Objects Obtained by γ Quanta Irradiation with Threshold Energy of 10 MeV of Pure Gaseous He, under High Pressure, in CuBe₂ Apparatus

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Abstract: A HeHPC (Helium high pressure chamber) filled up with pure gaseous helium at initial pressure about 1.1 bar was irradiated by braking γ -rays of 10 MeV threshold energy during 1.0×10^5 s at the electron beam current $22 \sim 24 \mu\text{A}$. After irradiation, the residual pressure inside was equal to 430 bar. Synthesized foils of black color and other multiple objects were found inside the HeHPC mainly at the entrance window for γ -rays made from beryllium bronze as a plug of beryllium bronze HPC, at the inner surfaces of the reaction chamber made of high purity copper and at the copper collector. The element analysis, using SEM (Scanning electron microscopy) and MPRA (Microprobe roentgen analysis), allowed us to establish that the foils consist predominantly of carbon and the smaller quantities of other elements from carbon to iron. An explanation for the observed elements is suggested on the basis of helium fusion reactions under the action of γ -rays with the reactions taking place in giant stars (thermally activated). The possible mechanism after 3α reaction is na reactions and under barrier reactions. A second experiment with initial pressure of 3.05 kbar (with pressure drop by about 65 bar - after almost the same procedure of γ -rays irradiation and with fully beryl bronze environment) suggests another possible nuclear reactions - $\text{He}(\text{Be}, p)\text{C}$, $\text{He}(\text{C}, \gamma)\text{O}$, and so on. The developed approach agrees well with a series of studies carried out by the authors where dense hydrogen and deuterium gases are acted on by γ -rays in the presence or absence of metals in the reaction chambers.

Key words: Irradiation, high pressure, helium, PACS 25.20.Dc, 25.45.De.

1. Introduction

The element compositions of synthesized particles and objects, as well as the surface structure of elements of the DHPC (Deuterium high pressure chamber), have been studied using samples of metals such as Al, V, Cu, Pd, Sn, Re, YMn₂ alloy and stainless steel in the shape of rods and wires which were placed in molecular deuterium gas under high pressure and acted on by braking γ -rays of 10 MeV [1-7] and 23 MeV [8-12] energy. Analogous investigations aimed to study the possibilities of nuclear reactions were performed using HHPC (Hydrogen high pressure chambers) with

Pd-rods inside [13] and in the presence of hydrogen without any metallic samples in the chamber [14, 16] under irradiation by 10 MeV braking γ -rays. Possible phenomenological modeling approaches for nuclear fission reactions in the liquid-drop model and for nuclear fusion are discussed in [17-24].

The goal of the present work is to point out some regularity in the formation of new elements which were absent in the HeHPC material observed earlier by authors and first described in [25, 26, 28].

2. Descriptions of the Technique

Fig. 1 shows the scheme of a modified high pressure chamber filled with helium (HeHPC) whose pressure was equal to 1,092 bar at the start of the irradiation with

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Fig. 1 The schematic drawing of high pressure apparatus. 1: gamma quanta, 2: closing screw (CuBe₂), 3: reinforcing SS high pressure chamber body, 4: CuBe₂ “window – plug” (58°/60° cones), 5: places where mainly C elements were observed, 6: CuBe₂ high pressure chamber, 7: helium under high pressure, 8: pure Cu sleeve, 9: expected reaction product on pure Cu plug, 10: temperature measurement channels, 11: high pressure connecting capillary to high pressure valve, strain gauge pressure sensor and inlet-outlet system of gaseous being investigated (not shown in the picture).

γ -rays. Helium of specific spectral purification had 99,999 at.% purity specified in its data sheet. The filling of the HeHPC chamber with helium was carried out by iterations of the following operation: filling of the chamber of volume with helium up to a pressure of 0.2 kbar, releasing the pressure up to atmospheric one, repeating this procedure and then filling the chamber with helium up to the 2 kbar pressure. The degree of purification from atmospheric gases was approximately 10^{-6} .

The initial pressure in the HeHPC, measured prior to irradiation using a strain sensor (Fig. 1, pos. 11) and Model P3 measuring module, was found to be 1,092 bar. At helium pressure about 1.1kbar, its atomic density is evaluated as being approximately 1.5×10^{22} at./cm³ [27].

Irradiation of the HeHPC was performed during 27 h and 51 min (or 1.02×10^5 s) at the MT-25 electron accelerator of the G.N. Flerov Laboratory of Nuclear Reactions of JINR, Dubna, Rus. The energy of the electron beam was 10 MeV, and the electron beam current ranged from 21 to 23 μ A. The braking γ -rays of

continuous spectrums with threshold energy of about 10 MeV were obtained using a braking target in the shape of a tungsten foil of 2.5 mm thickness and an aluminum absorber of electrons with 25 mm thickness. During the irradiation, the temperature inside the outer protective steel cylinder of HeHPC increased to about 60 °C at the steady-state regime of the chamber’s irradiation. The pressure in the chamber increased at the start of irradiation from 1,092 to 1,242 bar, i.e. by 150 bar, which seems to be a pure temperature effect. Before opening of the chamber – here it was the most objective and precise measurement – its inside pressure was registered to be 426 bar. Thus, it had dropped by 666 bar. Upon opening the chamber, a few oily (see explanation below) black foils of round shape were observed in its inside area (Fig. 1, pos. 5).

These black foils of considerable size (Fig. 2 below) were composed mainly of carbon. As the foils were laid out on a special clean sheet of roll paper (tracing one), it appeared that the latter (its surface) looked to be soaked with oil in the area of such foils.

Fig. 2 Images of two groups of black foils (a, b) observed at position 5, shown in Fig. 1.

3. Optical Studies of the Oily Black Foils Synthesized under Braking γ -Rays

After opening of the HeHPC chamber, foils of black color with reinforcing needles were observed at the juncture of the entrance window and reaction chamber (Fig. 1, pos. 5), part of such needles protruding from the foils as lengthy rods of constant thickness and white color. Fig. 2 shows images of multiple black foils of round form that acquired such shape due to cylindrical symmetry of the entrance to the reaction chamber. These images were obtained using a special photo-micrographic device.

4. SEM and MPRA Studies of Black Thin Foils Synthesized after Irradiation γ -Rays

The structure and element composition of all the elements of the HeHPC chamber which were in contact with dense helium, such as the cut along the cylinder symmetry axis: a) two inner and outer surfaces of the beryllium bronze entrance window; b) two inside surfaces of the copper sleeve in which nuclear and chemical reactions predominantly took place; c) copper collector of reaction products, were studied at two independent analytical centers (Skobielcyn Laboratory of Moscow Lomonosow State University, Russian Federation and FGBNU NII PMT, Moscow, Russian Federation.

As was noted in the previous section, upon opening the HeHPC, oily foils of black color with reinforcing rods of small diameter and uniform thickness, either protruding or scattered over the surfaces of the black foils, i.e. inside them, were found at the juncture of the entrance window and reaction chamber (Fig.1, pos. 5).

Here, results of the second Laboratory (where full elements analyses were done), will be taken under consideration. The set of foils being considered here, found after opening of the HeHPC is shown in Figs. 3-6.

Similar to the results described by the first center, the patches of studied foil exhibit thin lengthy sticks, either observed on the foil surface or protruding in random directions. Figs 4a and 4b show SEM images of two regions of this large foil, where element content was measured at points 18 and 19 respectively. Data shown in Table 1 are element concentrations at these two points.

As can be seen from Table 1, the foil in Fig. 4 contains a lot of carbon and oxygen with presence of substantial amounts of nitrogen in a chemically bound state, of volatile fluorine, and almost all elements up to Ca and Fe (not shown here).

Fig. 5 displays some SEM images of black particles of complex shape and points 20 and 21, where MPRA were done as can be seen, a large amount of carbon is

Fig. 3 SEM images of a large foil and place with like rod formation with larger magnifications.

Fig. 4 A SEM image of area on a black foil and places where MPRA were done, points 18, 19.

Table 1 The main element composition of foils, shown in Figs. 4a and 4b, at points 18 and 19.

Element	Z	Series	wt. %	at. %	wt. %	at. %
				Fig. 5, point 18	Fig. 5, point 19	
Carbon	6	K	59 ± 7	66.38	60.7 ± 7	67.04
Nitrogen	7	K	5.9 ± 1.2	5.69	5.5 ± 1.3	5.22
Oxygen	8	K	30.14 ± 3.8	25.42	32.6 ± 4.4	27.05
Fluorine	9	K	-	-	0.37 ± 0.17	0.26
Sodium	11	K	0.42 ± 0.06	0.25	0.03 ± 0.03	0.02
Magnesium	12	K	3.02 ± 0.20	1.68	0.44 ± 0.05	0.24
Aluminum	13	K	0.18 ± 0.04	0.09	0.11 ± 0.03	0.05
Silicon	14	K	0.25 ± 0.04	0.12	0.07 ± 0.03	0.04

present along with oxygen in three objects where MPRA was made. Noteworthy that one can observe raised quantities of nitrogen (Table 3) and magnesium (Tables 1-3 spectra in Figs. 5 and 6). The element concentrations belong to these three points 20-22 were shown in Table 2.

5. Mean Content of Elements in Measuring Points

In Table 3, values of element concentrations are shown at measuring point of measurements particle, for first elements (up to Si). In the last column means value

for five points are calculated. Based on this data it was possible to find the dependence of contents of elements, in at.%, as function of atomic number A.

In Fig. 7 graphical correlation between content of

observed elements in at.% and atomic number of elements is shown. The successive element content (larger by 4 atomic mass units, alpha particle) is smaller than content of previous one, in rough calculation,

Fig. 5 SEM images of four particles and measure points 20 and 21.

Fig. 6 (a) SEM images of two particles and (b) characteristic X-rays spectrum, obtained at point 22.

Table 2 The main element composition of the foils shown in Figs. 5 and 6, at points 20-22.

Element	Z	Series	wt.%	at.%	wt.%	at.%	wt.%	at.%
Fig. 14, point 20				Fig. 14, point 21		Fig. 15, point22		
Carbon	6	K	58 ± 7	65.9	53 ± 6	62.14	51 ± 5	62.1
Nitrogen	7	K	-	-	-	-	4.9 ± 1.3	5.09
Oxygen	8	K	38.6 ± 5	32.0	37.5 ± 4.8	33.11	24.30 ± 3.0	22.2
Fluorine	9	K	0.53 ± 0.20	0.38	0.73 ± 0.23	0.55	-	-
Sodium	11	K	0.18 ± 0.04	0.10	0.77 ± 0.08	0.47	0.05 ± 0.03	0.03
Magnesium	12	K	1.35 ± 0.10	0.75	3.08 ± 0.20	1.79	14.6 ± 0.6	8.78
Aluminum	13	K	0.10 ± 0.03	0.05	0.36 ± 0.05	0.19	0.29 ± 0.04	0.15
Silicon	14	K	0.22 ± 0.04	0.11	0.41 ± 0.04	0.20	0.59 ± 0.05	0.31

Table 3 Simplified summing up of observed data of element concentration for five large particles.

Element	A/Z	Series	at.%	at.%	at.%	at.%	at.%	at.%
Ralpha	2/4		point 18	point 19	point 20	point 21	point 22	mean
Carbon	6/12	K	66	67	66	62	62	65
Nitrogen	7/14	K	6	5	0	0	5	3
Oxygen	8/16	K	27	25	32	33	22	28
Fluorine	9/19	K	0	0.3	0,4	0,6	0	0.3
Neon	10/20		?	?	?	?	?	12?
Sodium	11/23	K	0.3	0.02	0.1	0.47	0.03	0.2
Magnesium	12/24	K	2	0.2	0.75	2	9	3
Aluminum	13/27	K	0.09	0.05	0.05	0.2	0.2	0.1
Silicon	14/28	K	0.1	0.04	0.1	0.2	0.3	0.2

Fig. 7 Dependence of mean concentration of observed main elements in five points, for different probes, as a function of atomic number A. 100% of He and Be is here symbolical and presents number o nuclei having part at the beginning in observed phenomena. In red colors there is shown in large approximation time dependence of helium pressure which was at the beginning 2,025 bar (100%) in NCNR Poland is shown in large approximation. Dotted line presents four days waiting time for irradiation, transportation from Warsaw to Dubna, during which small helium leakage probably took place. Continuous line presents irradiation process as it was described in the text, performed in JINR, Dubna. Time scale, in hours, is 12 times larger in the A scale. The stars present results from the second experiment (see below).

Fig. 8 Linear elements on the not regular layers on the inner wall of collector (Fig. 1, position 8) [28]. The last figure presents a chosen view of surface before irradiation.

by a coefficient of 0.4, which may suggest that there is the same action mechanism. Noted larger difference between measured and projected values for heavier elements is related to bigger errors.

6. Results

Paper [25] describes supplementary detailed experimental results on the measurement of element concentrations for the observed objects on the cut along the axis of the cylindrical symmetry: a) two inside and outside surfaces of the entrance window from beryllium bronze, b) two inner surfaces of the copper sleeve where nuclear and chemical reactions primarily took place, c) copper collector of reaction products (see Fig. 1, pos. 5, 4, 8 and 9 respectively). Such division of the data of one experiment into two independent publications is due to the large volume and significance of the obtained results that ought to be presented for the sake of reliability. It was shown that, as in the present study, the major element was carbon in presence of heavier elements of masses from carbon to iron, nickel and copper. It should be noted specially that practically all the inner surfaces of the elements of the HeHPC were coated with a noticeable layer of carbon, and the chemical element analysis of the observed structures approximately corresponds to the compositions given in this study

The explanation for the observed effects can be made on the basis of the fusion reactions of helium nuclei “heated” by γ -rays (with 10MeV energy) at the expense of the elastic scattering:

Other effects arising due to scattering of γ -rays on helium atoms [15-19]. As is known, the reaction [22]:

which can proceed only through the short-living ${}^8_2\text{Be}$ nucleus with the lifetime $\tau \approx 10^{-16}$ s. However, in dense helium this nucleus may capture a third helium nucleus (and process can be continued, see “alpha process”). In Fig. 9, we can observe that in probe the decreases of

percentage of such elements as C, O, Mg and Si occur regularity which can suggest the same mechanism for its creations. On the other hand such elements as N, F, Na and Al appear in very small amounts, so we can say its creation is of smallest probability. We have no information about amounts of Ne because we did not make its chemical analyses noting only the fact that the smell of gas transported to the air had an intensive unpleasant character.

The chemical elements as O, Mg and Si could be also formed in sub-barrier reactions of synthesis [21, 22] of type:

The details of possible processes are under consideration. Some of the reactions proceeding in dense helium during “helium burning” in astrophysics are presented in literature, see for instance [20, 21] and classical works [22-23]. It is well known that the probability of a number of basic nuclear reactions of synthesis described in the above phenomena is extremely small, and some of them have never been realized under terrestrial conditions. In our the second, control, experiment with initial helium pressure about 3 kbar [28] we have observed much smaller decrease in pressure, only about 65 bar, much less carbon like elements of large dimensions and with contents with large amount only C 47 at.%, O (36 at.%), N (5 at.%) and the base material Cu (5 at.%) - see Fig.7 shown as stars - which may suggest that the effect of the experiment strongly depends on the value of helium pressure. Data are the mean values, from measurement of 12 different objects, which have been found in the pressure chamber. Fig. 8 shows one example of observed object on the inner wall of collector (Fig. 1 position 8) made in this experiment of beryllium bronze consisting linear elements (of composition 44 at.% C, 36 at.% O, 15 at.% N and 10 at.% Cu) and non regular layers.

Such situation suggests the action of another mechanism: sufficiently strong γ quanta activates α particles (nuclei of compressed helium), those bombarding ${}^9_4\text{Be}$ on the inner wall surface gives reaction $\alpha + {}^9_4\text{Be} = {}^{12}_6\text{C} + n$, next $n = p + e^- + \nu$, next p goes to ${}^1_1\text{H}$ (H_2 , increasing partial pressure in the chamber). Picture of surface structure of inner surface of beryl bronze sleeve, after it mechanical treatment (but before irradiations) speaks of their biggest difference that confirms of existing of the carbon-like layer.

So in this interpretation, following the reaction (α , n) type, take place:

(alpha particles strongly accelerated by gamma quanta).

Later (α , γ) type:

later (α , γ) type:

and so on, but real, more precise explanation of the results presented here, is the open problem.

7. Conclusions

This paper is devoted to a study of synthesized large black carbon foils with extended rods placed both along the surface of the foils (inside them) and jutting out, as well as of smaller particles (Fig. 2, and SEM images in Figs. 3-5 and 6a. As visible from Fig. 2a, the largest pieces of foil resemble twisted foils, as though peeled off the walls of the high pressure chamber (Fig. 1, pos. 5 and 6), of cylinder shape with a diameter equal to the chamber's diameter.

There is an estimation of the amount of helium which was apparently expended on the synthesis of new elements [26], from initial pressure of 1,092 bar and the end pressure equal to about 426 bar. Taking data from [27] the number of helium atom was calculated as $0.82 \times 1,022 \text{ at. He/cm}^3$ and mass for elements produced during irradiation as $0.0269 \sim 0.0277 \text{ g}$ in working volume of HeHPC equal to about

0.75 cm^3 .

Weighting was not performed for the black foils. However, one may conclude that the mass amount of helium $\Delta m_{\text{He}} \approx 0.027 \text{ g}$ is quite comparable with the total amount of carbon foils and other objects, including the carbon coating over the surface of the copper reaction chamber or copper sleeve (Fig. 1, pos. 8) [24].

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References

- [1] Didyk, A. Y. and Wiśniewski, R. 2012. *EPL* 99: 22001-6.
- [2] Didyk, A. Y. and Wiśniewski, R. 2013. *EPL* 103: 42002-6.
- [3] Didyk, A. Y. and Wiśniewski, R. 2012. *Physics of Particles and Nuclei Letters* 9: 615-31.
- [4] Didyk, A. Y., Wiśniewski, R. and Wilczyńska-Kitowska, T. 2013. *Journal of Surface Investigation. X-ray, Synchrotron and Neutron Techniques* 7: 239-47.
- [5] Didyk, A. Y. and Wiśniewski, R. 2013. *Inorganic Materials: Applied Research* 4: 5-13.
- [6] Didyk, A. Y., Wiśniewski, R. and Wilczyńska-Kitowska, T. 2013. *Phys. of Part. and Nucl. Let.* 10: 804-19.
- [7] Didyk, A. Y., Wiśniewski, R. and Wilczyńska-Kitowska, T. 2013. *Phys. of Part. and Nucl. Let.* 10: 820-32.
- [8] Didyk, A. Y. and Wiśniewski, R. 2012. *Phys. Part. and Nucl. Lett.* 11: 5-13.
- [9] Didyk, A. Y. and Wiśniewski, R. 2013. *Journal of Physical Science and Application* 3 (4): 209-17.
- [10] Didyk, A. Y. and Wiśniewski, R. 2012. Preprint P15-2012-75. Dubna. p.15.
- [11] Didyk, A. Y. and Wiśniewski, R. 2014. *Phys. Part. and Nucl. Let.* 11: 169-79.
- [12] Didyk, A. Y. and Wiśniewski, R. 2014. *Phys. Part. and Nucl. Let.* 11: 309-28.
- [13] Didyk, A. Y. and Wiśniewski, R. 2013. *Phys. Part. and Nucl. Let.* Preprint P15-2013-80, Dubna, JINR, Rus, 32.
- [14] Didyk, A. Y. and Wiśniewski, R. 2014. *Phys. Part. and Nucl. Let.* Preprint P15-2014-2, Dubna, JINR, Rus, 44.
- [15] Didyk, A. Y. and Wiśniewski, R. 2014. *Phys. Part. and Nucl. Let.* Preprint P15-2014-3, Dubna, JINR, Rus, 44.
- [16] Didyk, A. Y. and Wiśniewski, R. 2014. *Phys. Part. and*

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- Nucl. Let. Preprint P15-2014-6, Dubna, JINR, Rus, 34.
- [17] Didyk, A. Y. and Wiśniewski, R. 2014. *Phys. Part. and Nucl. Let.* Preprint P15-2014-7, Dubna, JINR, Rus, 24.
- [18] Ishhanov, B. S., Kapitonov, I. M. and Tutin, I. A. 2009. *Nucleus Synthesis in the Cosmos*. Publisher LIBROKOM, 302. <http://nuclphys.sinp.msu.ru/nuclsynt.html>.
- [19] Muhin, K. N. 1983. *Experimental Nuclear Physics . Physics of Atomic Nucleus*. Publisher: Electroatomizdat. 1: 616.
- [20] Bethe, H. A. 1939. "Energy Production in Stars." *Phys. Rev.* 55: 434-56.
- [21] Gamov, G. 1938. "Nuclear Energy Sources and Stellar Evolution." *Phys. Rev.* 53: 595-604.
- [22] Marshak, R. E., Morse, P. M. and York, H. 1950. "Equation of State of Hydrogen, Helium, and Russel Mixture at High Temperatures and Pressures." *Astrophysical Journal* 111: 214-20.
- [23] Uglov, W. W. 2011. "Radiating Effects in Solids." Minsk, Byelorussian, 207.
- [24] Ishhanov, B. S. and Kapitonov, I. M. 1979. "Interaction Electromagnetic Irradiations and Atomic Nucleus. Moscow State University, 215.
- [25] Didyk, A. Y. and Wiśniewski R. 2014. Preprint JINR, P15-2014-50, Dubna, Russia, 34.
- [26] Didyk, A. Y., Wiśniewski, R. and Wilczyńska-Kitowska, T. 2015. *EPL* 109: 22011.
- [27] Didyk, A. Y. and Wiśniewski, R. 2013. "Properties of Hydrogen and Its Isotopes under High Pressure, and Technological Applications." Dubna, JINR, 320. Monograph, ISBN 978-5-9530-0358-2.
- [28] Didyk, A. Y. and Wisniewski, R. Preprint JINR, P15-2014-87, Dubna, Russia, 2914, 24.

Appendix

Data from [28].

There were observed and analyzed the 15 different points inside pressure chamber obtaining following data:

Object Nr **1 2 3 4 5 6 7 8 9 10 11 12 13 14 15** means values

C at.% 50 50 47 40 46 32 49 45 52 25 19 48 44 42 47 42 or **47**

O at.% 35 40 38 39 47 43 30 41 34 30 38 38 26 32 27 37 or **36**

Cu at.% 2 2 4 7 4 **20** 8 1 2 **36** **22** 5 10 8 5 9 or **5**

N at.% 10 5 9 10 0 0 9 8 0 0 0 0 15 7 7 5 or **5**

If eliminate points 6, 10 and 11, where anomalous of Cu content was found, we obtain more proper data shown as last position. Another elements were has been founded occasionally or in small amounts. The figure bellow presents strictly collision situation (often demonstrated in literature, mean distances between nuclei are much larger).

In thermal equilibrium at high temperature and high pressure, motion of nuclei is random, very intensive and collision can realize is in any point and any direction and are spontaneous. Mean distance between alpha particles is one order bigger than its dimensions.

Bellow shown scheme is possible but effective areas for such events are very small! In the picture the distances between not bonded alpha particles are very large, so it is difficult to give proper proportion.

Direction of perturbation element is in one direction, thermal nuclei motion does not play any role, initiating reactions have beginning near to face part of compressed helium, and has a continual character. "White dots" - free helium nucleon, "yellow dots" - activated nucleon helium and "red dots" - bonded nucleons. Mean distance between alpha particles one order bigger than those in case of The Sun and 3-4 order bigger than those in giant red object.