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Specially conditioned em fields to reduce nuclear fusion input energy needs

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Abstract

Particles of like-charge repel when embedded in ordinary electromagnetic (EM) fields - causing coulomb repulsion between fusion fuel ions that are being compressed by electic or magnetic forces in fusion reactors. By contrast, such fusion fuel ions experience attraction if they become embedded in the SU(2) force fields of weak interactions in atomic nuclei. This drives such ions closer and closer until their fusion finally begins. In this respect, Barrett has conditioned ordinary U(1) EM fields into EM fields with the same SU(2) gauge symmetry as SU(2) matter fields in nuclei. This has led us to explore the possibility of SU(2) EM fields causing fusion fuel ions to attract (rather than repel) each other in fusion reactors – thereby reducing the enormous compression energies EM fields must exert for fuel ion fusion to occurr. This preliminary investigation considered conditioning of U(1) EM field energy into SU(2) EM field energy by phase and polarization modulation of U(1) wave energy inside inertial electrostatic confinement (IEC) fusion reactors. Parametric fusion performance estimates indicated 10-20 fold reduction in input energy if SU(2) EM fields could lessen ion repulsions over distances 2-3 orders of magnitude greater than the 10^{-18} distances where ion fusions by SU(2) weak interaction fields occur. We concluded that evidence of changed ion-ion repulsion by SU(2) EM fields could be best obtained by: (a) modifying existing U(1) radiofrequency (RF) transmitters in helicon ion beam generators to emit SU(2) RF waves; and (b) detecting any change in ion repulsions by comparing ion beam voltages, currents and densities in the ion beam generator chamber for U(1) RF and SU(2) RF radiation.

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1. Specially conditioned electromagnetism

Ordinary electromagnetic (EM) fields possesses U(1) Lie group symmetry and charged particles like fusion fuel ions who are embedded within them to repel. By contrast, the matter fields associated with the weak nuclear forces in the nuclei of fusion fuel ions possess higher SU(2) symmetry; and fusion fuel ions confined in these fields attract – drawing closer and closer together until their fusions occur). In this respect, EM fields that embody SU(2) symmetry have been derived by one of us (Barrett). This has led us to consider the possibility of SU(2) EM fields in reactors causiing fusion fuel ions to attract – somewhat like SU(2) matter fields in nuclei do.. If so, fuel-compressing, ion-attracting SU(2) EM fields inside fusion reactors would face less resistance and, thus, expend less field energy in accomplishing fusion.

EM fields, such as those currently used to compress fusion fuel ions in reactors, are described by the classical Maxwell equations which is a theory of U(1) symmetry form. However, in special situations, specially conditioned EM fields can be produced that require an extension of Maxwell theory to higher symmetry. For such situations, Barrett [1] has used topology, group and gauge theory to derive specially conditioned SU(2) EM fields. Even more complex EM fields than SU(2) are describable by more complex symmetry groups like SU(3). However, only SU(2) EM fields have been described in any detail.

1.1 Maxwell equations for conventional and specially conditioned EM fields

Using group theoretic methods, EM radiation fields of SU(2) symmetry can be created by special conditioning of the conventional U(1) EM fields are described by Maxwell's equations in Table 1. These equations describe electric field strength (***E***), magnetic flux density (***B***) and current density (***J***). The ***E*** and ***B*** fields of force can be related to a vector potential" (***A***) and a "scalar electric potential" (φ) that, themselves, are not physical. However, they are of mathematical convenience in U(1) EM field theory.

Table 1. The four Maxwell vector field equations for conventional U(1) symmetry electromagnetic radiation fields

Gauss' Law	$\nabla \bullet \boldsymbol{E} = \boldsymbol{J}_0$
Ampere's Law	$\frac{\partial \boldsymbol{E}}{\partial t} - \nabla \times \boldsymbol{B} - \boldsymbol{J} = 0$
Coulomb's Law	$\nabla \bullet \boldsymbol{B} = 0$
Faraday's Law	$\nabla \times \boldsymbol{E} + \frac{\partial \boldsymbol{B}}{\partial t} = 0$

$$E = -\frac{\partial A}{\partial t} - \nabla\phi, \quad B = \nabla \times A$$

In the SU(2) field theory, Barrett [1] shows that the potentials ***A*** and φ have actual physicality. Table 2 shows extended Maxwell equations that describe propagation of specially conditioned SU(2) EM fields. These Maxwell equations are described by tensor, rather than vector quantities. SU(2) Maxwell equations include ***E*** and ***B*** fields just as U(1) Maxwell equations do. But they also include added tensor field terms that include imaginary number i (viewed as either square root of -1 or as an orthogonal rotation occurring in x, y, z, ct spacetime) and electron charge (q). These added tensor field terms describe added ***A x E*** and

A x B and ***A • E*** and ***A • B*** interactions (Barrett [1] on p 145-147). All tensors (matrices) function as operators that obey non-commutative, non-Abelian algebra. So, unlike vector multiplication, the product (***A • B***) doesn't equal (***B • A***) and (***A x B***) doesn't equal (***B x A***) in the matrix algebra of SU(2) fields.

Table 2. The four Maxwell tensor EM field equations for conditioned SU(2) symmetry electrinomagnetic radiation

$\nabla \bullet \boldsymbol{E} = \boldsymbol{J}_0 - iq(\boldsymbol{A} \bullet \boldsymbol{E} - \boldsymbol{E} \bullet \boldsymbol{A})$
$\frac{\partial \boldsymbol{E}}{\partial t} - \nabla \times \boldsymbol{B} - \boldsymbol{J} + iq[\boldsymbol{A}_0, \boldsymbol{E}] - iq(\boldsymbol{A} \times \boldsymbol{B} - \boldsymbol{B} \times \boldsymbol{A}) = 0$
$\nabla \bullet \boldsymbol{B} + iq(\boldsymbol{A} \bullet \boldsymbol{B} - \boldsymbol{B} \bullet \boldsymbol{A}) = 0$
$\nabla \times \boldsymbol{E} + \frac{\partial \boldsymbol{B}}{\partial t} + iq[\boldsymbol{A}_0, \boldsymbol{B}] = iq(\boldsymbol{A} \times \boldsymbol{E} - \boldsymbol{E} \times \boldsymbol{A}) = 0$

The Lorentz force (***F***) plays important roles in the plasma dynamics of many nuclear fusion processes. It arises from an electromagnetic interaction that involves ***E*** and ***B*** fields and the velocity (***v***) of moving particles with a charge (e). Table 3 shows Lorentz force equations for U(1) EM vector fields in terms of magnetic vector potentials and electric scalar potentials. It also shows Lorentz force equations for SU(2) tensor fields, in terms of these vector and scalar potentials. SU(2) Lorentz forces contain extra terms that include these potentials. So, they can be of different magnitude and direction than U(1) Lorentz forces.

Table 3. Comparison of Lorentz force equations for U(1) symmetry and SU(2) symmetry EM fields from Barrett [1].

U(1) Lorentz Force	$\mathscr{F} = e\mathrm{E} + ev \times \mathrm{B} = e\left(-\frac{\partial \mathrm{A}}{\partial t} - \nabla\phi\right) + ev \times \left((\nabla \times \mathrm{A})\right)$
SU(2) Lorentz Force	$\mathscr{F} = e\mathrm{E} + ev \times \mathrm{B} = e\left(-(\nabla \times \mathrm{A}) - \frac{\partial \mathrm{A}}{\partial t} - \nabla\phi\right) + ev \times \left((\nabla \times \mathrm{A}) - \frac{\partial \mathrm{A}}{\partial t} - \nabla\phi\right)$

1.2 Example of the special conditioning of an ordinary U(1) EM field into an SU(2)symmetry EM field

An example of ordinary U(1) EM field energy being transformed into specially conditioned SU(2) EM field energy is described on pages 46 and 61 of Barrett [2]. This example uses a wave guide system paradigm to portray oscillating U(1) EM wave energy being transformed into SU(2) EM wave energy by phase and polarization modulation. Figure 1 shows a completely adiabatic system where oscillating wave energy: enters from the left; divides into 3 parts; is modulated and re-combined; and exits from the right. One part of the input wave energy is unchanged, another part of the input wave energy provides phase modulation ($\partial\varphi/\partial t$) and then combines with an orthogonally polarized part that has passed through a "polarization rotator". Two orthogonally polarized oscillating wave forms (with one being the unchanged fraction of oscillation wave energy) result. The two wave forms are then superimposed at an output where they are combined into a single EM beam of emitted SU(2) radiation. Owing to phase modulation of one waveform with respect to the other, and their initial orthogonal polarization, the output SU(2) radiation is of continuously varying polarization during one cycle of wave oscillation. This is symbolized by the diagram in the lower right hand portion of Figure 1. This diagram represents time-varying E and B-field polarizations that traverse continuously through: horizontal-linear; right-vertical-elliptical; right-circular; right-horizontal-elliptical; horizontal-linear; left-horizontal-elliptical; left-circular; left-vertical-elliptical polarization during a polarization modulation period Δt. And, here: $\partial\varphi/\partial t$ = constant and $0 < \varphi < 360^o$.

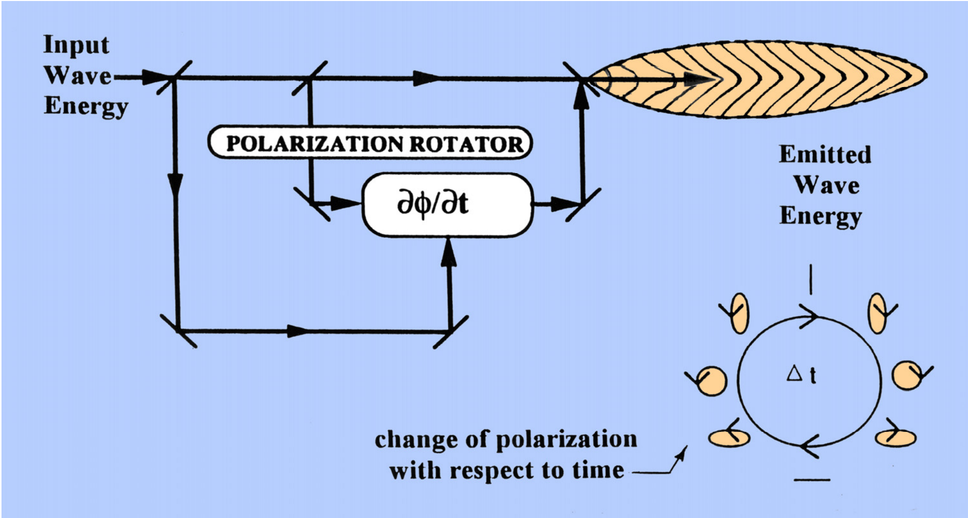

Figure 2, from Barrett [1] shows the magnitude and direction of the electric field *E* within a beam of SU(2) EM radiation during a cycle of its phase and polarization modulation. It is seen that magnitude and direction of the electric field can vary rapidly during one cycle of phase and polarization modulation and that many E field rotations can occur during a very short time and over a very short length of beam travel.

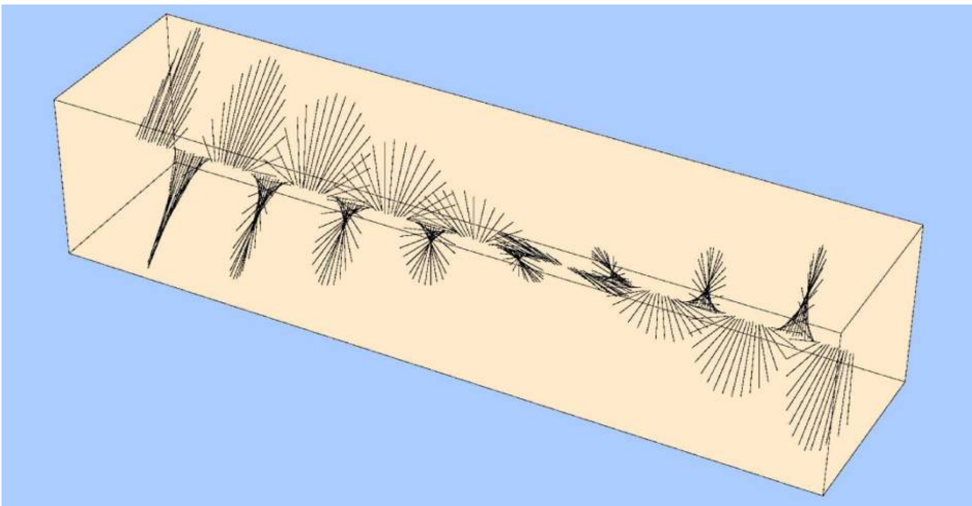

Figure 2. Rapid change in electric field vector direction and magnitude over a very short time and very short distance

Rapid electric and magnetic field rotations in SU(2) EM beams, combined with rapid change in field intensity result in different angular dynamics than that of U(1) EM beams with fixed linear or circular or elliptical polarization. And the added angular dynamics inside an SU(2) EM beam [compared to that in a U(1) beam] might be reflected in different forces acting on fusion fuel ions inside SU(2) EM beams.

2.0 Polarization-modulated SU(2) EM fields for Inertial Electrostatic Confinement fusion systems

We explored the possibility of SU(2) EM fields lowering electrical input energy needs for fusion in certain "Inertial Electrostatic Confinement" (IEC) nuclear fusion systems. One IEC nuclear fusion system uses a central, negatively charged electrode (a grid) that draws many converging streams of positively charged ions from plasma injectors (RF ion guns) located around the reaction chamber periphery. Figure 3 shows such an IEC system at the University of Illinois accomplishing hundreds of fusions per second.

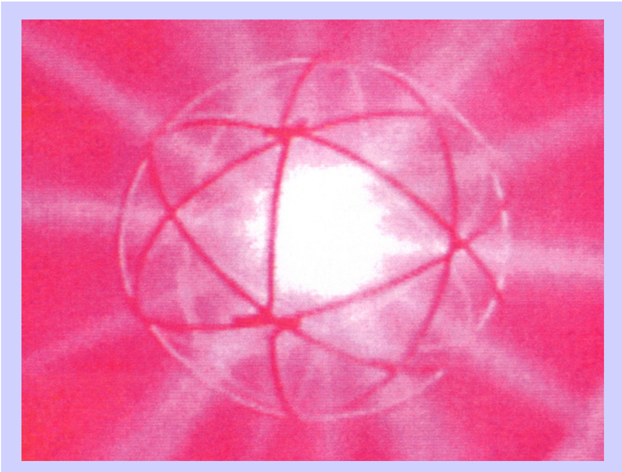

Figure 3. Operating IEC Fusion Reactor accomplishing hundreds of D-D fusions per second at University of Illinois

Each radial ion stream in Figure 3 is emitted from a plasma generator that contains: nuclear fusion fuels; needed electrical power; and radio-frequency (RF) antenna discharges to transform fusion fuels into plasma and transform plasma into a focused ion beam. Figure 4 shows an IEC system installation at the University of Illinois with one of many plasma generators (one of many RF ion guns) that are needed.

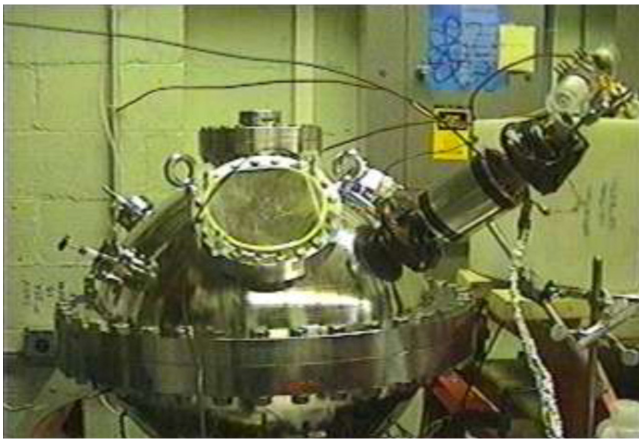

Figure 4. IEC fusion reactor chamber with helicon plasma injector (RF ion gun) operated at the University of Illinois

Each circumferentially-distributed injector contains a radio frequency (RF) antenna system that deposits pulsed energy into nuclear fuel material in the injector, transforming the material into flowing plasma. A magnetic field is also induced by current flow in windings. Such a plasma injector, developed by Miley at the University of Illinois [3], is shown in Figure 5. High power (13.5 MHz) discharges result from RF wave propagation through a coaxial copper helical resonator which is a single-layer coil in a copper shield**.** The RF system's helical coil antenna is magnet wire wound directly to a glass tube.

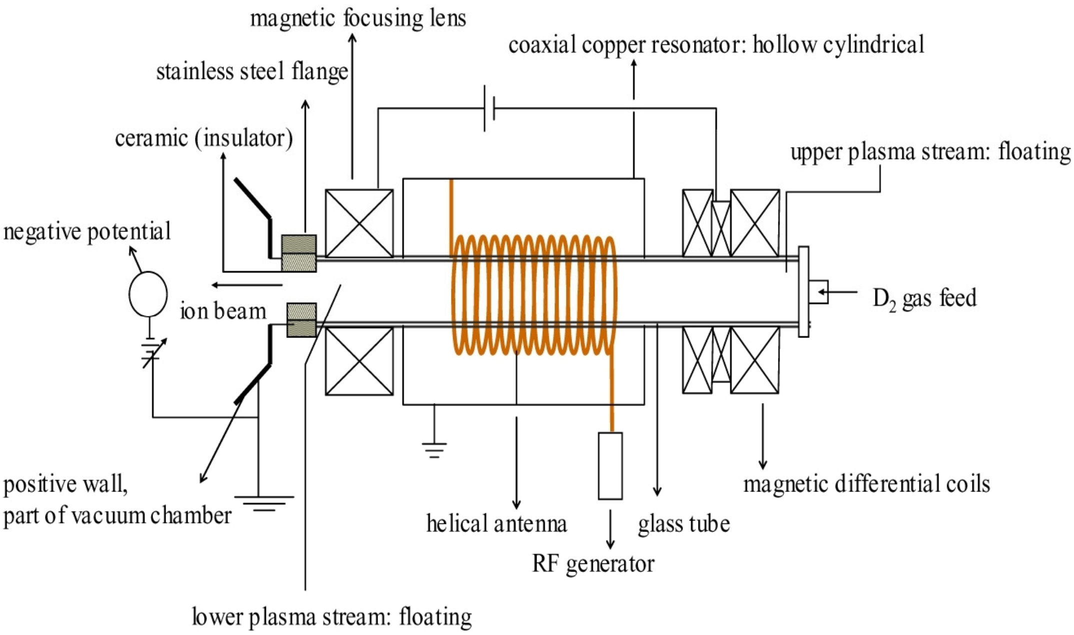

Figure 5. Typical schematic of one of the plasma injectors that are circumferentially-located in a IEC reactor

Barrett's transforming of ordinary U(1) EM waves into SU(2) EM waves is extended to EM plasma waves emitted from plasma injectors. Windings and antenna elements of each injector would be modified to modulate both phase and polarization of the created SU(2) EM beam and favorably effect electrons and ions inside it. If SU(2) field content causes some ion attractions, coulomb resistance to applied EM input power will lessen, So, less input energy need be expended by ion-attracting SU(2) EM fields in bringing ions close enough for SU(2) weak force matter fields in the ion nuclei, themselves, to cause their fusion.

We are now exploring possibilities for adding another set of helicon windings to the existing set. Such a circuit would "wiggle" RF discharges somewhat like an undulator (wiggler) in a free electron laser (FEL) accelerates and decelerates electrons. Electron accelerations and decelerations in a FEL can give off enormously complex and varied bursts of EM radiation as FEL undulator is 'played' like a very highly tuned musical instrument. Therefore, a critical issue is helicon windings (or selective driving of helicon windings) to provide control precision that may have to approach that of very large and complex FELs.

One current unknown is interaction of SU(2) EM beams from modified plasma generators with the U(1) electric field of the negatively-charged grid. The grid's negatively-charged U(1) direct current (DC) electric field is not expected to interact with SU(2) RF radiation. Thus the grid should properly repel ions inside the SU(2) beam, while not interfering with the SU(2) field. One possibility might be to eventually remove the grid entirely and let the mutual attraction of the merging nuclear fuel ions from the many converging SU(2) ion beams coalesce themselves naturally into a central region of increasing ion compactification. Hopefully, this would create a deep potential well of attracting fuel ions - a potential well that would, finally, enable fusion of fuel ions by the SU(2) matter fields in the fuel ions, themselves.

3. Recommended early experiments involving SU(2) EM Field generatio n in a helicon plasma gun

Theoretical explorations of possibilities for ion-attracting SU(2) EM plasmas will require much work. And early experiments, to augment and guide early analysis, are needed. Early experiments would involve modification of a helicon plasma generator for SU(2) ion beam emission. This need not involve expensive nuclear fuel plasmas. Instead, more ordinary, inexpensive plasmas from RF discharges in gases like Argon or Xenon are created in helicon plasma generators. Figure 6 shows a well instrumented helicon plasma generator chamber located at the Australian National University in Canberra Australia.

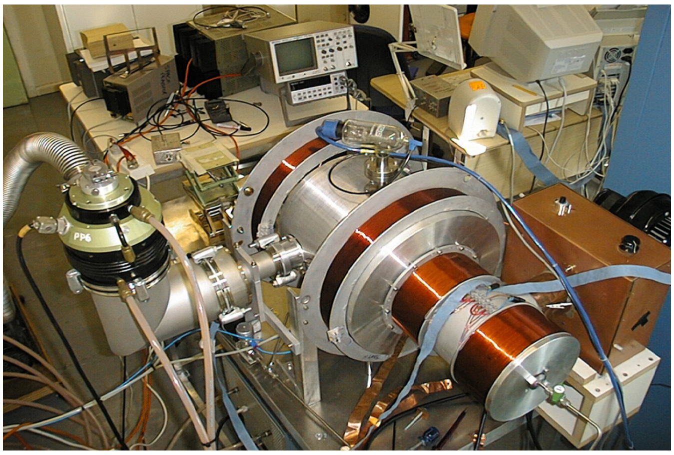

Figure 6. Helicon plasma generator in the Plasma Dynamics Laboratory of the Australian National University

Figure 7, shows some of the plasma properties measured in Australian National University's helicon plasma chamber shown in Figure 6. Typical measurements, described in [4] include plasma voltage and current mapping throughout the plasma generator chamber, where ion speed, voltage and energy variation can be achieved with high spatial and temporal resolution in the chamber. And such measurements and resolutions would be needed to detect ion-ion attractions and ion-electron repulsions in SU(2) RF beams.

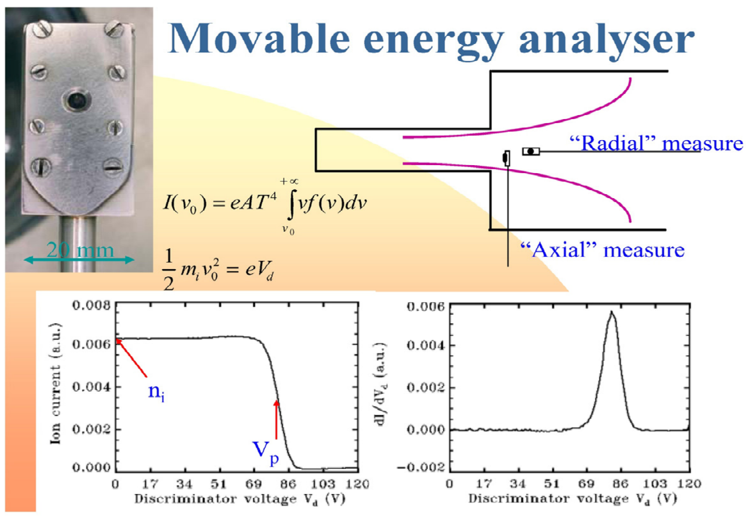

Figure 7. Energy analyzer that maps plasma properties and flows throughout the plasma generator chamber

4. Preliminary analyses of potential reductions in fusion input energy needs with SU(2) EM fields

Figure 8, from Duncan [5], shows the effect of input electrical power (in thousands of electron volts) - on the cross-sectional areas of regions where ion fusions can occur. These areas are usually described in units called "barns", where a barn is 1.5 x 10^{-28} m^2, the approximate area of a uranium nucleus. It follows that fusion cross-section sizes are associated with numbers of ion fusions and amounts of fusion power.

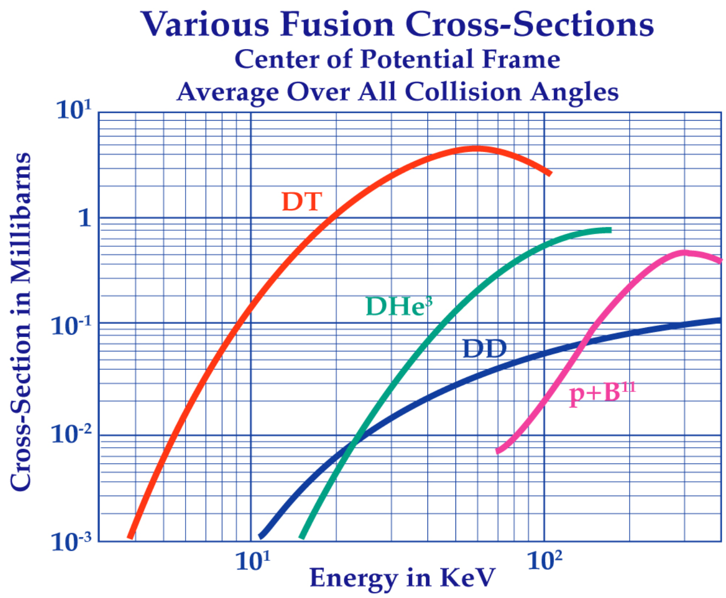

Figure 8. Cross-sections of reaction regions where nuclear fusions occur - as a function of input electrical field energy

Since we cannot yet claim that SU(2) EM fields can induce attractions between ions, it is certainly not possible to predict any input energy reductions these fields can provide. Possible input energy reductions, if any, would have to be ascertained by experiments with existing IEC reactors and ion guns. However, preliminary parametric explorations are possible with fusion cross-section and input energy information from sources like Figure 8 and by assuming certain SU(2) ion-attracting and electron-repelling scenarios.

SU(2) EM field creation and its accomplishment of ion-attracting states can be viewed as the product ($\alpha\beta$) of two efficiencies – with α: the efficiency in creating SU(2) EM field energy by phase and polarization modulation of input U(1) EM field energy in IEC ion guns; and β: the efficiency of created SU(2) EM field energy in mulling fuel ion repulsions in IEC fusion reactors. It follows that: (1-α) is the fraction of input energy dissipated during the phase and polarization modulation processes that create SU(2) field energy; while (1- β) is wasted field action from EM couplings that hamper achievement of ion attractions in SU(2) EM beams. Such couplings can begin as soon as RF discharges create electron-ion clouds and screening from intervening electrons hamper initial attractions of ions inside these clouds.

Increased input field energy force ions into closer proximity to increase probability and numbers of their fusions. And increased cross-sectional areas reflect increased numbers of ion fusions. For example, Figure 8 shows a modest 4 KeV of EM input energy enabling only a modest amount of DT fusion inside a small (10^{-3} millibarn) cross section. But, a 24-fold increase in input energy to 200 KeV results in 10^3-fold increase in fusion cross-section to 1 millibarn and a 10^3-fold increase in fusion output energy. Thus, if ion-attracting SU(2) EM fields could null all fuel ion repulsions within a 1.0 millibarn cross-sectional area area by the time 4 KeV of EM field energy is spent, no more energy expenditure would be needed, For all ions in this region would now be attracting and moving ever closer until their fusion by the SU(2) fields of the weak nuclear force occurs at distances of about a 10^{-3} millibarn area. Hence, 4 KeV of input

SU(2) EM field energy – if generated with negligible losses by polarization modulation of U(1) EM field energy - would achieve the same output fusion power as 200 KeV of ordinary U(1) EM energy provides.

Figure 9 illustrates this. It indicates that if SU(2) EM fields could cause ion attractions over distances 10^3 to 10^4 times longer than the 10^{15} cm range of the ion-attracting, fusion-causing weak nuclear force, input energies could be reduced by factors of 10 to 20 for achieving a given DT fusion power. In this scenario, ion-attracting SU(2) fields cause fuel ions to be drawn closed and closer by mutual attraction until their fusions are accomplished by the SU(2) matter fields associated with the weak nuclear forces in the ions themselves. Significant reductions in input energy are seen to be achievable, even for fairly poor field efficiencies ($\alpha\beta$ of 1.0 % to 10 %.), if ion-attractions in SU(2) EM fields can occur over distances that are 10^2-10^4 times the 10^{-15} cm distance where fuel ion fusion can occur. It must also be mentioned that Figure 9 assumes all fuel ions transition from repelling to attracting at the same time. But, of course, ions actually reach attracting state at different times, so ion resistance to compression is reducing long before all ions become attracting. Figure 9 calculated input energy is, thus, more than is actually needed.

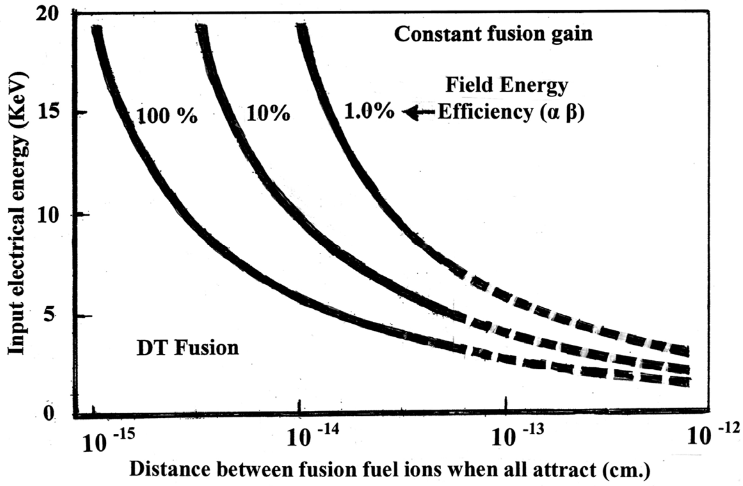

Figure 9. Influence of fusion fuel ion separation distance when all become attracting - on input energy needed o achieve a given fusion power. Dashes denote extrapolation of Figure 8 reaction cross-section information.

A very *clean* nuclear fusion reaction is fusion of Hydrogen and Boron 11 nuclei. Figure 10, from [5], shows this reaction culminating in: the energy of 3 charged helium ions (which can be converted directly to electricity); no harmful, radioactivity-causing neutron emissions; and, hence, little radiation shielding.

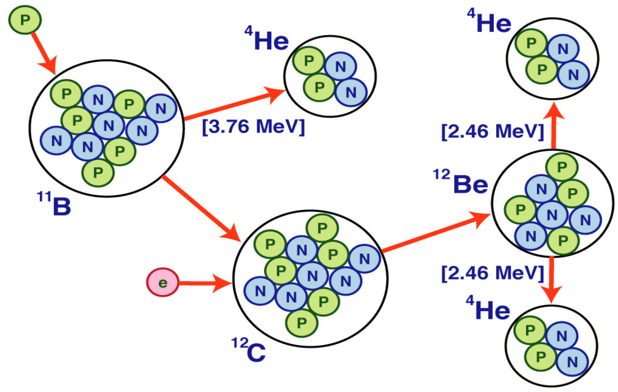

Figure 10. Aneutronic pB11fusion resulting in 8.68 MeV of energy and the electricity of 3 Helum 4 Ions

Effective, ion-attracting SU(2) EM field interactions would generate fusion power with less electrical input energy for any of the fusion reaction in Figure 8. However, "clean" p-B11 reactions, which result in very low radioactivity because very few neutrons are emitted, might benefit most from SU(2) EM fields.

Figure 8 shows p-B11 fusion reactions requiring about 15-times more input energy than less-clean DT fusion reactions to achieve a given fusion power. This results in higher ignition temperatures which can cause phenomenon such as bremsstrahlung radiation losses that certain fusion systems find very difficult to prevent or to cope with. Figure 11 compares reduced input energy needs for DT and p-B11 fusion for a given fusion output power and for a fairly modest SU(2) EM field efficiency ($\alpha\beta$) of only 10 percent.

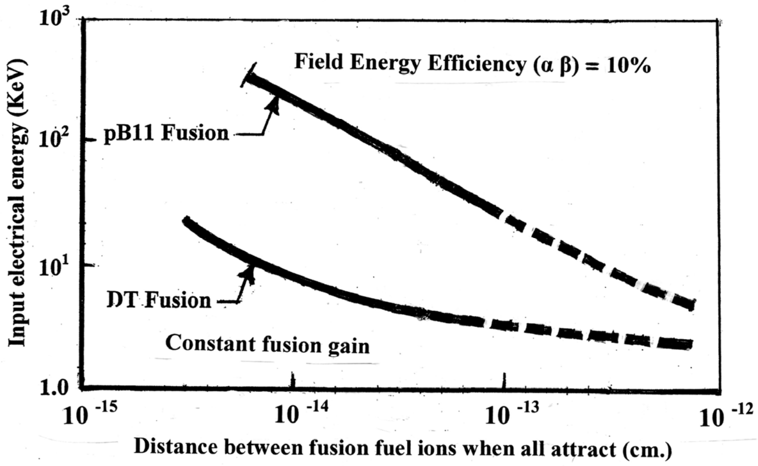

Figure 11. Obtaining longer ion-attracting range in SU(2) EM fields reduces DT and p-B11 fusion input energy needs

Aneutronic p-B11 fusion is seen to requires more input energy than D-T fusion for a given reaction distance. But, ion-attracting SU(2) EM fields are seen to enable larger input energy reductions for p-B11 fusion than for D-T fusion. If so, these reductions should avoid things such as bremsstrahlung radiation.

Conclusions

Barrett has shown the possibility of EM radiation fields with the same SU2 gauge symmetry as the ion-attracting matter fields associated with ion-attracting, weak nuclear forces in nuclei that cause fusion. If so, ion-attracting SU(2) EM radiation fields in fusion reactors could conceivably attract (rather than repel) fusion fuel ions to reduce the coulomb resistance and electrical compression energy needed for fusion of these ions. So, the authors have begun exploring this seemingly bizarre possibility theoretically. However, an experiment to modify a helicon plasma generator to create SU(2) EM discharges and ion beams, and to search for ion-ion attractions and ion-electron repulsions inside the generator is also a needed first step.

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