Laser and Particle Beams

cambridge.org/lpb

On the ignition of small thermonuclear assemblies

Friedwardt Winterberg

Carl Friedrich Gauss Academy of Science, Potsdam, Germany and Reno, Nevada, USA

Research Article

Cite this article: Winterberg F (2018). On the ignition of small thermonuclear assemblies. *Laser and Particle Beams* **36**, 232–235. https://doi.org/10.1017/S0263034618000204

Received: 16 February 2018
Accepted: 20 February 2018

Key words:
Particle beams; Rayleigh–Taylor instability; thermonuclear fusion

Author for correspondence:
Friedwardt Winterberg, Carl Friedrich Gauss Academy of Science, Potsdam, Germany and PO Box 18265, Reno, Nevada 89511, USA.
E-mail: fwinterbe@gmail.com

Abstract

A novel way for igniting small thermonuclear assemblies by inertial confinement is proposed, by replacing the positive mass of an imploding dense star with the negative mass in the reference frame of a rapidly rotating thermonuclear target. According to Einstein's general theory of relativity, this negative mass can be orders of magnitude larger than the positive mass density of a neutron star. This novel concept also replaces the Plutonium 239 "spark plugs" of large thermonuclear devices with a shell of natural uranium surrounding a target composed of DT or Li^6D.

Unlike the ignition by a laser – or particle beam – induced spherical implosion, this configuration, similar to that of an imploding star is not only Rayleigh–Taylor stable, but it can be realized with intense relativistic electron or ion beams, with an energy of about 100 MJ, having a short range in the dense high Z natural uranium shell.

Introduction

The holy grail of controlled nuclear fusion research, be it by magnetic or inertial plasma confinement, is to find a way to achieve ignition without the energy input from a large nuclear fission explosion. At the present, the only known way to achieve the release of nuclear energy is by the fusion of light atomic nuclei in large thermonuclear explosive devices.

While the realization of nuclear fusion by magnetic confinement is expected to be feasible in the near future, it is unlikely to be possible in compact devices. At the present state of technology, nuclear fusion by lasers is out of reach for lasers, but it may be possible with electric pulse power or by impact fusion. The reason for the rather large energy, more than 50 MJ for ignition, is the Rayleigh–Taylor instability, as was shown by the analysis of Kidder (1998).

In this communication, a third possibility is analyzed: the stable implosion of a rapidly rotating target with natural uranium enclosing the fusion fuel, and imploded by intense relativistic electron beams stopped in the dense uranium shell over a distance of a few centimeters. One can for the same purpose also use an ion beam, but this would require a level of intensity and energy that is much more difficult to produce.

In this third way for the achievement of controlled nuclear fusion, the expensive Plutonium 239 "spark plugs" of large thermonuclear explosive devices are replaced with comparatively cheap natural uranium. It can also work with thorium and perhaps even boron 10. Its feasibility is a consequence of Einstein's general theory of relativity, in its importance first recognized by Hund (1948). It is that in a non-inertial reference frame, there can be large actual negative masses, with a negative mass density, which for technically feasible rapid rotation velocities, of the order of ∼10 km/s, can be larger than the positive mass density of a neutron star.

This makes it possible to build a cm-size "mass-inverted" virtual miniature neutron star, which as its positive counterpart can be stably imploded.

Kidder's scaling law for the implosion of spherical targets

All laser ignition concepts did not take into account the scaling law for spherical implosion inertial confinement fusion targets by Kidder (1998), which is obtained as follows: the energy input for ignition is:

$$E = \frac{1}{2} M V_{\mathrm{imp}}^2 \simeq \rho R^3 \simeq \frac{(\rho \mathrm{R})^3}{\rho^2}, \tag{1}$$

where M is the mass of the target and V_{imp} the implosion velocity. For thermonuclear burn in DT, one has $\rho R \sim 1\,\mathrm{g/cm^2}$, hence

$$E \simeq \frac{1}{\rho^2}. \tag{2}$$

© Cambridge University Press 2018

CAMBRIDGE UNIVERSITY PRESS

If $R = R_0$ is the radius at the beginning of the implosion and $R < R_0$ the final radius at the end of the implosion, one has,

$$\frac{\rho}{\rho_0} = \left(\frac{R_0}{R}\right)^3, \tag{3}$$

and hence

$$E \simeq \left(\frac{R}{R_0}\right)^6, \tag{4}$$

or

$$\frac{R_0}{R} \simeq E^{-1/6}. \tag{5}$$

This means that the ignition energy is very sensitive to the ratio R_0/R, or *vice versa*, the ratio R_0/R is very insensitive to the energy input and limited to the Rayleigh–Taylor instability (Landau and Lifshitz, 1971). The latest data obtained by the laser implosion experiments of the National Ignition Facility of the Lawrence Livermore National Laboratory have shown no ignition with a laser energy input of 2 MJ. Therefore, raising the laser energy tenfold, from 2 to 20 MJ, would only decrease the ratio R_0/R by the insignificant factor $10^{-1/6} \approx 0.7$. Together with the limitation set by the Rayleigh–Taylor instability, this all but excludes lasers as a means for thermonuclear microexplosion ignition.

The third way

The proposed third way for the controlled release of energy by nuclear fusion is explained in Figures 1 and 2. Figures 1 shows how through the arrangement of chemical high-explosive lenses, a hollowed-out natural uranium cylinder can be brought to a large rotational velocity of the order of 10 km/s. Figure 2 shows how this cylinder can be three-dimensionally imploded by two intense relativistic electron beams projected from above and below the two upper and lower ends of the uranium cylinder.

Assuming that the fusion fuel is Li^6D salt, as it is used in "dry" H-bombs, the velocity inside the rapidly rotating cylinder is large enough for the chemical decomposition of Li^6D into its components, lithium 6 and deuterium. Due to centrifugal forces, the lithium will accumulate at the inner surface of the natural uranium cylinder, while the deuterium will remain in the center. A pulse of relativistic electrons of about 100 MJ dissipated into the uranium shell, will cause the shell, along with the deuterium, to implode it three-dimensionally and ignite a fusion reaction.

The occurrence of the large negative mass densities in the general theory of relativity

While it is not possible to make a laboratory-size star, it is possible to reach a centrifugal field comparable to the gravitational field of a very dense star, with a negative density of the same order of magnitude as the positive density of a neutron star. It is the general theory of relativity (Landau and Lifshitz, 1971) in which the gravitational energy cannot be localized but is described by Einstein's pseudo tensor t^{ik}, the energy and momentum are expressed by a sum of products of Christoffel symbols Γ^i_{kl}, which are the forces. In a non-inertial reference frame, these forces are generally different from zero even in the absence of

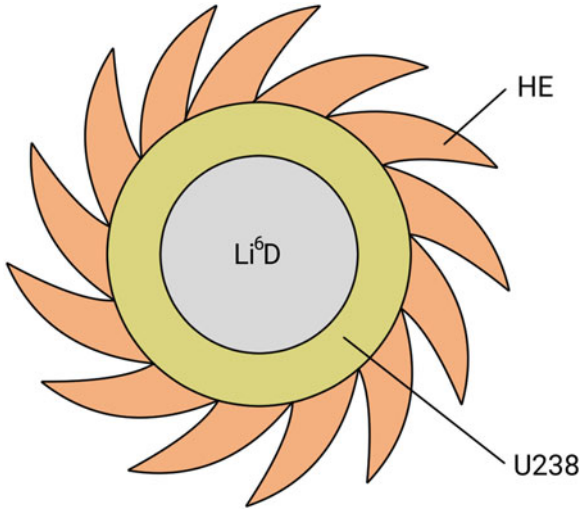


Fig. 1. Arrangement of chemical high-explosive lenses.

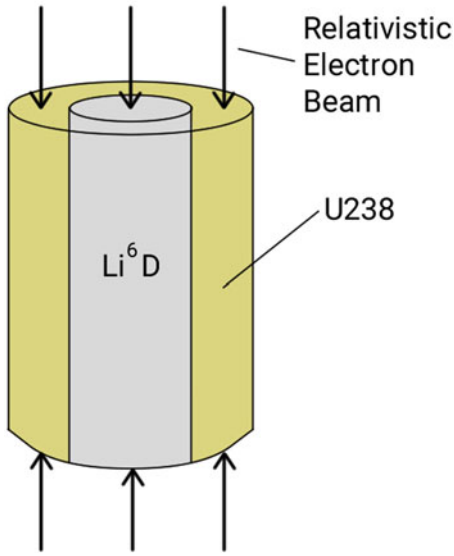


Fig. 2. Uranium cylinder three-dimensionally imploded by two intense relativistic electron beams.

gravity-producing masses. As it was shown by Hund (1948), for non-relativistic velocities, these forces can be obtained by Newtonian mechanics. In the rotating reference frame inside the rapidly rotating uranium cylinder, the equation of motion for a test particle is given by:

$$m\frac{d\mathbf{v}}{dt} = m\mathbf{F} + m\frac{\mathbf{v}}{c} \times \mathbf{C}, \tag{6}$$

where

$$\mathbf{F} = \omega^2\mathbf{r} \tag{7}$$

is the centrifugal force, and

$$\mathbf{C} = -2c\boldsymbol{\omega} \tag{8}$$

https://doi.org/10.1017/S0263034618000204 Published online by Cambridge University Press

the Coriolis force, with $\boldsymbol{\omega}$ the angular velocity vector of rotation. If **F** is a gravitational acceleration produced by the mass distribution of density ρ as the source of Newton's law of gravity, one has:

$$div\mathbf{F} = -4\pi G\rho, \tag{9}$$

where G is Newton's constant. A centrifugal acceleration is also not free of sources, because of (7) one has

$$div\mathbf{F} = 2\omega^2 \tag{10}$$

and hence the negative mass density

$$\rho = -\frac{\omega^2}{2\pi G}. \tag{11}$$

This negative mass is not fictitious and can be felt as the repulsive force in a merry-go-round. For $\omega = 0.6$/s (an example given by Hund), one has $\rho = -10^6$ g/cm^3, comparable with the positive mass density of a white dwarf star.

The mass density (11) represents a physical reality as the mass density of the electric field **E,**

$$\rho_e = \frac{\mathbf{E}^2}{8\pi c^2}. \tag{12}$$

While the mass density (12) is positive, because the equal sign charges repel each other, the mass density of a gravitational field **g** where equal sign masses attract each other, is negative and is

$$\rho_g = -\frac{\mathbf{g}^2}{8\pi G c^2}. \tag{13}$$

Likewise the mass density of the Coriolis field (8) is

$$\rho = -\frac{\boldsymbol{C}^2}{8\pi G c^2} = -\frac{\omega^2}{2\pi G} \tag{14}$$

equal to the mass density given by (11). This means the centrifugal force is caused by the negative mass density of the Coriolis force field. By comparison, the negative mass density $-\mathbf{F}^2/8\pi G c^2$ of the centrifugal force field (7) is smaller by the order v^2/c^2.

Let us compare the negative mass density with the positive mass density, $\rho_N = 10^{14}$g/cm^3, of a neutron star. With $\omega \simeq v/R_0$, $R_0 \simeq 1$ cm is the radius of the target chamber and $v \simeq 1$ km/s = 10^5 cm/s, one finds that $\omega = 2.6 \times 10^5$/s and $\rho = -10^{17}$ g/cm^3, three orders of magnitude larger than the positive mass density of a neutron star.

Nernst effect

In the proposed concept, the plasma is confined by the outwardly directed gravitational force of the negative mass of the Coriolis field, and by the inwardly directed magnetic force from the wall of the target chamber, by the Nernst effect.

With the temperature gradient ∇T from the cold wall into the hot deuterium plasma and **B** the magnetic field, the thermomagnetic current by the Nernst effect is for a hydrogen plasma given by Spitzer (1962):

$$\mathbf{j}_N = \frac{3knc}{2B^2}\mathbf{B} \times \nabla T \tag{15}$$

with the magnetic force density of the plasma:

$$\mathbf{f} = \frac{1}{c}\mathbf{j}_N \times \mathbf{B} = \frac{3nk}{2B^2}(\mathbf{B} \times \nabla T) \times \mathbf{B} \tag{16}$$

or with ∇T perpendicular and **B** parallel to the wall

$$\mathbf{f} = \frac{3}{2}nk\nabla T. \tag{17}$$

With the Nernst effect acting like a small magnetohydrodynamic generator, it would only need a small seed-field, equilibrium condition being

$$\nabla p = \mathbf{f} \tag{18}$$

with $p = 2nkT$, $\nabla p = 2nk\nabla T + 2kT\nabla n$, one has

$$2nk\nabla T + 2kT\nabla n = \frac{3}{2}nk\nabla T, \tag{19}$$

which upon integration yields

$$Tn^4 = \text{const.} \tag{20}$$

In a Cartesian x, y, z coordinate system with the cold wall at $z = 0$, and the magnetic field **B** into the x-direction, the Nernst current density **j** is in the y-direction, and is

$$\mathbf{j}_y = -\frac{3knc}{2\mathbf{B}}\frac{dT}{dz}. \tag{21}$$

From Maxwell's equations $4\pi\mathbf{j}/c = \text{curl}\ \mathbf{B}$ one has

$$\mathbf{j}_y = \frac{c}{4\pi}\frac{d\mathbf{B}}{dz}. \tag{22}$$

Eliminating $\mathbf{j}_y$ from (21) and (22) one obtains

$$2\mathbf{B}\frac{d\mathbf{B}}{dz} = -12\pi kn\frac{dT}{dz}. \tag{23}$$

If in the plasma far away from the wall $n = n_0$, $T = T_0$, one has from (20)

$$n = \frac{n_0 T_0^{1/4}}{T^{1/4}}. \tag{24}$$

Inserting this into (23) one finds

$$d\mathbf{B}^2 = -\frac{12\pi k n_0 T_0^{1/4}}{T^{1/4}}dT. \tag{25}$$

With the boundary condition $B = B_0$ at $z = 0$ and $T = T_0$ at $z = \infty$, integration of (25) yields

$$\frac{\mathbf{B}_0^2}{8\pi} = 2n_0 kT_0. \tag{26}$$

https://doi.org/10.1017/S0263034618000204 Published online by Cambridge University Press

The meaning of (26) is that the magnetic pressure $\mathbf{B}_0^2/8\pi$ exerted on the plasma from the wall surface at $z = 0$, balances the plasma pressure $2n_0kT_0$ at $z = \infty$. With $n_0 = 10^{23}/\text{cm}^3$ and $T \simeq 10^8$ K, one finds that $B_0 \simeq 10^7$ Gauss.

With the Nernst effect, where according to (20) $T\text{n}^4 = \text{constant}$, the bremsstrahlung losses going in proportion to $n^2\sqrt{T}$ (Spitzer, 1962) are constant across the entire plasma, which for $\text{n}T = \text{constant}$ would rise in proportion to $T^{-3/2}$. The reason are the large thermomagnetic currents set up in between the hot plasma and the cold wall of the spinning uranium cylinder, leading to a large magnetic force repelling the hot plasma from its wall.

For the working of the Nernst effect one must have

$$\omega\tau \gg 1, \tag{27}$$

where ω is the electron cyclotron frequency and τ is the electron–ion collision time. At high magnetic fields of the order $B \simeq 10^7$ G and temperatures of the order 10^8 K, with a particle number density $n \simeq 10^{23}/\text{cm}^3$, one has $\omega \simeq 10^{14}\ \text{s}^{-1}$, $\tau \simeq 10^{-9}$ s (Spitzer, 1962) and hence $\omega\tau \simeq 10^5 \gg 1$.

Ignition

The ignition is achieved by a 100 MJ pulse of an intense relativistic electron beam as it was originally proposed by the author (Winterberg, 1968), except that here the beam stopping does not depend on the two-stream instability, but instead on the classical stopping length. For MeV electrons, the stopping length is determined by the uranium mantle of the target chamber, which implodes the target. The stopping length is given by Winterberg (2010):

$$\lambda \simeq \frac{1}{\rho}(0.543E - 0.16)\ \text{cm}, \tag{28}$$

where ρ is the target density in g/cm^3 and E is the electron energy in MeV. For $\rho \simeq 20\ \text{g/cm}^3$ and $E \simeq 10$ MeV, one obtains $\lambda \simeq 2.6$ cm, about equal to the linear dimension of the uranium cylinder.

With 100 MJ $\simeq 10^{15}$ erg, deposited in a volume $\text{V} \simeq \pi R_0^2 h > 25\ \text{cm}^3$, the temperature given by $E \simeq nkT$, with $\text{n} \simeq 10^{23}$ particles/cm^3, is $T \simeq 10^6$ K. A threefold implosion of the deuterium increases its temperature by the factor of 100, from $T \simeq 10^6$ to $T > 10^8$ K, meaning it would reach the ignition temperature of the deuterium reaction.

Conclusion

If feasible, the novel thermonuclear fusion concept would have worldwide far-reaching consequences. It could bring an end to the combustion of fossil fuels and minimize the effects of global warming, leaving the fossil fuels for other much more important application in chemistry and medicine.

Unfortunately, the prospect of the much cheaper fission-less ignition of large thermonuclear explosive devises also poses a serious challenge for a world without nuclear weapons.

References

Hund F (1948) Zugänge zum Verständnis der allgemienen Relativitätstheorie. *Zeitschrift für Physik* **124**, 742.

Kidder RE (1998) Laser fusion: the first ten years (1962–1972). In Philips CR (ed.) *High-Power Laser Ablation, SPIE Proceedings*, vol. **3343**, Bellingham, WA: SPIE, pp. 10–33.

Landau LD and Lifshitz EM (1971) *The Classical Theory of Fields*. New York: Pergamon Press, p. 306.

Spitzer L (1962) *Physics of Fully Ionized Gases*. Princeton, NJ: Interscience Publishers, John Wiley & Sons, p. 145.

Winterberg F (1968) The possibility of producing dense thermonuclear plasma by an intense field emission discharge. *Physical Review* **174**, 212.

Winterberg F (2010) The release of thermonuclear energy by inertial confinement. *Ways Towards Ignition*. Nevada: World Scientific, p. 83.

https://doi.org/10.1017/S0263034618000204 Published online by Cambridge University Press