A Multi-Fluid Analysis of Burning Plasmas

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The Lawson criterion [1], easily compared to experimental parameters, gives the value for the triple product of plasma density, temperature and energy confinement time needed for the plasma to ignite. Lawson's inaccurate assumptions of 0D geometry and single-fluid plasma model were improved in recent work, where 1D geometry and multi-fluid (ions, electrons and alphas) physics were included in the model, accounting for physical equilibration times and different energy confinement times between species [2]. Both steady-state (Lawson-like) and time-dependent calculations were considered. A much more meaningful analysis than Lawson's for current and future experiment is carried out in terms of breakeven (Q=1, where Q is the ratio between fusion power and heating power), burning plasma state (Q=5), or reactor conditions (Q∼40). A versatile set of Mathematica notebooks was developed, which allow to evaluate the plasma conditions needed to achieve any desired value of Q both in the 0D and the 1D multi-fluid plasma description. Arbitrary density and temperature profiles can be assigned from input. In particular, minimum parameters for reaching Q=5 are calculated based on experimental profiles for density and temperatures and can immediately be compared with experimental performance by defining a no-alpha pressure. This is done in terms of the pressure that the plasma needs to reach for breakeven once the alpha heating has been subtracted from the energy balance. These calculations can be applied to current experiments and future burning-plasma devices. Special emphasis is put into obtaining simple analytical approximations of the Lawson product needed for any assigned value of Q given any set of input profiles, in order to simplify the application of the results of this work.

[1] J. D. Lawson, Proc. Phys. Soc. London Sect. B 70, 6 (1957)
[2] L. Guazzotto and R. Betti, Phys. Plasmas **24**, 082504 (2017)