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GENERATION OF ACCELERATED PARTICLES IN SOLID MATRICES SATURATED WITH ISOTOPES OF LIGHT NUCLEI

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Experimental results on the generation of accelerated particles in solid matrices saturated with isotopes of hydrogen under electric discharge are presented. Registration of accelerated particles was carried out by measuring the spectra of charged particles emitted by the target. The emission of α-particles with an energy yield of 10…14 MeV, the yield of protons with an energy in the range of 5.8…7.8 MeV, and the yield of neutrons with an energy in the range of 3…10 MeV were observed. These observations may indicate that the low energy nuclear reactions took place under investigated conditions.

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INTRODUCTION

Low-energy nuclear reactions (LENR) in solids have attracted a lot of attention since 1991 [1]. Experimental studies of LENR are based on the measurement of anomalous heat effects (AHE) [2 - 5], anomalous generation of accelerated particles (AGAP) [6, 7], and anomalous transmutation effects (ATE) in solid matrices saturated with isotopes of light nuclei [8]. In this paper, we present experimental results on AGAP in comparison with those of other authors.

1. EXPERIMENTAL SETUP

Gas-discharge experiments with nickel and palladium samples were carried out on a thermophysical stand (Fig. 1). The experiments involved bombarding palladium and nickel targets with an electric discharge in hydrogen and deuterium. The schematic diagram of the vacuum system of the thermophysical stand is shown in Fig. 1.

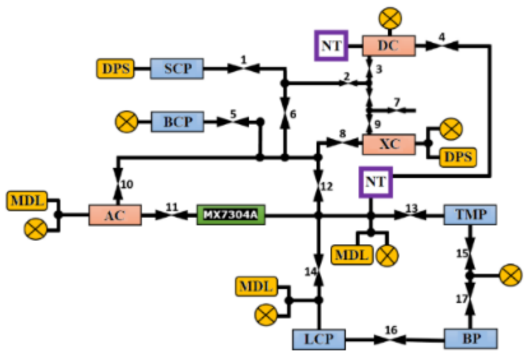

Fig. 1. Diagram of the vacuum system of a thermophysical stand: 1-17 – vacuum valves; DPS – deformation pressure sensor (7 – for gas inlet); ⊗ – thermistor lamp; MDL – magnetic discharge lamp; SCP – small chem. pump; BCP – large chem. pump; BCP – large coal pump; TMP – turbo molecular pump; BP – fore vacuum pump; DC – deuterium chamber; XC – "CROSS" chamber; AC – analysis chamber; MX7304A – gas analyzer MX7304A; NT – nitrogen trap

The thermophysical stand consists of a high-vacuum stainless-steel chamber equipped with a set of tools and devices capable of initiating fusion and conducting experiments. Devices for obtaining and maintaining a high vacuum ($P \leq 10^{-7}$ Torr) include: turbomolecular and cryogenic coal pumps, nitrogen traps, etc. For storage and injection of H_2 and D_2 into the unit and purification of ^4He and ^3He from these gases, the unit provides two chemical pumps based on Zr-Al-Fe-absorbent. The water jacket of the chamber serves as a flow calorimeter and, using heat-insulating materials, makes it possible to register heat release in the chamber with an accuracy of about ± 2.5% of the input power. The stand was equipped with a protective screen made of lead plates 55 mm thick, as well as a screen made of polypropylene plates "stop-neutron". The complex includes an Inspector-2000 spectrometer with a germanium HPGe detector (Canberra Industries). The local protection of the detector's recording crystal, in addition to lead blocks, includes a copper tube with a wall thickness of 1 mm. The background in the γ-detector chamber in the energy range of 180...250 keV was suppressed by a factor of ~ 9. To study γ-activity, a stationary low-background spectrometer with background level suppression by a factor of 50 was used. The discharge unit was located in the experimental chamber so that the distance from the electrodes to the recording crystal of the γ-detector was minimal (6...7 cm). The thickness of the chamber wall in the region of the discharge device was reduced to 0.4 mm. At this location outside the chamber, ALNOR and DTU detectors for detecting the level of neutron radiation (ALNOR) and the total radiation level (DTU) are located.

To study the chemical and isotope compositions of the working gas, the thermophysical stand was equipped with an MX7304A gas analyzer and a gas discharge lamp for optical spectral analysis using an SL40-2 spectrometer.

Power was supplied from two power sources BP-100, which feed magnetic discharge pumps "NORD". One of them relative to the "earth" has a potential "minus", the second – "plus". The sources are bridged to the central electrode of the discharge device through an electromechanical switch and operate alternately, switching for 15 min each. The circuit allows one to maintain constant modes of different polarity (Fig. 2).

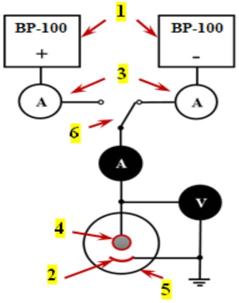

Fig. 2. Simplified electrical circuit of the experiment: 1 – power supplies; 2 – outer electrode; 3 – exemplary ammeters M2018 and M1107; 4 – central electrode; 5 – vacuum chamber; 6 – electromechanical relay with timer; Uni-T multimeter used as an ammeter; Mastech multimeter used as a voltmeter

The discharge was ignited between two nickel electrodes, one of which (outer electrode) was a plate (14×24×0.2 mm), the second (central electrode) was a nickel cylinder 60 mm high and 16 mm in diameter, formed by winding of a nickel wire (Ø = 0.5 mm) on an alundum tube (Fig. 3). A resistive heater and a thermocouple are placed in the tube to calibrate the calorimeter and maintain and control the temperature of the electrode.

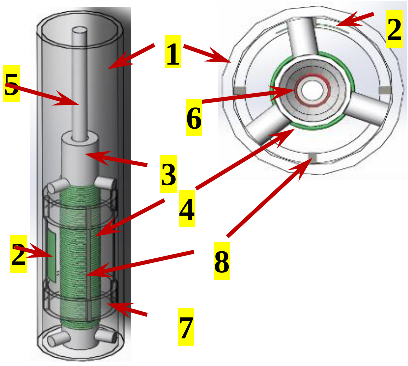

Fig. 3. Schematic representation of the gas discharge unit: 1 – quartz tube (electrical insulation from the thickness of the chamber); 2 – nickel plate 14×24×0.2 mm (external electrode); 3 – hollow ceramic tube (Ø1=15 mm, Ø2=7 mm, L=100 mm) wound with nickel wire; 4 – nickel wire winding Ø=0.5 mm, L=60 mm (inner electrode); 5 – ceramic rod with ohmic heater; 6 – ohmic heater (R=15 Ω); 7 – quartz insulator ring; 8 – fasteners for the "basket" of the external electrode (nickel)

The discharge unit (see Fig. 3) was installed in the chamber opposite the γ-detector in such a way that the distance to the electrode (2) was minimal. The distance from the recording crystal to the central electrode (4) of the discharge device was 7...8 cm. The distance between the electrodes (2) and (4) was 10 mm. Outside the chamber there was a water jacket (calorimeter) and a heat insulator.

1.1. CALORIMETER

The water jacket of the chamber (a serpentine made of PVC pipe with a diameter of 6 mm and a wall thickness of 1 mm) serves as a flow calorimeter, which makes it possible to register the heat release in the discharge with an accuracy of ±1.5…2.5% of the input power. During calorimetric measurements, the water flow rate and the temperature difference at the outlet and inlet are recorded. The thermal power absorbed by water was calculated by the formula:

$$P_{therm} = \frac{C_{H_2O} * \Delta T * V}{t_{con}}, \quad (1)$$

where CH2O is the heat capacity of water equal to 4.18 J/(g·K); ΔT is the temperature difference between outlet and inlet; t_{con} is the time during which a volume of water equal to V flows. The calorimeter in our installation can operate at a water flow rate in the range of 30...300 ml/min.

Knowing the electric power P_{el} (W), one can determine the efficiency of the system:

$$\eta = \frac{P_{therm}}{P_{el}}. \quad (2)$$

The error of our temperature meter did not exceed ± 0.5°C.

2. RESULTS

Abnormal generation of accelerated particles.

Anomalous generation of accelerated particles is one of unexplained phenomena of low-energy fusion [9, 10].

Charged particles were registered in the present experiment directly. Neutrons were registered by secondary recoil particles of nuclear reactions.

The α-particles traces were recorded with a CR-39 type detector. After etching, the traces became visible, which could be examined under an optical microscope.

Triple tracks from α-particles (Fig. 4) emanated from one point, which made it possible to separate these reactions from the interactions of neutrons with the nuclei of the CR-39 detector [11]. The resulting energy of accelerated α-particles was 10…14 MeV. The yield of protons with energies in the range of 5.8...7.8 MeV and the yield of neutrons with energies in the range of 3…10 MeV were also observed. Similar results were obtained in the works of Takahashi and Roussetski [9, 10, 12]. Table 1 presents the energies of particles measured in the present experiment in comparison with works [9, 10, 12].

Table 1

High-energy α-particles, protons and neutrons obtained in deuterium fusion scenario

E_α (present experiment), MeV	14.436	11.627	12.054	11.464	12.05	10.139	8.756
E_α [9, 10], MeV	14.0…9.2						
E_p (presentexperiment), MeV	8.86	7.2	6.74	5.26	5.45	-	-
E_p [9, 10], MeV	7.8	-	-	5.6	-	-	-
E_n (present experiment), MeV	7.54	8.84	9.48	6.47	9.47	6.09	5.7
E_n [9, 10], MeV	10…3						

According to [13, 14], during the bombardment of palladium target by an electric discharge, many nuclei were formed in deuterium. The excitation energy of such nuclei is removed due to the emission of n, p nucleons or their bunches d, T, ^{3}He, ^{4}He. The calculation of the process of fission of the excited $^{106}Pd^{*}$ nucleus with the formation of accelerated particles (1)-(3) (Table 2) showed that the $^{106}Pd^{*}$ nucleus was excited to a level at which the excitation energy of the nucleus $E_{exc.}$ (nucleon excitation energy) significantly exceeds the energy of a nucleon separated from the nucleus – $E_{nucl.sep}$.(nucleon separation energy). However, the emission of γ-quanta by the nucleus in the region of high excitation energies ($E_{exc.}>E_{nucl.sep.}$) occurs with a probability much less than the probability of the nucleon emission.

Table 2

Alleged LENR reactions

$$^{104}_{46}Pd^{*} + {}^{2}n \to {}^{106}_{46}Pd^{*} \to \begin{cases} \to {}^{105}_{45}Pd + n(8.48\,MeV); & (1) \\ \to {}^{105}_{45}Rh(\beta; 35.4\,h) + p(7.2\,MeV); & (2) \\ \to {}^{102}_{44}Ru + \alpha(11.6\,MeV); & (3) \end{cases}$$

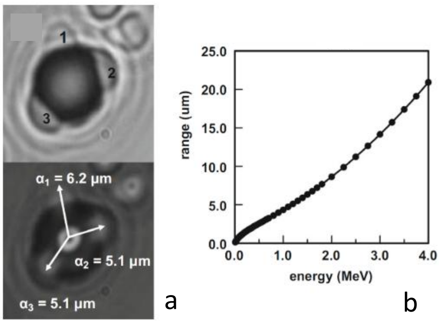

Fig. 4. Photographs of the triple track: Photographs of the triple track is shown. The top image was taken with the optics focused on the surface of the CR-39 detector. The bottom image is an overlay of two photomicrographs taken at different focusing depths (detector surface and bottom of the pits). In the lower image, the light circle seen on the track indicates the location where the neutron collided with the carbon atom. The arrows are drawn to show the directions in which the alpha particles moved after the destruction of the carbon atom. The distances traveled by alpha particles are indicated (a).
Linear energy transfer curve (LET) for alpha particles in CR-39 calculated using Ziegler and Biersack's SRIM-2003.26 code [15] (b)

In the present experiment, neutrons with an energy of 8.8 MeV, protons with an energy of 7.2 MeV, and alpha particles with an energy of 11.6 MeV were observed (see Table 1).When studying the ɤ spectra, the ^{105}Rh and ^{102}Ru lines were observed, however, the lines had a low intensity (≥3σ) of the spectra.

Changes in the electrical parameters of the discharge.

The process of generating accelerated particles was accompanied by a change of electrical parameters.

During the transition to the active mode, the resistance of the discharge gap, changed from 8...7.5 to ~ 2 kΩ as the output of excess heat increased. In this case, the discharge current increased from 83 to 143 mA, and the voltage across the discharge interval dropped to values at which the discharge was not ignited at the beginning of the experiment. The change in the electrical parameters of the experiment is shown in Fig. 5.

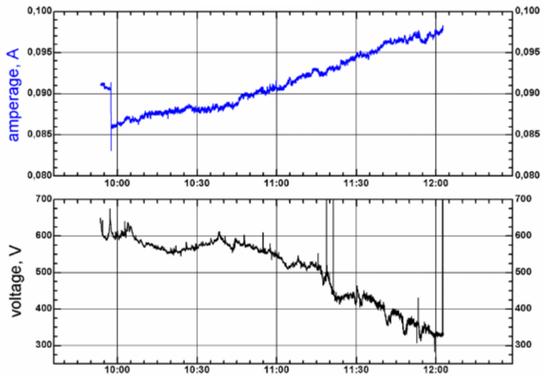

Fig. 5. Electrical characteristics of experiment 7.07.19

The process of generating accelerated particles was also accompanied by the appearance of impurities in the matrix. The impurities have an anomalous isotope composition. The reported experiments also revealed a change in the nickel isotope composition (Table 3). Decrease in the concentration of all nickel isotopes, except of the isotope ^{62}Ni, whose concentration has increased, can be explained if one assumes that the observed changes in the isotope composition are the result of the absorption of bineutrons by the nickel nucleus according to the reaction [13, 14]:

$$^{x}_{28}Ni + {}^{2}n \to {}^{x+2}_{28}Ni^{*} \to {}^{x+1}_{27}Co + p(E). \qquad (3)$$

The reaction (3) of the absorption of a bineutron by the ^{62}Ni nucleus cannot be accompanied by the release of a proton (proton energy is below the Coulomb barrier), therefore, the accumulation of the ^{62}Ni isotope should take place.

Table 3

The isotope composition of nickel in nature and in the present experiment

No	Isotope	Natural composition, %	Isotope composition on the cathode surface, %	The energy of protons in the reaction ($^{x}Ni + {}^{2}n \to {}^{x+1}Co + p\ (E)$)	Coulomb bar (E_K), MeV	(E_p - E_C), MeV
1	^{58}Ni	67.76	66.52	10.7	~7 ± 1	+3.7
2	^{60}Ni	26.16	26.72	10.24	~7 ± 1	+3.2
3	^{61}Ni	1.25	1.24	6.06	~7 ± 1	-1
4	^{62}Ni	3.66	4.42	3.9	~7 ± 1	-3.1
5	^{64}Ni	1.16	1.1	-	-	-

The change of the parameters of the gas discharge detected in the present work upon entering the regime of excess heat release may indicate the participation of conversion electrons [13, 14]. Table 4 shows the results of gas analysis, where reaction (3) took place.

Table 4

Gas analysis results

Pressure, Pa	Analyzed gas	The ratio of the peak intensities $^3He/^4He$
$2.5\ldots 4.7\cdot10^{-4}$	Vacuum	2.7…5.5
$7.9\ldots 9.6\cdot10^{-5}$	D_2/H_2 (99%/1%) + chem. pump	8…9.5
$0.5\ldots1\cdot10^{-4}$	Vacuum	0.7…3.5
$0.5\cdot10^{-4}$	D_2/H_2 (85%/15%) + chem. pump	6.4…17

During the experiment, the isotope composition of the working gas changed (see Table 4). The ratio of the mass-3 peak height to the mass-4 peak height in the experiment with the gas composition of 85% D_2 and 15% H_2 reached the value of 17. In the experiment with a low hydrogen content (~ 1%), this ratio was equal to 10. This gives reason to conclude that ^3He was formed in the experiment. The content of D_2 and H_2 molecules in the analyzed gas was minimized due to their absorption by the adsorbent in the chemical pump and could not significantly affect the $^3He/^4He$ ratio.

It should be noted that in addition to AGAP, the nickel electrodes produced excess heat for 13 h at a power of ~ 30...35 W, with the maximum efficiency was at the level of 1.8...1.9. However, the operation of the energy source has not been optimized. The process was interrupted due to electrode burnout, so the efficiency values obtained in this work (1.8…1.9) should be considered as the lowest possible efficiency value.

3. DISCUSSIONS

The present results may indicate at the low energy nuclear reactions taking place in solid matrices saturated with isotopes of hydrogen under electric discharge. This matter is a subject of debates [1]. Below we discuss possible scenarios of nuclear reactions taking place in the present experiment.

It has been argued that the best conditions for initiating nuclear reactions in a gas discharge are a mixture of 85% D_2 and 15% H_2. Under these conditions, ^3He atoms can be generated according to the fusion reaction (4) [13, 14]:

$$D^+ + e^- + H^+ \to {}^3_2He + +e^-_{conv.}(\Sigma E = 5.5\ MeV). \quad (4)$$

A characteristic feature of reaction (4) is that ^3He is produced. In a free gas, this phenomenon has an extremely small cross section. It was suggested in [13] that in a crystal lattice, a quasimolecule (D^++e^-+H^+) can be formed. In this case, the presence of the discharge of energy excitation of the $^4He^*$ nucleus is suspected. Thus, the ban on the reaction d+d→^{4}He+γ is removed. The energy transfer in this case is carried out along the chain: excited nucleus – virtual γ-quantum – conversion electron – matrix. The change in the resistance of the discharge gap during the fusion may bean evidence of the participation of electrons of the internal conversion occurring in the reaction (4) [13, 14].

In the experiment, bineutron reactions occur with the participation of Ni, with the release of protons. The corresponding change in the isotope composition of Ni is presented in Table 3.

Changes of gas discharge parameters during the transition of the system to the regime of intense heat release may testify that excess heat in the experiment is removed by the conversion electrons [13].

It should be noted that neither during the experiment, nor during the subsequent registration, γ-radiation different from the background was detected. Possible explanation for this is that the following reaction takes place [13]:

$${}^{60}_{28}Ni + {}^2n \to {}^{62}_{28}Ni^* \to {}^{61}_{27}Co \left(\beta;\ T_{\frac{1}{2}} = 1.65;\ E_\gamma = 0.067MeV\right) + +p \to {}^{61}_{27}Ni_{stable} + p. \quad (5)$$

The absorption of a bineutron causes the rearrangement of the nucleus and the emission of nucleons or their clusters which may explain the absence of γ-radiation in the experiments.

When creating the chamber, care was taken to obtain the maximum signal from this reaction. Calibration of the chamber with an americium source showed that the intensity of the 0.067 MeV line in the control experiment was suppressed by a factor of 5. Considering this and taking into account the rate of production of nickel isotopes, it can be expected that the 0.067 MeV line was recorded reliably in the course of the control experiment.

CONCLUSIONS

Experimental results on the generation of accelerated particles in solid matrices saturated with isotopes of hydrogen under electric dischargeare presented. Registration of accelerated particles was carried out by measuring the spectra of charged particles emitted by the target. The emission of α-particles with an energy yield of 10…14 MeV, the yield of protons with an energy in the range of 5.8…7.8 MeV, and the yield of neutrons with an energy in the range of 3…10 MeV were observed. It was established that in the process of gaseous discharge in 85% D_2 and 15% H_2, ^3He atoms were generated. These observations may indicate that the low energy nuclear reactions took place under investigated conditions. This matter is a subject of debates. To make a more definite conclusion, further experiments are required.

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ГЕНЕРАЦІЯ ПРИСКОРЕНИХ ЧАСТИНОК У ТВЕРДИХ МАТРИЦЯХ, НАСИЧЕНИХ ІЗОТОПАМИ ЛЕГКИХ ЯДЕР

В.О. Гамов, В.І. Дубинко, В.М. Борисенко, Клі Ірвін

Наведено експериментальні результати з генерації прискорених частинок у твердих матрицях, насичених ізотопами водню. Реєстрація прискорених частинок здійснювалася шляхом вимірювання спектрів заряджених частинок, що випускаються мішенню. Спостерігалося випромінювання α-частинок з енергетичним виходом 10…14 МеВ, вихід протонів з енергією в діапазоні 5,8…7,8 МеВ і вихід нейтронів з енергією в діапазоні 3…10 МеВ. Ці спостереження можуть вказувати на те, що низькоенергетичні ядерні реакції протікали у досліджених умовах.