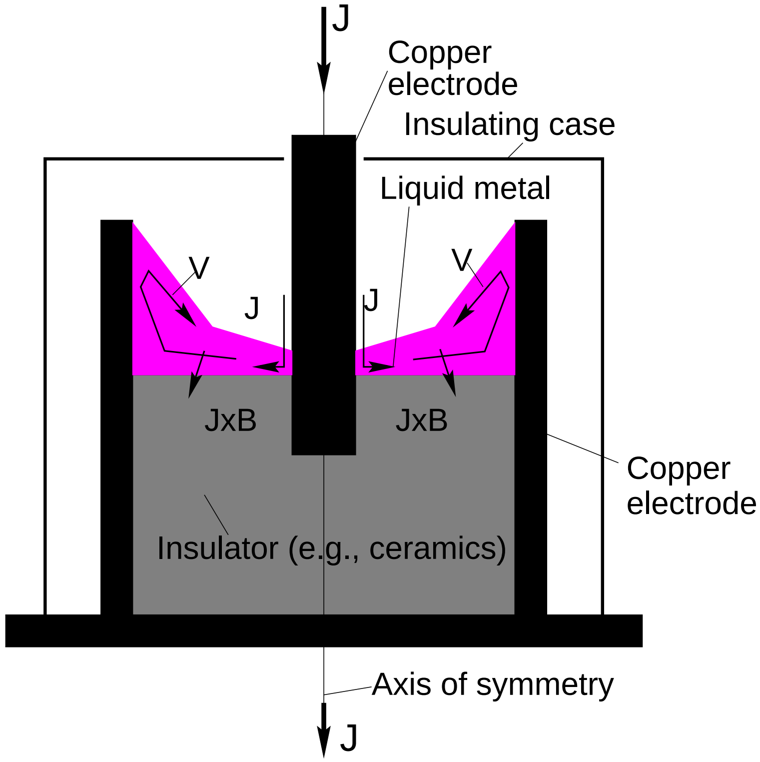
5 Scheme of demonstration experiment

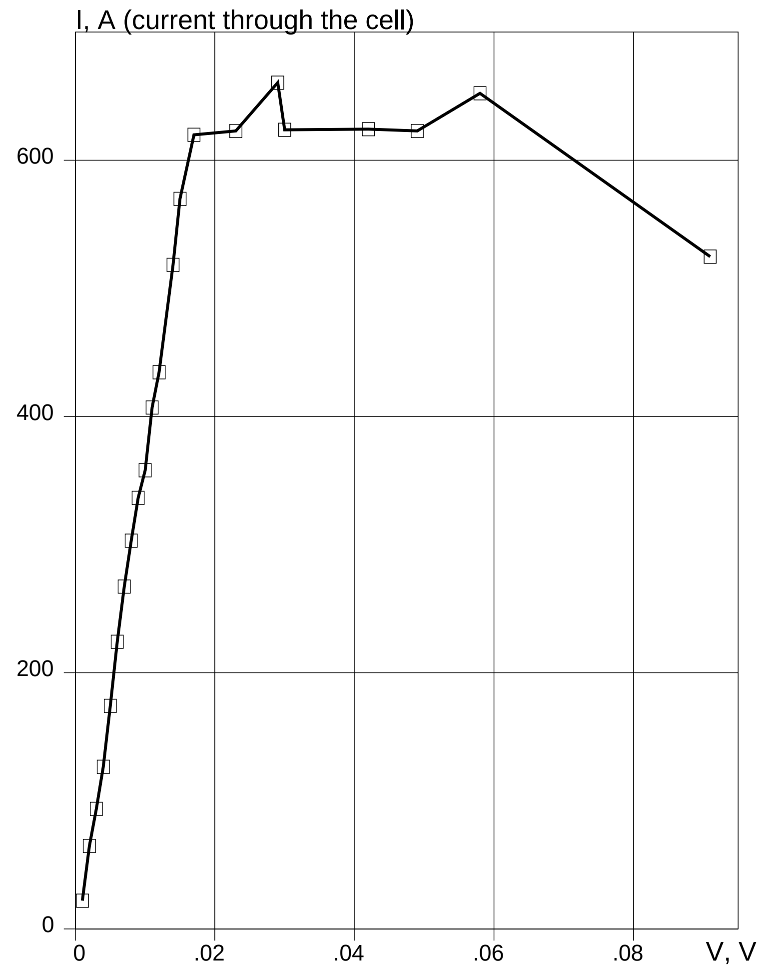


Scheme of a propulsion demonstration experiment



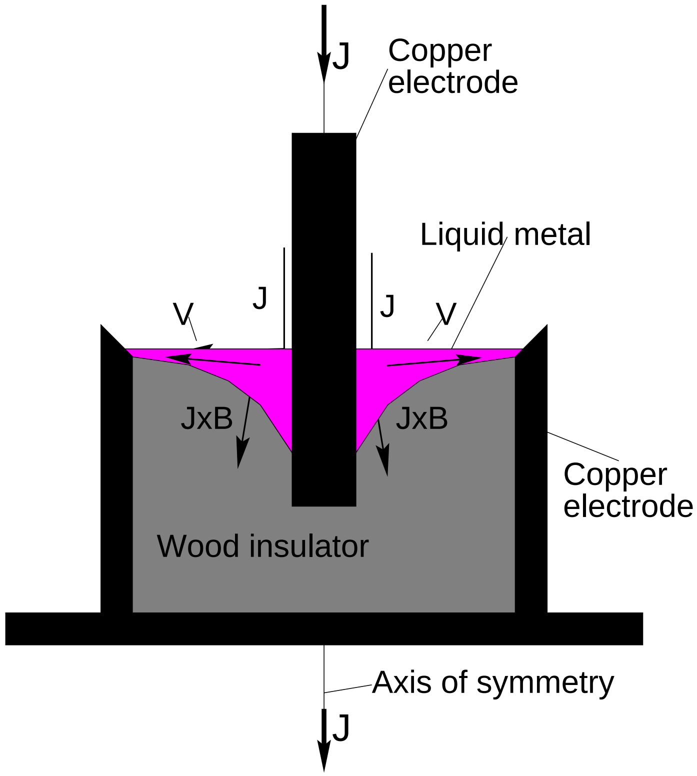
6 Current limiting action



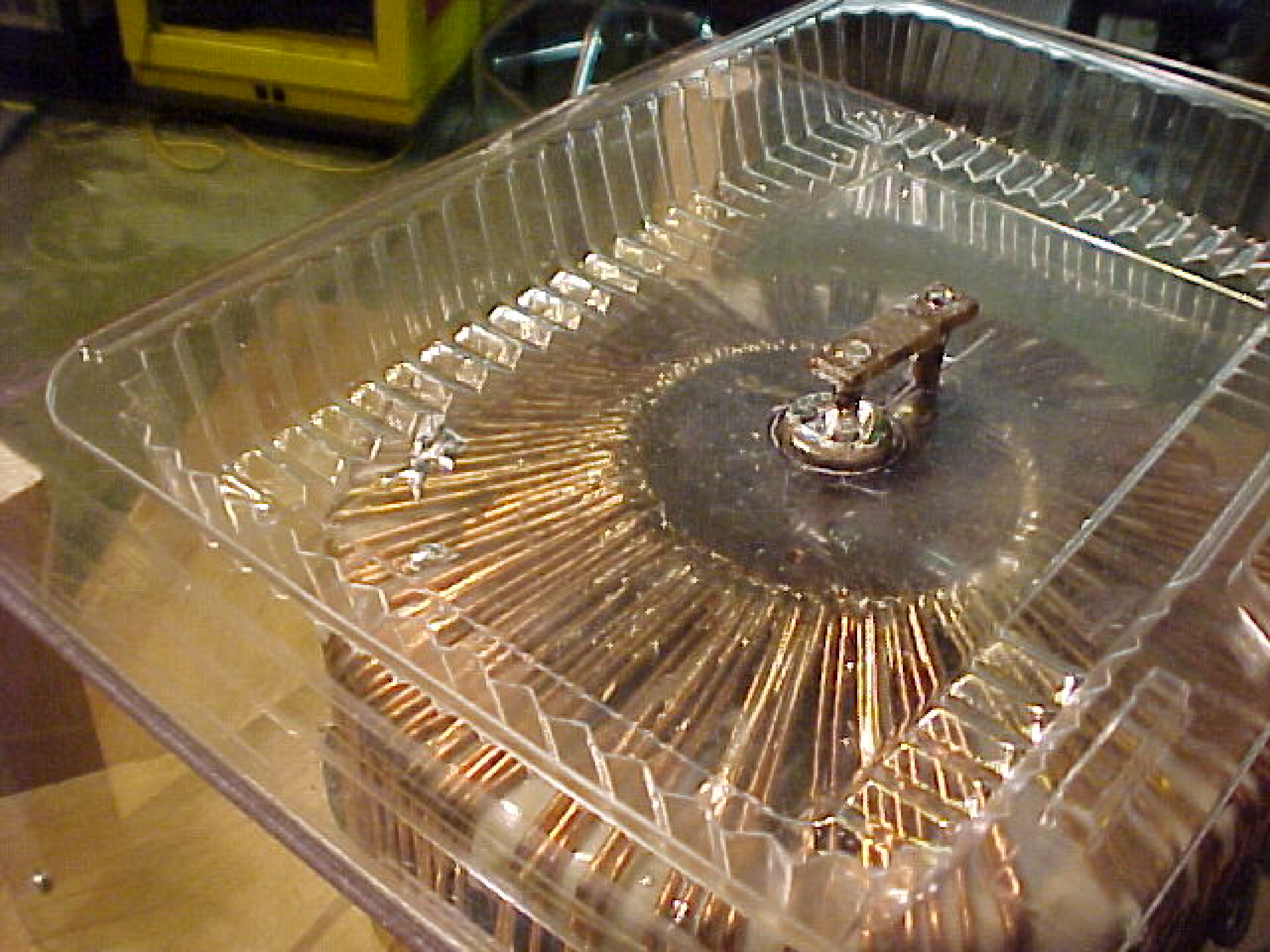


$$r_{central\ electrode} = 2.5\ mm, \quad r_{wall\ electrode} = 7\ mm \tag{6.1}$$

7 Propulsion (circuit breaking) action

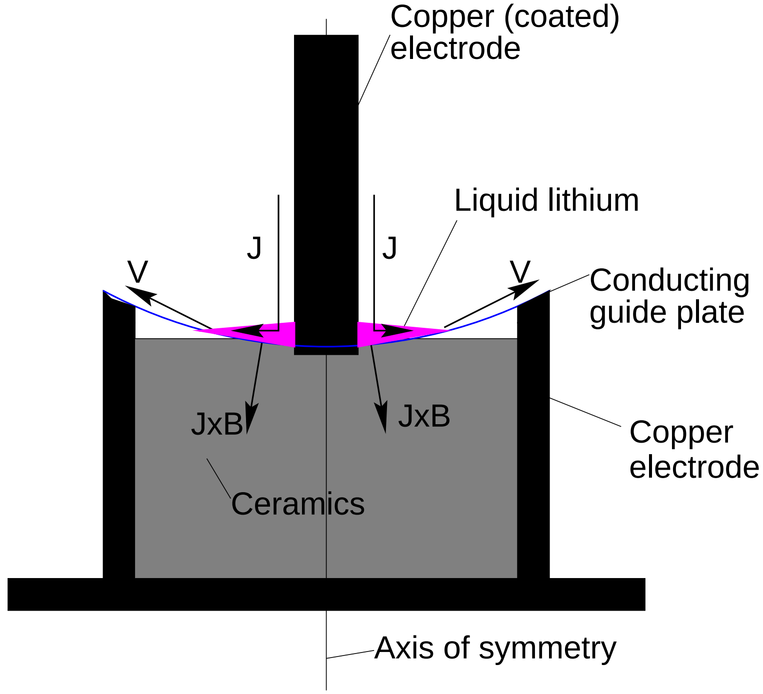


$$r_{central\ electrode} = 2.5\ mm, \quad r_{wall\ electrode} = 7\ mm, \quad depth = 5\ mm \tag{7.1}$$



8 Propulsion of the lithium

Lithium is 12 times lighter than Gallium. All MHD effects should be more visible and at bigger sizes.



Physics/chemistry of Li/guide plate contacts might be a primary issue.

9 Summary

Magnetic propulsion effect has been confirmed experimentally using the simplest propulsion cell with AC current.

These very first experiments may have many extensions including studies of liquid metal convection, flow stability, metal motion around obstacles, etc.

Experiments with liquid lithium can be designed as an extention of the present Gallium experiments.