Research on Nuclear Reactions in Exploding (Li + LiD) Wires

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Z. Naturforsch. **42 a**, 538–542 (1987); received February 25, 1987

It is shown that under certain conditions the nuclear reaction ^{7}Li(d, n) 2 α occurs within the plasma of "exploding" (Li + LiD)-wires. The reaction is not thermo-nuclear but of a hybrid character, i. e. the plasma is not heated to a sufficient temperature but electric fields complete the reaction. By an electrical discharge a (Li + LiD)-wire is heated to temperatures below 200 eV. After the heating the plasma expands turbulently. During this time, electrical fields postaccelerate the Li and D nuclei leading to the formation of the unstable ^{8}Be followed by α-decay. These reactions occur frequently and are observed during a time much longer than one cycle. The energy of the α-particles does not remain in the plasma and can be used for external purposes. It is discussed why the exploding wire method has not led to results of practical interest in the past.

Nuclear fusion is obtained in plasmas consisting of deuterium and tritium.

Unfortunately the temperature necessary for thermo-nuclear fusion is above 10^8 K. Up to the present, technical difficulties have not allowed to obtain a positive energy balance.

As an alternative to the thermo-nuclear discharges, the method of "exploding wires" was investigated during the sixties. The purpose of many of these experiments [1] was to reach thermonuclear D–D reactions. In these experiments a positive energy balance was not reached because the cross section for thermo-nuclear D–D fusion is much below the cross section for thermo-nuclear D–T fusion [2]. At 10^8 K the difference is two orders of magnitude and for 10^9 K still more than a factor 10.

The leading idea for the exploding wire experiments was taken from Anderson [3]. He suggested that large quantities of energy fed within a short time into a small quantity of matter should heat the matter up to very high temperatures. Consequently large capacitors charged to many kV were discharged through thin wires. But the high temperatures expected were not obtained. Instabilities developing during the discharge prevent high temperatures. Therefore the idea of reaching high temperatures before the development of instabilities was put forward using fast discharges and a confinement of matter by inertia or by magnetic forces. Extremely fast capacitor discharges reaching current rise times of 10^5 Amp/μs or more were used to explode thin wires loaded with deuterium. All these experiments aimed at D–D reactions. As far as we know, the highest number of neutrons was obtained by Stephanakis et al. [4] by exploding deuterated nylon wires in vacuo with a capacitor loaded up to 10^6 Volt. They obtained 10^{10} neutrons. Only half of the D–D fusion reactions lead to ^{3}He and neutrons the other half to ^{3}T and protons. Both reactions lead to a small energy gain, 3.3 and 4 MeV, respectively. The desired gain of about 18 MeV is set free in a second collision of deuterium with either Helium-3 or tritium. It is obvious that two subsequent collisions occur rarely in exploding wire phenomena even in case 10^{10} neutrons are observed. After this was recognized, the method of exploding wires was abandoned. However, this method is still of interest if energy gain in a single collision is possible.

Here the famous experiment of Cockroft and Walton 1932 should be mentioned, at that time called "the first artificial nuclear disintegration". They bombarded ^{7}Li with a proton and obtained the unstable ^{8}Be which disintegrated into two α-particles. The energy gain in this decay (17.3 MeV is comparable to the energy obtained from a D–T fusion (17.6 MeV). The decay of ^{8}Be delivers the energy as α-particle kinetic energy.

Unfortunately, the α-particles having small collision cross sections are not suited to induce succeeding nuclear reactions. Nevertheless, they represent a considerable source of energy. It is the purpose of the present paper to show that the Cockroft and Walton process can be used in exploding wire experiments. The energy of the α-particles can be used for external purposes.

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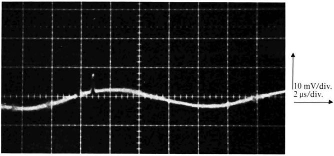

Fig. 1. Registration of the photomultiplier in case of a pure Li wire. The upward deflection is the timing pulse.

Following these lines, the author has examined the electrical "explosion" of wires made of a mixture of Li and LiD. The mixture is essential because LiD is an insulator. Much time was invested to reach a solution of Li in LiD or vice versa but no useful results were obtained. Therefore Li and LiD were stamped together in a mortar so that the resultant mixture was still a conductor. It was found that the LiD is used preferably not as a fine powder but as little crystals having a size of a few tenth of a millimeter. The procedure of stamping together was done in a pure Argon atmosphere. The mixture was pressed into a wire of about 1.3 mm diameter and about 60 mm length, fitted into a glas capillary and sealed at both ends with iron plugs which also served as electrodes. The capillaries were short-circuited in a rather slow capacitor discharge (100 kV, 20 kJ, 60 kHz). The particles emitted corresponded to the reaction ^{7}Li(d, n)2α + 15 MeV.

In this case the energy is distributed between three particles, the neutron (10 MeV) and two α-particles having 2.5 MeV each [2]. The fast neutrons were detected by a large scintillating plastic block (type Nuclear Enterprise NE 102A) attached to a photomultiplier [5]. The detection efficiency according to the space angle covered by the scintillator was 4%. The resolution time of the scintillating recoil counter together with the photomultiplier and the oscilloscope was 8 ns. A timing pulse was given in the upward direction, while every lightpulse was switched to give a signal in the downward direction. Apart from the timing pulse the zero line of the photomultiplier was smooth showing a small waveform only.

The waveform results from the magnetic field due to the capacitor discharge in spite of double screening of the cables leading from the detector to the oscilloscope cabin. This wave was used to ascertain the current maximum, minimum, and phase. For reasons of simplicity, the oscilloscope was triggered from the rising discharge current. As a result of this, events during the first microsecond could not be observed, i.e. the time which was expected to be most important in previous research was excluded. But now a large number of neutrons was observed at much later times, starting a few microseconds after the beginning of the discharge and lasting for several cycles of the discharge *.

During the time of the discharge the adiabatic expansion of the wire material has already begun and the temperature was certainly not sufficient for thermo-nuclear reactions. However, an inspection of Fig. 2 shows that beside the neutrons (which cause sharp, spike like pulses downward over several increments of the scale) rather broad signals are recorded (lasting for about 0.1 µs) almost sym-

* Perhaps it is necessary to state, that the same scintillating equipment is sensitive to cosmic radiation. However, to register the latter, a completely different oscilloscope setting has to be used. For checking purposes it is sometimes usefull to switch over to observation of the cosmic radiation. In these cases the zero line is completely straight. After switching back to the observation of neutrons, the zero line is again influenced from the discharge and gets a waveform.

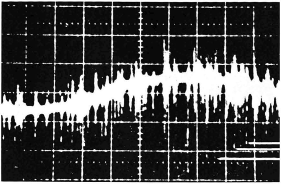

Fig. 2. Registration of the photomultiplier using a Li + LiD wire. The neutrons cause very small spike-like traces downward over at least two divisions of the scale. The symmetrical rather broad deflections come from perturbations of high frequency (MHz) caused from small sparks in the plasma. Neutrons and sparks appear simultaneously, but some sparks appear without neutrons. In this case, the latter have not passed the scintillator.

metrical to both sides of the zero line. Certainly these are not signals recorded from the photomultiplier because these are always asymmetrical, going downward only. Similarly it can be excluded that the backswing of the oscilloscope after a registration causes an upward signal, because the neutron pulses are needle sharp while the symmetrical registrations are very broad indeed. They indicate electrical disturbances of a very high frequency (in the MHz region) which are able to pass through the smallest fissures of the double screened oscilloscope leads. These disturbances originate from small sparks in the expanding yet current leading plasma. From inspection of Fig. 2 it becomes evident that these sparks and the neutrons are registered simultaneously. Sometimes the sparks are not accompanied by neutrons. In these cases, the neutrons may be emitted in a direction not registered by the scintillator. From this we have a first indication that we are not dealing with thermonuclear reactions but with a hybrid reaction, effected partly from a heated plasma and partly from electrical fields. Two more proofs will follow.

Surprisingly enough, the sparks appear even if the discharge current passes through zero. But the plasma is subject to a number of instabilities ($m = 0$ in the initial phase and $m = 1$ in the expanding phase). These cause high electrical fields by induction, the more so, as the material of the exploded wire was not homogeneous but consisted of conducting and insulating material. Also the current and voltage are not in phase.

A second argument for non thermal nuclear reactions is obtained from the discussion of the energy. The wire of 1.35 mm diameter and 60 mm length had a volume of $0.09\ \text{cm}^3$ and contained 4×10^{21} atoms of Li. Each Li atom requires 203.3 eV for total ionization. Thus all the atoms of the wire require together 8×10^{23} eV. This is more than the energy fed in, being $20\ \text{kJ} = 1.23 \times 10^{23}$ eV only. Therefore, no surplus energy is available to heat up the plasma after (incomplete!) ionization. In spite of this, numerous nuclear reactions have been observed from the neutrons emitted. This again indicates the existence of hybrid reactions i.e. an accelerating action of electrical fields on the newly produced ions. The acceleration work is done by the discharge. The number of ionization processes will be diminished accordingly.

A third argument is obtained, theoretically, from the size of the fusion cross section $\langle \sigma v \rangle$ listed in the ORNL tables for the thermonuclear reactions [2]. These include for the Li–D reaction a range of temperatures from 10 to 1000 keV only. Extrapolation down to below 200 eV indicates that practically no reactions occur. We have therefore to conclude that the neutrons observed are produced by reactions stemming partly from ionization by the current and partly from acceleration of the ions by electrical fields. These accelerations occur during the explosion in a highly turbulent state of the plasma. It appears that zones of turbulence, where the direction of the electrical fields is completely irregular, are essential for the emission of neutrons. In addition, it is of importance that only one collision is necessary to obtain the reaction energy of 15 MeV.

Here we should mention a characteristic of the electrical explosion of metallic wires. The beginning of the explosion is always accompanied by strong vapour jets perpendicular to the wire. The vapour jets can easily be made visible on a glas plate placed near an exploding wire. These vapour jets, emitted with supersonic velocity are always connected with strong turbulence leading in extreme cases to backward motion of the expanding gas. These are the main characteristics of the wire explosion leading to further turbulence. The current passes partly through the outer turbulent zones and only during this time nuclear reactions take place.

The turbulent zones in the later times of the explosion are considered to be the sources of the observed nuclear reactions. The high potential applied to the wire can accelerate the Li^{3+} and the D^{+} ions only in the same direction and only to about the same velocity, as e/m (charge divided by mass) in the two cases is 0.43 and 0.5 respectively. However, in turbulent plasmas ions are accelerated in every direction. Opposite directions lead to nuclear reactions. Another possibility could arise from the vapour jets which cross the turbulent zones. In any case, every effort should be made to enhance the turbulence.

As an example, this could be effected by two wires situated a small distance apart. Than the normal expansion of the wire material following the explosion is mutually influenced. Every difference between the two explosions in time, in strength, or in composition will change the appearance and the behaviour of the turbulence. As the wires consist of inhomogeneous material the distribution of current and voltage in the two wires will be different. The two wires may be of different length and also of different diameter. They may be situated in parallel or at a certain angle to each other. In addition the wires could be bend in such a way that the magnetic forces between the wires are locally different. The simultaneous explosion of several wires may also be of interest. Finally a small loop in series with one of the wires will lead to a small time difference in the development of the individual explosions. A large field of experimental research is open for making the turbulence the dominant feature of the discharge. Theoretically, the turbulence could be treated with the methods developed for a predetermined chaos.

In the present research the diameter of the wire was limited to 1.2 mm by the mechanical forces necessary to operate a press containing the Li + LiD mixture in a box containing pure Argon. Katzenstein and Sydor [6] have succeeded to press pure Li through nozzles of 0.001 inch diameter using a "blanket of carbon dioxide against chemical attack". The Li-wire was mounted ready for explosion and deuterated in situ by active deuteron atoms, generated with a subsidiary electrical discharge of 5000 V ac at 10^{-5} torr pressure lasting for two hours. But contrary to our research, they have studied the exploding wire discharge as a "Fast Dynamic Pinch". The discharge was made extremely fast and the possibility of thermo-nuclear (D, D) reactions was prooved. They obtained 5×10^5 up to 2×10^6 neutrons at a calculated temperature of 300 eV only. It can be doubted that they have obtained thermo-nuclear conditions in fact.

In our experiments, the major part of the plasma was fully ionized during the explosion. In this case, most α-particles will leave the plasma without any collision. Outside the plasma, the mean free path is determined by the density of the surrounding gas. At atmospheric pressure the mean free path is a few cm only. In case of Li + LiD filled capillaries, dark red brown colored clouds appeared after each successful explosion. These clouds are very dense and not at all transparent. They are characteristic for an explosion in air leading to nuclear reactions. In case no neutrons appear, no clouds are observed. It is concluded that the clouds are produced from the energetic α-particles which ionize the surrounding air and induce chemical reactions leading to vapours containing nitrous oxide. In case the surrounding gas is not air and the pressure is diminished the range of the α-particles is increased and may serve usefull purposes. Than the fuel should not be Li + LiD but Li + LiH. Here, the energy is higher (17.5 MeV) and is transferred to two α-

particles without the appearance of neutrons. In this case any radioactivity is avoided. Even a wilful destruction of the whole installation would not lead to any environmental damage. In the present research, LiD and the neutron were only needed to proof the appearance of nuclear reactions.

In addition to the dark brown clouds, strong X-rays appeared the wavelength of which was not yet determined.

At this point it may be said that we have succeeded in achieving non thermal nuclear reactions. It is important to continue with this work. Some experiments to increase the turbulence and to extract the energy are still needed.

In astrophysics it is generally accepted that in the sun exists a zone of the so called "lithium-burning". This zone is situated in the outer zones of the sun, just below the zone of general (hydrogen) turbulence i.e. about 30 000 km below the surface. There, the temperature is $2.4 \cdot 10^6$ K or 206 eV only. The temperature obtained with exploding wires is surprisingly near to this value. This again indicates the importance of further experimental work.

Contrary to all previous research with exploding wires it is wrong to believe in achieving thermonuclear fusion in the explosion of wires by feeding in as much energy as possible in a time as short as possible. *Instead it is necessary to produce electrical fields for a time as long as possible at moderate temperatures, and the turbulence of the explosion should be made as strong as possible.*

In conclusion it should be mentioned that the number of neutrons observed in the present research was very limited, perhaps 10^4, a small number indeed. But the research was not meant to obtain many neutrons, but to indicate a new way to obtain nuclear reactions.

I wish to thank my collegues J. Kistemaker in Amsterdam and E. Bagge in Kiel and to the very unfortunately recently deceased Joh. Richter for valuable discussions.

[1] The literature concerning exploding wires during the sixties has been collected in the 4 volumes "Exploding wires" edited by W. G. Chase and K. H. Moore, Plenum Press 1959, 1961, 1964, 1967.
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