Simulation of a device providing nuclear fusion by electrostatic confinement, with Multiplasma

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Revision B

Revision B: replacement of the term « efficiency » by « yield » to avoid an ambiguity and the aneutronic fusion H+ <-> B11+ taken into account.

1. Goal

To design your own electrostatic confinement nuclear fusion reactor.

It is addressed to people interested by nuclear fusion, having a good general culture in physics (and who are patient because simulations can be long).

It is set aside the fact that your project is physically achievable or not.

2. Warning

This design will be just for the « fun » or from curiosity, because even if the calculations done by Multiplasma are as serious as possible, in the limit of the knowledge of the author (who is not a nuclear physicist but a generalist engineer), of course, nobody is going to build your nuclear reactor…

Otherwise, none checking has been made by another person and the program development does not follow any quality assurance process (so there are probably a lot of errors). It is just a personal program made available to those interested by this subject.

3. Brief explanations of a few of the terms used:

- Deuterium (D or D2) / Tritium (T or T2): these are hydrogen isotopes comprising, besides one proton, either one neutron (Deuterium) or 2 neutrons (Tritium). As other elements, they are susceptible to produce fusions by collisions. The Deuterium is relatively abundant, in sea water, for example. It constitutes 0.01 % of hydrogen. The tritium is naturally present at traces amounts but it is produced (as a gaseous effluent) by fission nuclear centrals, in very small quantities.

- Interaction: it refers to the effect produced by two particles bumping each other : it can be an excitation, a dissociation or a radiation (not considered by Multiplasma), a collision, an ionization, a fusion.
- eV: the eV is a unit of energy quantity used in the particles domain.
  1 eV is equivalent to 1,602 10^{-19} J.
- Fusion: specific interaction where two particles (as D+) collide with sufficiently energy to be transformed in other particles with production of a certain quantity of kinetic energy (besides the initial kinetic energy of the particles colliding each other).
  The fusion reactions managed by Multiplasma 1.6 are given below :
  - D+ + D+ ->T+ (+1.01 MeV) + p+ (+3.02 MeV) (at 50%)

    D+ + D+ ->He3+ (+0.82 MeV) + n (+2.45 MeV) (at 50%)
  - D+ + T+ ->He4+ (+3.5 MeV) + n (+14.1 MeV)
  - H+ + B11+ ->3 He4 (+ 8,68 MeV) (aneutronic fusion)
- Ions: in our case, it can refer to an atom (D or T) having lost an electron. So it is an atomic ion (noted D+ or T+). It can also be a molecular ion if the molecule has lost an electron (D2+ or T2+). A molecule (D2) can be dissociated in atoms (D + D) and/or ionized (D+ + D+ or D2+).
- "Ions" is abbreviated to "I". "Neutrals" (gas molecules) is abbreviated to "N".
- Cross section: it refers to the collecting surface of the interaction. The larger it is and the more it will be produced interactions. It can also be seen as an interaction probability.
- Space charge: each ion and each electron creates its own electrical field to which all other charged particles are submitted. So, the space charge is equal to the sum of all these individual micro-electrical fields. In total, the particles of the same polarity tend to deviate from one another (it is one the problem of this type of reactor).
- Confinement time (or duration): it is the time during which ions regularly circulate in the reactor without loss of an ion away from the reactor or collision with an electrode. So, this confinement time is equal to the interval of time between the injection of the first ion and the first ion loss or more probably the first collision.

4. Basic principle of this type of fusion reactor

The basic principle is the following: an electrostatic field obliges Deuterium and/or Tritium ions to circulate in an electrostatic trap. The environment where the ions progress is a gas at very low pressure, the Deuterium. During their circulation, ions are subjected to interactions with gas molecules and with other ions. Most of these interactions are deleterious for the confinement (collisions, ionization, charge exchange and, by extension, the space charge) but are inevitable. The sole interesting interactions are the ones relative to fusion (between ions or between ions and molecules), but they are rare.

> Note : this gas D2 is, in fact, just a trouble because the fusions are mainly produced by collisions between ions, not by collisions of ions with D2 molecules. However, it must be considered, as it can't be avoided. Indeed, a pressure of gas equal to 0 Pascal (absolute vacuum) is not achievable.

5. Possible objectives of the user

- The minimum objective is that the kinetic energy of the fusion products supplied by the reactor be superior to the consumed electrical energy (fusion yield>1).
- A more ambitious objective is to generate more than 3.333 times more kinetic energy than the consumed electrical energy (fusion yield>3.333), so that to permit an hypothetical exploitation of the produced energy, supposing that the thermodynamic yield permitting to transform this kinetic energy in electricity be equal to 0.3 (standard pessimistic value).
- Criteria to evaluate the performances of your reactor are described below. The final calculation must be done in "Very good" accuracy.
  The following conditions must be verified (to keep a good accuracy, to be sure that the confinement is successful and to be able to compare):
  - All the mean radius of cross section (to the right of « I-N, « I-I » or « s0 ») must be inferior or equal to 0.1 pixel,
  - The "Maximum displacement » must be inferior or equal to 0.2 pixel.
  - The scale (pixel size) is equal to 1 mm/pixel (default value).
  - The dimensions are such that the reactor volume stands in the display window "/125".
  - The number of charge exchanges "I-N Charge exchan." is equal to 1 as a minimum (to show that it has been taken into account), or « x S charge exchange » is equal to 1E10 as a minimum.

- The number of fusions ("**I-I** Fusion") is equal or superior to 100 (to be representative).
- « x S colli. (with preserved effect) » is set to 1.

The evaluation criteria are:

- The gas pressure, must be the highest possible (as a minimum equal to 10 pPa).
- The type of fusion: D+<->D+, D2+<->D2+, D+<->T+ or D2+<->T2+, listed from the most difficult to the easiest (a priori, choose D2+<->T2+).
- The fusion yield (« E ») read on the "**Fus.E./Elec E. Ratio**" label (Ratio between the total kinetic energy carried by particles issued from fusion and the consumed electrical energy), must be the highest possible.
- The fusion energy (« Ef ») read on the "**Fusion energy (J)**" label, must be the highest possible.
- The objective is to have the biggest **exploitable energy** ("Ee), with Ee=Ef x ((E-3,333)/E).

Note 1: for these subjects (and others), see the papers:
http://f6cte.free.fr/Proposal_of_a_new_type_of_fusion_reactor.pdf
http://f6cte.free.fr/Proposal_of_an_aneutronic_fusion_reactor.pdf

Note 2 : your configuration is stored in the CONF_PLASMA.SER file and can be stored and managed in the CONFIGURATIONS sub-directory (see the manual for details).

Nota 3 : thanks not to inform the author of your results (there is no record to break…)..

6. Main parameters to control

- The geometry of the trap. According to its geometry, the equipotentials can be modified and consequently the electric field will evolve. This one must force the ions to remain inside the trap (« confinement »). The confinement must be able to control the largest electrical charge possible.
- The type of fusion used. The user can begin with D+/D+ fusions which have a weak fusion cross section but emit less neutrons than D+/T+ fusions (moreover Deuterium is much more abundant than Tritium). The user can, afterwards, try D2+/ T2+ fusions. The cross section is elevated for relatively low voltage, so the energy production is easier than D+/D+ fusions.

- The voltage on electrodes. The more elevated is the voltage, the more efficient is the confinement and the more there are fusions. But in the reality, it is difficult to pass 1 MV.

- The gas pressure : the higher it is, the more it reduces the possibility to have a yield superior to 1. However, it must be considered some pressure. It is good to have some values in mind (not guaranteed…):

    - 10 pPa is the minimum value of pressure obtained in laboratory. It is also the pressure at an altitude of 10000 km,

    - 1000 pPa is the minimum obtained industrially,

    - 10000 pPa is the vacuum obtained in the particles accelerators. It is also the pressure at an altitude of 1000 km,

    - 10 µPa is the vacuum obtained relatively easily with a turbo-molecular pump. It is also the pressure at an altitude of 400 km.

- Electrons or ions are supposed ejected by a « cathode », which has a strict meaning only for electrons, and which must be interpreted as an electrons gun or as a ions gun. However the emission laws for particles follow the ones that one would have for electrons escaping from an heated cathode (such as in speed as in direction). It must be supplied a temperature or an initial mean speed to particles. This parameter is not very important, up to a certain point. It can be also specified a linear and/or symmetric injection (see the manual for details).

  The cathode is supposed to supply a given current which depends on the cathode area. It will be supplied a given current density (A/cm2). This density will be put into a current according to the cathode area.

  The current is very important. The more elevated it is and the more fusions it occurs, but the more difficult it will be to confine this current. One must look for the maximum electric charge which can be confined. This charge depends on the current and on the ions injection time (Q=I x t).

- The accuracy is important, because the calculation duration can be very long. To rough out the problem, prefer the « Mediocre » accuracy. For the final calculation, prefer the « Very good » accuracy. Note that even in « Very good » accuracy, the result has a very large variability, due to the calculations complexity.

7. Hints for simulation

- It is necessary to monitor the « Maximum displacement » parameter which must be inferior to 0.2 for a good accuracy. The « Time step (ps) » will permit to adjust this parameter.
- It is better to send a salvo of packets of ions rather than an uninterrupted emission, to limit the time of calculation. For about the number of packets of ions to send (« Limit (packets »), try to send sufficiently packets (at least 1000) so to have the maximum of ions along the trap, in all positions. The worst is to have a bunch of packets of ions circulating together along the trap because, in that case, there will not have any frontal collision between ions. Use the « Last position » function to observe particles and the calibration function (« Correction of the speed ») to determine the number of pixels travelled by an ion during a cycle (see the handbook for details).
- An amplification/reduction of phenomena must be done to limit the calculation time. For this, it is used multipliers which are « x S fusion », « x S charge exchange » and « x S colli. (with preserved effect) ». For the two first multipliers, the effects are reduced by the same multiplier factor, so to keep stable the global effect, whatever the simulation time is. Reversely, it is not possible to reduce the effects for the third multiplier (because a collision cannot be reduced : either it occurs or it does not occur). For this last case, it must be considered as a phenomena accelerator. One can, for example, simulate on a small duration all what can occur on a much larger period. It will be necessary to be sure that despite this phenomena acceleration, the confinement is able to bring back the ions.
- All the mean radius of cross section (to the right of « I-N, « I-I » or « s0 ») must be inferior to 0.1 pixel to keep a physical meaning.
- In normal working, one must be in continuous emission: ions are sent successively until the packets limit is reached.
- Also in normal working, the space charge must be on service. However, it takes a big CPU load (especially in « Very good » accuracy option). So it can be chosen to avoid the space charge calculation for preliminary tests, or to limit it by setting the accuracy in “Mediocre”.

8. Reactor models proposed

It will be found, by default, the reactor proposed by the author (simple reactor which confinement is done thanks to only one electrostatic lens). It is supplied in a configuration in “mediocre” accuracy, to limit the calculation time. This one is also stored in the sub-directory « CONFIGURATIONS » under the name « LKR1 » (simple

reactor which confinement is done with only one electrostatic lens)), with LKR1m, LKR1m2 and LKR1m3 which derive from LKR1. The study of these reactors is done in the following documents:
http://f6cte.free.fr/Proposal_of_a_new_type_of_fusion_reactor.pdf
http://f6cte.free.fr/Proposal_of_an_aneutronic_fusion_reactor.pdf

It is also stored:

- a Fusor model under the name « FUSOR ». This model is given for information. The Fusor definitely generates fusions but its yield is very weak.
- a sort of Penning trap under the name « PSEUDO_PENNING_TRAP », intended to study the different effects in a plasma (see further the study of this model),
- a trap under the name « TEST_CORRECTION_AND_FREQUENCY », to show how to do a test of speed correction and oscillation frequency (see further the test of this model).

It is possible to load any of both configurations by clicking on the « **Load Conf.** » button.

Note : you can store your own configuration in the sub-directory « CONFIGURATIONS » by clicking on the « **Save Parameters** » button, then in naming your configuration.

9. What to do at the first start-up

It is proposed, as a basis, the author "LKR1" reactor. The basic instructions to do are the following:

- First start "**Multiplasma**". A default set of parameters is proposed. Don't change it.
- At this level, you can click the <**Help**> menu then again on "**Help**". The handbook will appear. You can test a research on a word or print the handbook.
- Click on the "**Graph**" button, then on the red "**On**" button.
- Observe, first, the preparation of the calculation. Once finished, the calculation starts. Observe:
    - the ions circulation on the graph,
    - the reactor yield on the "**Fus.E./Elec E. Ratio**" label (Ratio between the total kinetic energy carried by particles issued from fusion and the electrical energy consumed),

  - the energy supplied on the "**Fusion energy (J)**" label.

- Once the simulation is finished ("**Off**" button pushed), you can do a snapshot with the "**Diskette**" button, the picture being stored in the "SCREEN" sub-directory.

- Afterwards, click on the "**Quit**" button and again on "**Quit**" to abandon the program.

Afterwards

- Study the handbook and the model of reactor given by default.

- Change only one parameter (geometric, for example) and observe the effect of your change.

10. For more information with the « PSEUDO_PENNING_TRAP » configuration

Click on the "**Load. Conf.**" button, load the « PSEUDO_PENNING_TRAP » configuration (a sort of Penning trap), intended to study the different effects in a plasma. The particles emitted are, here, electrons and not ions.

- Click on the "**Graph**" button, then on the red "**On**" button.
  It can be observed, at the end of the calculation (on 6000 steps), that the electrons are confined (no electrons losses).
  There are no collisions with the gas (see the fields: « EI-N Elastic », « EI-N Excitation » and « EI-N Ionization" at 0).

- Click on the "**Space charge**" button, then re-start by clicking on the "**On**" button.
  It can be observed, during the simulation, that the electrons move away from each other (due to the space charge) and that, rapidly, electrons and confinement are lost.

- Click on the "**Quit**" button to come back to the Configuration window. Add a magnetic field of 0.1 Tesla : click on the « **B field** » button then adjust the magnetic field to 10 cT.
  Click on the "**Graph**" button, then on the red "**On**" button.
  It can be observed, during the simulation, that the electrons are confined in the XY plane by the magnetic field, but the confinement is not made along the Z axis (electrons are lost lengthwise).

- Click on the "**Quit**" button to come back to the Configuration window. Reduce the current density to 1 µA and delete the magnetic field by unclicking the « **B field** » button.
  Click on the "**Graph**" button, then on the red "**On**" button.

It can be observed that the electrons remain confined, this because the space charge is now very weak, the number of electrons by packet having been reduced by a factor 100000.

- Click on the “**Quit**” button to come back to the Configuration window. Increase the gas pressure, with a factor 1000000, by clicking on the « **µPa** » button (instead of « **pPa** »).
  Click on the “**Graph**” button, then on the red “**On**” button.
  It can be observed that electrons are no more confined and many collisions occur (see the fields: « EI-N Elastic », « EI-N Excitation » and « EI-N Ionization”). Many collisions are ionizing ones (it appears many (slow) ions in blue). Note that electrons are on average slowed by these collisions.

- Click on the “**Quit**” button and again on “**Quit**” to abandon the program.

11. Use of the « TEST_CORRECTION_AND_FREQUENCY » configuration

Click on the “**Load. Conf.**” button, load the « TEST_CORRECTION_AND_FREQUENCY » configuration. It is an example intended to determine a speed correction and the oscillation frequency of a particle in a trap (see the manual for more precisions).

Click on the “**Graph**” button, then on the red “**On**” button.
It can be observed, below the green bar, the evolution of data relative to the speed correction and the oscillation frequency. Once the correction determined, it can be read « N=255/255 » followed by different pieces of information :

- Oscillation frequency: 12061.8 KHz,

- Number of time steps covered per cycle : 829.06. It is an important data to dimension the number of packets to send (one by one), because this number of steps (or a multiple) permits to have the best distribution of particles in the trap.

- The proposed correction : -0.1 ppm (weak correction).

<u>Note</u> : the speed correction is linked to the fact that the calculation introduces a very weak digital error which accumulates with time. This correction can, possibly, be used on long term calculations (let’s say superior to 10000 steps), but generally speaking, it is better to avoid to use this function which is also an errors source.
It has to be noted that the relative amplitude of the error depends on the distance travelled during one step (cf. « maximum displacement » parameter). The larger is this distance and the more important is this error. This error can be reduced by decreasing the step time and hence the distance by step, but extending the calculation time. However, the error can’t be reduced to 0 (but we can correct it).

12. Limitation

This software is “freeware” for a non-commercial use only.

13. Technical questions and proposals

The author does not answer to technical questions (no individual answer to technical questions about Multiplasma or the fusion) and does not take into account any proposals of improvement or addition (because no new version is expected at the moment). **The program is to be used, as it is.**

Questions relative to fusion can, possibly, be asked, in English, to one of the forums of the fusor.net discussion group (http://www.fusor.net/board/). You can also search answers on Internet (keywords: “Fusion”, "Fusor”, “Linear ion trap”, “electrostatic confinement”, “electrostatic lens”...) or in books or in scientific articles.