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Research Article

# The Use of Graphene for Controlled LENR in Thin Conductive Targets via Optimized Low-Voltage Corona Discharge

V. I. Vysotskii and M. V. Vysotskyy
*Taras Shevchenko National University of Kyiv, Kyiv, Ukraine*

S. Bartalucci
*INFN - Laboratori Nazionali di Frascati, Frascati, Italy*

**Abstract**

The problem of optimizing nuclear reactions at low energy of moving particle based on accelerator nuclear fusion is considered. It is shown that the optimization process may be linked to the formation of coherent correlated states of moving particles and accompanying fluctuations of transverse energy (30–100 *keV*). These phenomena occur when particles traverse a crystalline graphene channel (graphene nanotube) with an optimal energy of longitudinal motion around 500 *eV*. Furthermore, the study establishes that the most efficient method for implementing such systems is the use of a negative corona discharge in hydrogen or deuterium gas near the surface of conductive graphene nanotubes, in the presence of lithium or other fusion-optimal isotopes inside these nanotubes.
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*Keywords:* Graphene nanotubes, Coherent correlated state, Low energy nuclear reactions, Corona discharge, Nuclear fusion

## 1. Introduction

Traditional "accelerator nuclear fusion" methods rely on the need to use high kinetic energy particles that interact with remote unoriented targets possessing optimal isotopic composition for fusion. The efficiency of such fusion remains quite low ($3 \ldots 5\%$) due to the substantial non-nuclear deceleration of moving particles upon interaction with atomic electrons of the target [1]. While employing the channeling motion of accelerated particles in oriented crystal targets significantly reduces the rate of non-nuclear deceleration, the probability of nuclear fusion decreases even more rapidly. Such interaction modes necessitate intricate and costly accelerator systems. It has been shown that the combination of these methods using thin layers of graphene leads to the possibility of a simple alternative implementation of low-energy, self-sustaining and self-regulating fusion.

## 2. Application of Coherent Correlated State of Moving Particles for LENR

In our previous investigations [2]–[5], we have demonstrated the feasibility of accelerator $p + Li^7 = 2He^4$ fusion utilizing moving protons with an optimal low velocity $v_{z,\mathrm{opt}} = 2d < \omega(z) >$ and low kinetic energy $E_{z,\mathrm{opt}} =$

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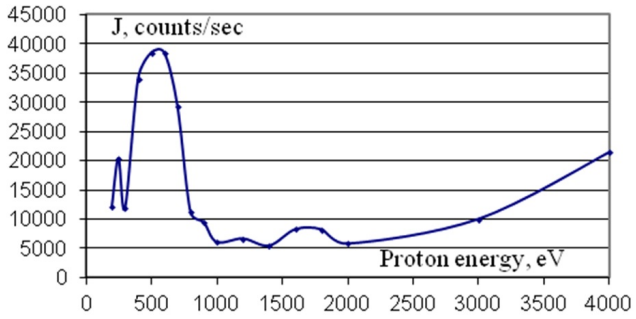


**Figure 1.** Dependence of the intensity of $Li^7(p,\alpha)He^4$ fusion reaction versus proton energy $E_z$ [6].

$Mv^2_{z,\mathrm{opt}}/2 \approx 500\mathrm{eV}$, corresponding to longitudinal motion within the periodic interplanar potential

$$V(r_\perp, r_\parallel) = V(r_\perp, r_\parallel + nd) = M\{\omega(z)\}^2 x^2/2, \quad r_\perp = x, r_\parallel = z \tag{1}$$

of *Li* crystal. These conditions align well with the experimental date [6] (see Fig. 1) and correspond to the formation of a coherent correlated state (CCS) of the moving particle upon traversing a crystalline channel [2]–[5].

It should also be noted that the optimal energy $E_{z,opt}$ for different isotopes of the same chemical element (e.g., *p* and *d*) will be identical. This follows directly from the formulas for $v_{z,opt}$ and $E_{z,opt}$ , taking into account that for different isotopes $\omega(z) \sim 1/M^{1/2}$.

This CCS is characterized by significant fluctuations $\delta E_x$ in transverse energy at low energy $T_{opt}$ of longitudinal motion, leading to subsequent nuclear fusion within the volume of the same *Li* crystal. This process is associated with the formation of an optimal coherent superposition of eigenfunctions of each particle, satisfying the criteria for realizing Schrödinger-Robertson uncertainty relations for various pairs of dynamic variables (e.g., $p_x, x$ and $E_x, t$ [2]–[4], [7]–[22]):

$$\delta p_x \delta x \geq \frac{\hbar}{2\sqrt{1-r^2_{p_x x}}} \equiv G_{p_x t}\hbar/2 \equiv \hbar_{\mathrm{eff}}/2, \delta E_x \delta t \geq \frac{\hbar}{2\sqrt{1-r^2_{T_x t}}} \equiv G_{E_x t}\hbar/2 \equiv \hbar_{\mathrm{eff}}/2, \tag{2}$$

$$r_{p_x x} = \frac{\{<xp_x> + <p_x x>\}}{2\sqrt{<p_x^2><x^2>}}; \quad r_{E_x t} = \frac{\{<tE_x> + <E_x t>\}}{2\sqrt{<E_x^2><t^2>}};$$

$$G = 1/\sqrt{1-r^2}; \quad 0 \leq |r| < 1; \quad 1 \leq G < \infty.$$

Here *r* is the coefficient of correlation, and *G* is the coefficient of correlation efficiency, characterizing the increase in amplitudes of dynamic variables fluctuations. It is noteworthy that during the formation of a coherent correlated state based on, for example, an excited oscillator, the Schrödinger-Robertson uncertainty relation is an obvious generalization of (2) and takes the form [10], [11]

$$(\delta p_x)^2 (\delta x)^2 \geq G^2(2n+1)\hbar^2/4. \tag{3}$$

The value *n* corresponds to the number of the energy level in the transverse potential well, associated with the transverse energy of the particle upon entering the interatomic channel. From these equations, a simple estimate for the lower limit (minimum value) of the kinetic energy fluctuation of a particle with mass *M* localized within the spatial interval $\delta q_\perp$ can be derived:

$$\delta E_\perp^{(\min)} = (\delta p_\perp)^2/2M = G^2(2n+1)\hbar^2/8M(\delta q_\perp)^2 \tag{4}$$

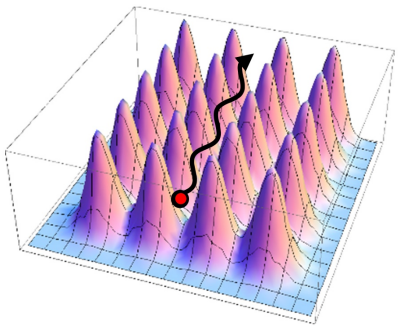

**Figure 2.** Adaptive channeling of low-energy proton in 3D crystal.

In particular, when a moving proton with mass *M* is localized in an interatomic region with size about 1.5*Å* ($\delta q_\perp \leq 0.75\mathring{A}$), typical for condensed matter, the minimum fluctuation of kinetic energy for a particle in CCS with realistic coefficient of correlation efficiency $G = (1...3) \cdot 10^3$ corresponds to the value $\delta E_\perp^{(\min)} \approx (1...10) \cdot (2n+1)$ keV. Actual fluctuations $\delta$E of transverse kinetic energy (2) can significantly exceed this minimum value $\delta E_\perp^{(\min)}$.

Notably, these fluctuations exhibit a considerably extended duration $\delta$t [21], [22] compared to the duration of quantum fluctuations associated with the conventional Heisenberg uncertainty relation $\delta E_\perp \delta t \geq \hbar/2$ for uncorrelated states with $r = 0$. The emergence of such states is linked to the physical mechanism of the formation of a mutually phased coherent superposition of particle eigenfunctions inside a nonstationary potential well. This potential well corresponds to the particle's state in the comoving coordinate system, linked to the moving particle within the periodic field of the interplanar channel of the crystal. This state corresponds to adaptive channeling within the actual periodic transverse electric field of the crystal (Fig. 2).

At the proton kinetic energy $E_{z,\mathrm{opt}} = M v_{z,\mathrm{opt}}^2/2$ , the coefficient of correlation efficiency increased up to $G_{\max} \approx (2...3) \cdot 10^4$ over three lattice periods [2]–[4]. This augmentation results in substantial fluctuations in transverse kinetic energy $\delta E_\perp \geq 30...100 keV$ and a pronounced increase in the transparency of the Coulomb barrier from an initial small value $D(E_{z,opt}) \leq 10^{-80}$ to $D(\delta E_\perp) \approx 0.01$.

A comparable, albeit less intense, effect transpires when a charged particle traverses a single lattice period, as may occur when a particle moves through a single-layer crystalline film of the graphene type (Fig. 3).

The motion of a proton through a unit cell of a single-layer graphene corresponds to a two-dimensional nonstationary harmonic oscillator with similar Schrödinger-Robertson uncertainty relations (1) for the corresponding variables $p_x, x$ and $E_x, t$. The results of the numerical calculation of CCS for a single-layer graphene [2]–[4] are shown in Fig. 4.

These calculations demonstrate that the optimal particle velocity giving the maximum correlation coefficients corresponds to the energy $E_{z,opt} \approx 500\ eV$ of longitudinal motion.

## 3. LENR on Targets Connected With Graphene Nanotubes During Corona Discharge In H or D Gas

The practical realization of this straightforward method for stimulating LENR can be achieved through two alternative approaches:

- utilizing a high-current proton accelerator with specific energy in vacuum system;
- employing the method of directed accelerating ions in a dense gaseous environment across the entire space between two electrodes with an optimal potential difference.

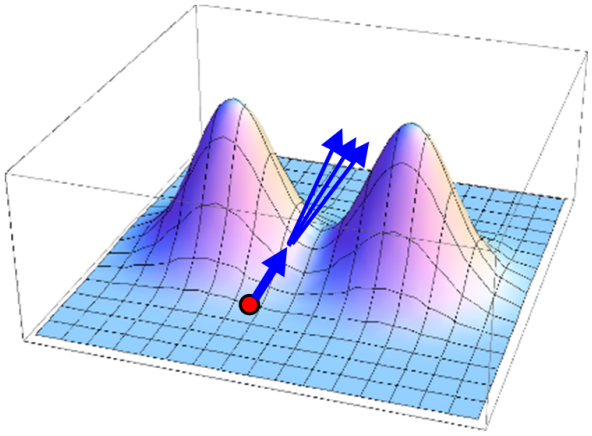

**Figure 3.** Adaptive channeling of protons in a single-layer crystalline film.

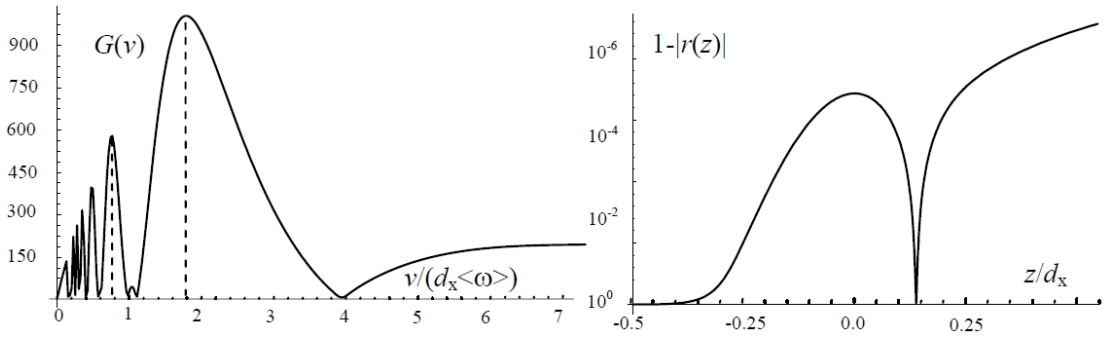


**Figure 4.** Dependence of the coefficients $r$ and $G$ on the velocity $v = v_z$ in the center of the longitudinal potential well of single-layer graphene with width $d_x$ (left) and on the longitudinal coordinate $z$ at the optimal longitudinal velocity $v_{z,opt}$ of the particle (right).

The first method demands specialized and rather intricate systems. Conversely, the second method faces challenges in maintaining a constant speed of protons due to multiple collisions between accelerated ions and other ions and atoms within the gaseous medium.

Simultaneous fulfilment of the conditions necessary for CCS creation and LENR realization (formation of quasi-monochromatic beams of particles with optimal energy and ensuring the optimal direction of their movement) can be attained by employing conductive single-walled graphene nanotubes and employing a corona discharge mode at the applied voltage $U$ in a gaseous environment with an optimal isotopic composition.

It is well known that the primary characteristic of a corona discharge is the acceleration of positively charged ions occurring directly near the cathode surface with a small radius $R$. In this region, a very high radial electric field strength

$$E_r = U/r\ln(r/R),\ r \geq R \tag{5}$$

is present and a maximum rate of ion acceleration towards the surface of cylindrical cathode is realized.

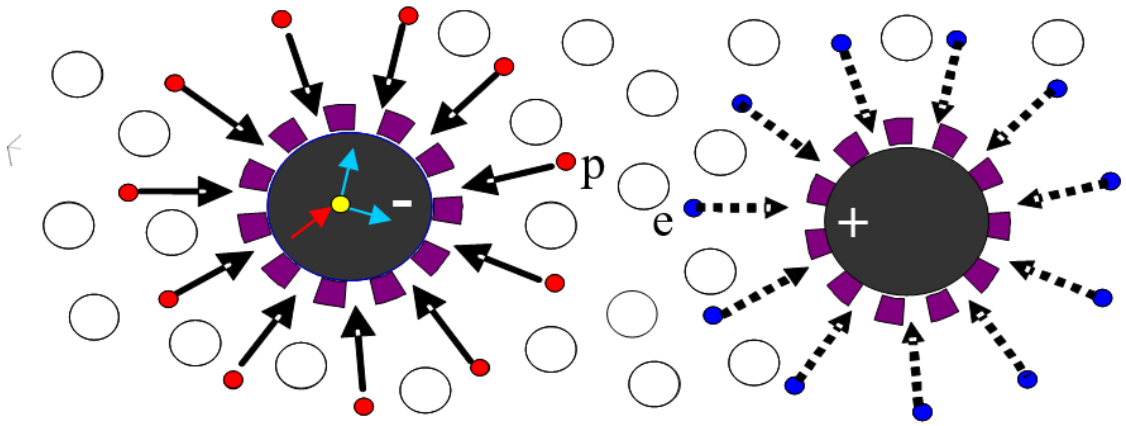


**Figure 5.** Setup scheme for CCS formation and LENR stimulation during negative corona *p* (or *d*) discharge near thin fusion active wires with optimal isotopic composition (e.g. *Li*), coated with single-layer conducting graphene tubes. Left: motion of protons or deuterons near wire cathode; right: motion of electrons near wire anode.

The schematic of a setup that meets all these requirements and can be used to implement nuclear fusion inside a target is shown in Fig. 5.

This system utilizes cathodes and anodes in the form of thin conductive wires with a small radius and optimal isotope composition for fusion (e.g., *Li*). They are coated with single-layer graphene tubes to enable a negative corona discharge mode.

The automatic provision of these conditions is associated with the features of the corona discharge near the surface of a cylindrical cathode with radius *R*. When the conditions for the existence of such a discharge are met, the entire process of ion acceleration occurs within a limited space interval $\Delta r \leq 10R$ near the cathode surface. The diminutive size of the acceleration path $\Delta r$ for corona discharge results in a substantial suppression of the process of scattering and deceleration of accelerated ions by other ions or gas atoms. This is attributed to the fact that the average path length of the accelerated ion $< l >= 1/\sigma_{\rm scat} n_{a,i}$ is significantly greater than the size $\Delta r$ of the ion acceleration region near the cathode surface composed of a graphene nanotube. Moreover, the movement of accelerated particles transpires in a direction perpendicular to the surface of a thin cylindrical cathode, ensuring the necessary orientation of particle movement. These conditions automatically ensure a high degree of monochromaticity for accelerated particles in a gas medium with an atom or heavy-ion concentration $n_{a,i} < 1/(10\sigma_{scat}R)$. In particular, at $R = 1$–$100\,nm$ and a typical value of $\sigma_{scat} = 10^{-16}\ cm^2$, we obtain the critical condition $n_{a,i} < 10^{23}$–$10^{21}\ cm^{-3}$.

In this setup, the initial acceleration of particles (*p* or *d*) to the optimal energy $E_{r,opt} \approx eU$ transpires radially within a small region near the cathode wires. As particles possessing the optimal energy traverse through a monocrystalline graphene film in a short-range channeling regime, a CCS of these particles is formed [2]–[4].

An important fact is that in close proximity to the surface of a graphene nanotube, the direction of the accelerated particles will typically deviate slightly from the strictly radial direction. This results in the occupation of quantum states with $n \geq 3-5$ within the space between graphene atoms and, consequently (as per equation (4)), an increase in transverse energy fluctuation $\delta E_\perp \sim (2n+1)$ up to $30\ldots100\ keV$ and more. This angular deviation in the direction of movement arises from the influence of the electric field immediately before the particle enters the space between atoms on the graphene surface.

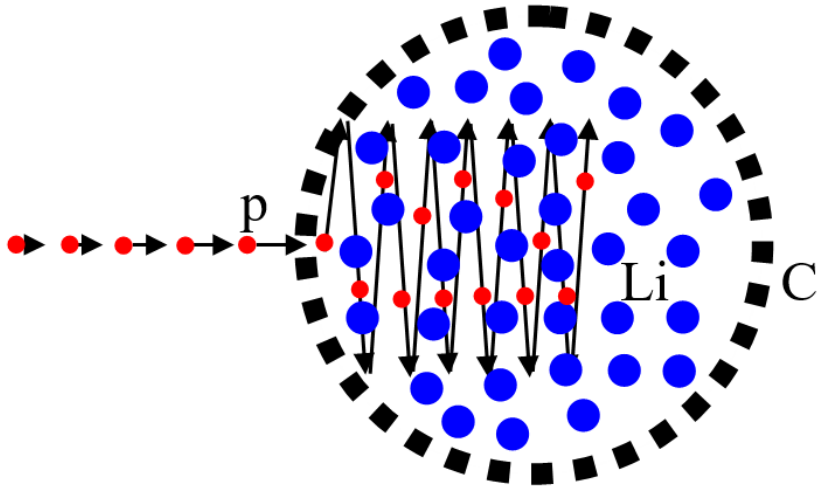


**Figure 6.** Schematic diagram of the motion of a proton with the optimal initial radial energy $E_{r,opt}$ and large transverse energy fluctuations $\delta E_{\perp}$ in the presence of CCS inside a nanotube filled with unstructured lithium.

The interaction of these particles in CCS with an adjacent unstructured *Li* cathode, proximate to the film, leads to effective $Li^7 + p = 2He^4$ nuclear fusion (see Fig. 6).

This corona discharge mode, with a voltage of $U \approx 450...500\ V$, can persist (in accordance with Peek's law [23], [24]) for an extended duration within hydrogen gas with a concentration up to $n_a \approx 10^{20}...10^{21} cm^{-3}$ at $R \approx 1...10\ nm$. For cathode surface self-cleaning and removal of space charge near the cathode surface, it is imperative to periodically interchange the anode and cathode by changing the voltage $U$ polarity.

An important factor in implementing this self-acceleration method is the energy loss that accelerated ions experience while passing through the surface of the graphene nanotube.

This issue is addressed in [25]. The authors conducted a detailed theoretical and experimental study of the parameters of such losses in the case of an oriented proton beam moving perpendicular to the surface of single-layer graphene. They showed that in this mode of motion, the energy loss increases linearly with the velocity of the incident particle. This finding is in good agreement with the Lindhard–Scharf theory of electronic stopping [26]. In particular, for single-layer graphene, the energy loss for protons with an energy of 500 $eV$ is about 10 $eV$, which does not significantly affect the efficiency of nuclear fusion.

## 4. Conclusions

The method of self-controlled formation of coherent correlated states of particles passing through an optimal single- or double-layer graphene-type nanotubes enables the generation of giant fluctuations in transverse momentum and energy. The optimal longitudinal energy for protons or deuteron is in the range of 450...500 $eV$. Such fluctuations are generated and exist not only during particle passage through a thin graphene surface, but also in the space beyond this surface (inside the graphene nanotube [20]). The most optimal approach to creating such a system with controlled particle energy is through a corona electric discharge in hydrogen or deuterium gas, involving conducting graphene nanotubes as both cathode and anode.

This configuration involves the interaction of protons accelerated to the optimal for CCS energy $E_{opt}$ with an unstructured fusion-active target (e.g., $p + Li^7 = 2He^4$) made of *Li*-type isotope material. This target is situated inside the conducting nanotube.

The use of nanotubes with different internal isotopic compositions allows a significant increase in the number of nuclear fusion reaction types, facilitating the search for the most optimal configurations. When empty graphene nanotubes are used, only a single optimal reaction $C^{12} + d = N^{14}$ can be implemented via the direct interaction of accelerated deuterons with the nanotube wall [27].

It is particularly important that the feasibility and high efficiency of implementing a corona discharge in a graphene nanotube system have been confirmed in successful experiments [28], [29]. These experiments did not involve nuclear physics studies but demonstrated the high efficiency of this electric discharge mode.

Another challenge in implementing such LENR technology concerns the formation of complex targets consisting of a graphene nanotube containing an isotope optimal for this fusion. At first glance, introducing such a nuclear-active core into a very thin graphene nanotube appears to be a highly complex and expensive technological task.

In practice, however, similar problems have already been successfully solved in applied electronics. One approach involves first forming thin nanowires from an optimal conductive material enriched with the required isotope using the electrospinning method, followed by a corona discharge in an atmosphere containing carbon. This process results in the deposition of a thin carbon layer in the form of graphene on the nanowire surface [30]. Another method for forming such systems involves introducing lithium into an existing graphene nanotube with a diameter of 1.5–5 *nm* via the thermocapillary effect at temperatures above 200°C [31].

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