Energetic Electrons and Nuclear Transmutations in Exploding Wires

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Nuclear transmutations and fast neutrons have been observed to emerge from large electrical current pulses passing through wire filaments which are induced to explode. The nuclear reactions may be explained as inverse beta transitions of energetic electrons absorbed either directly by single protons in Hydrogen or by protons embedded in other more massive nuclei. The critical energy transformations to the electrons from the electromagnetic field and from the electrons to the nuclei are best understood in terms of coherent collective motions of the many flowing electrons within a wire filament. Energy transformation mechanisms have thus been found which settle a theoretical paradox in low energy nuclear reactions which has remained unresolved for over eight decades. It is presently clear that nuclear transmutations can occur under a much wider range of physical conditions than was heretofore thought possible.

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Over eighty years ago, Wendt and Irion[1] reported nuclear reactions in exploding wires. The transmuted nuclear products emerged after a large current pulse was passed through a Tungsten wire filament which exploded. Sir Ernest Rutherford[2] expressed doubts as to whether the electrons flowing through the wire could carry enough energy to induce nuclear reactions. The exploding wire current pulse had been produced by a capacitor discharge with an initial voltage of only thirty kilovolts. On the other hand, Rutherford had employed a high energy but dilute beam of 100 KeV electrons fired into a Tungsten target. Rutherford did not observe any nuclear reactions. Wendt[3] replied to the Rutherford objections, asserting that the peak power in the exploding wire current pulse was much larger than the relatively small power input to Rutherford's electron beam. Most importantly, a large energy transfer from the many electrons in the wire to the nuclei could occur collectively which would allow for the nuclear transmutation energy.

This very old but important debate between Wendt and Rutherford has presently been experimentally settled in favour of Wendt. The more recent[4, 5, 6, 7, 8, 9] exploding wire experiments have, beyond any doubt, detected fast emerging neutrons capable of inducing nuclear transmutations. These observed fast neutrons have often been attributed to the products of deuteron fusion but we find that hypothesis unlikely to be true. Firstly, fast neutrons have been seen in exploding wires even though there were no deuterons initially present [4, 5]. Secondly, the gamma emission signature of deuterium fusion has not been observed. It is much more likely that the fast neutrons are products of inverse beta transitions of very energetic electrons being absorbed by protons and producing fast neutrons and neutrinos. The protons may be Hydrogen atomic nuclei or the protons may be embedded within more massive nuclei. The theoretical side of the difference of opinion between Wendt and Rutherford concerning how large amounts of energy can be transferred to and from the electrons in the wire has remained unresolved. The purpose of this work is to explain how this collective energy transfer may occur.

The reader has perhaps unwittingly observed exploding Tungsten wire filaments in household light bulbs. Normally, the hot wire glows in the yellow optical frequency, slowly evaporating metal atoms from the filament. Over time, the wire filament thins in some pinch regions, strongly increasing the Maxwell magnetic pressure. Then with a "pop", the filament explodes, shifting the final bright radiation pulse frequency upward into the blue. The filament is broken at the pinch points. The reader may have shaken the bulb and heard the broken metallic pieces of filament rattle from within the bulb or noted the explosion dust on the inside surface of the bulb before replacing the old light bulb with a new one. Now let us consider this process only at much higher currents, temperatures, pressures and energies[10].

The scale of wire currents required to induce nuclear reactions may be found by expressing the rest energy of the electron mc^2in units of a current I_0; i.e. by employing the vacuum impedance R_{vac} one finds

$$\frac{mc^2}{|e|} = \frac{R_{vac} I_0}{4\pi} \quad \Rightarrow \quad I_0 \approx 1.704509 \times 10^4 \ \text{Ampere.} \quad (1)$$

If a strong current pulse, large on the scale of I_0, passes through a thin wire filament, then the magnetic field exerts a very large Maxwell pressure on surface area elements, compressing, twisting and pushing into the wire. If the magnetic Maxwell pressure grows beyond the tensile strength of the wire material at the hot filament temperature, then the wire begins to melt and disintegrate. If the heating rate is sufficiently fast, then the hot wire may emit thermal radiation at a very high noise temperature. The thermal radiation for exploding Tungsten filaments exhibits X-ray frequencies indicating very high electron kinetic energies within the filament. Due to the electron kinetic pressure, the wire diameter starts to increase yielding a filament dense gas phase but still with some liquid droplets. The final explosive product consists of a hot plasma colloid containing some small dust particles of the original wire material. These products cool off into a gas and some smoke as is usual for explosions.

In order to understand how the electrons are accelerated into high energy regimes, recall that a very rapidly changing current induces a Faraday law voltage across an inductive circuit element. The Faraday law voltage per unit length E is determined by the self inductance per unit length $\eta\mu_0/4\pi$,

$$E = \eta\left(\frac{\mu_0}{4\pi}\right)\frac{dI}{dt} = \frac{\eta}{c}\left(\frac{R_{vac}}{4\pi}\right)\frac{dI}{dt}\ . \qquad (2)$$

The dimensionless geometrical factor η for the inductance per unit length varies very slowly with the wire cross sectional area A_0 and the area A along the circuit element collecting the magnetic flux, i.e. $\eta = \ln(A/A_0) > 1$. The electric field E will change the momentum p and thereby the energy W of a negatively charged electron $e = -|e|$. The equation of motion is $\dot{p} = eE$. In virtue of Eqs.(1) and (2), one finds the central result of our work, i.e. the power $e\mathbf{v}\cdot\mathbf{E}$ delivered to a moving electron by a changing current obeys

$$\frac{dW}{dt} = evE = -\eta mc^2\left(\frac{1}{I_0}\frac{dI}{dt}\right)\frac{v}{c}\ . \qquad (3)$$

A change in the collective current dI yields a changing single electron momentum and thereby a change in the single electron energy dW wherein v is the velocity of that electron. The single electron energy can thereby reach values far above the electron rest energy for a pulse peak current large on the scale of I_0.

The following comments are worthy of note: (i) The electromagnetic field configuration when the current pulse passes through the wire is a magnetic field tangent to the wire surface and normal to the wire axis and an electric field parallel to the cylinder. This is the low circuit frequency limit of the surface plasma polariton mode previously employed in the explanation[11] of inverse beta transitions in chemical cells. However, the natural surface patches whereon the long wavelength neutrons would form are in the case of thin wire filaments destroyed by the explosion. (ii) Radiation losses have not been included in the above discussion. These losses are not large because of the collective nature of the current. A single charged accelerating particle emits copious radiation whereas many electrons contributing to a smooth current in a wire will hardly radiate at all. However, some resistive wire heating energy will be removed from the wire filament as hot emitted thermal radiation. (iii) The Maxwell electromagnetic energy and pressure are largely due to the Ampere's law mutual attraction between electrons moving in the same direction. When an electron is combined with a proton to produce a neutron and a neutrino, the required energy is in part the attractive energy due to all of the other parallel moving electrons in the wire albeit only one electron is actually destroyed. For an electron moving at a velocity v uniform in time, the magnetic energy interaction of that single electron with the current I due to all of the other electrons follows from Eq.(3),

$$W_{magnetic} = -\eta mc^2\left(\frac{I}{I_0}\right)\frac{v}{c}\ . \qquad (4)$$

The velocity of the electron is opposite to the direction of the current since electrons are negatively charged.

Let us now return to the energy considerations concerning the Wendt-Irion[1] experiment. Typically, a capacitor discharge sent $N \sim 2\times 10^{16}$ electrons from one capacitor plate to the other capacitor plate. The initial energy in the capacitor was $W_{Coulomb} \sim 15$ KeV per stored electron. The total energy balance then dictates that at most $N^* \sim 10^{13}$ of these electrons could make inverse beta transitions causing nuclear transmutations. Many electrons acting cooperatively contribute energy $W_{magnetic}$ to inverse beta transitions even though only one of those electrons is destroyed. The Wendt-Irion peak current ratio I/I_0 was as high as two hundred[3] yielding $W_{magnetic} \sim 200$ MeV $\times\, v/c$. If the electron velocity in the filament is small, say $v/c \sim 0.1$, then $W_{magnetic}$ is more than sufficient for an inverse beta transition. From the time duration of the pulse, one finds a mean drift velocity $\bar{v}/c \sim 10^{-4}$ of the electrons from one capacitor plate to the other capacitor plate through the transformer coil and the filament much smaller than the required electron velocity in the filament. To confirm the inequality $\bar{v} \ll v$, consider an incompressible fluid moving between a thick pipe and a thin pipe. The fluid velocity is much larger in the thin pipe than the fluid velocity is in the thick pipe. A similar effect takes place for electrons flowing between thick circuit wires and thin wire filaments. Our energy considerations are now completed.

Finally, for an electron beam in the vacuum there is a mutual electric Coulomb repulsion energy which overcomes a mutual magnetic Ampere attraction energy. The repulsion hinders the above cooperative many electron energy transfer for an inverse beta transition employing a vacuum beam as did Rutherford. It is only the Wendt wire filament, wherein the Coulomb repulsion between electrons is screened by positive ions, that enables nuclear transmutations.

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