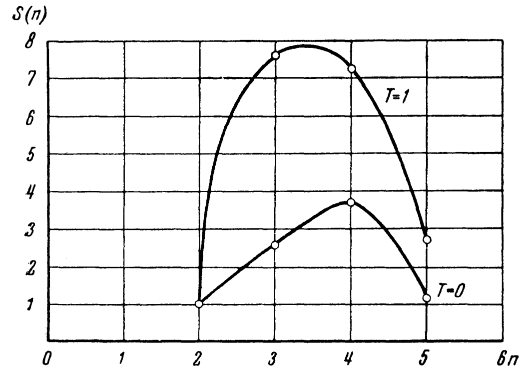
mately correct in our case. The formula for $W_n(E_0)$ is given as:

$$W_n(E_0) = \frac{\pi^{n-1}}{2^{n-1}} \frac{(4n-4)!\,(2n-1)}{[(2n-1)!]^2\,(3n-4)!} E_0^{3n-4}. \qquad (3)$$

The factor $f_{n,T}$, accounting for the preservation of isotopic spin and the identity of particles is given by the following formula (see Ref. 8): $f_{n,T} = g_n(T)/n!$, where

$$g_n(T) = (2T+1) \sum_i \frac{(-1)^{n+i}}{2i+1} \binom{n}{i} \binom{2i+1}{i-T}. \qquad (4)$$

Values of $g_n(T)$ for different d and T are computed in Ref. 8.



In the collision of two particles, proton and antiproton, the values of the isotopic spin may be equal only to 1 or 0. Indeed, the eigenfunctions $(p\tilde{p})$ (p--proton, $\tilde{p}$--antiproton), $(n\tilde{n})$ (n--neutron and $\tilde{n}$--antineutron), (np) and (pn) can be expressed in the following manner through the eigenfunctions of states with a given value of T (upper index) and its z component T_z (lower index):

$$(p\tilde{n}) = \Phi_1^1; \quad (p\tilde{n}) = \Phi_{-1}^1; \qquad (5)$$

$$(pp) = 2^{-1/2}\ (\Phi_0^0 + \Phi_0^1);$$

$$(n\tilde{n}) = 2^{-1/2}\ (\Phi_0^1 - \Phi_0^0).$$

In the Figure are shown the probability $S(n)$ for the distribution of the n-meson formation for values of isotopic spin $T = 0$ and $T = 1$. It is seen from the presented data that on the average four particles are formed, thereby making the energy per particle of the order of 0.5×10^9 ev. This justifies the assumption made that the particles are relativistic*. It is also of interest to investigate the distribution of the formed mesons according to charge. For the case of 2 and 3 meson formation this type of investigation was carried out by others (see Refs. 9 and 10).

In conclusion, we express our thanks to Messrs. M.I. Podgoretski and I.E. Tamm for their participation in the discussions of questions pertaining to this work.

* Computation of the statistical weight by the exact formula for the case when two particles are in the final state (see Ref. 11) showed that Eq. (3) gives values different from the exact values by about 1%.

[1] E. Fermi, Progr. Theor. Phys. 5, 570 (1950).

[2] L. Landau, Izv. Akad. Nauk SSSR, 17, 51 (1953).

[3] S. Z. Belen'kii and L.D. Landau, Usp. Fiz. Nauk 56, 309 (1955).

[4] E. Fermi, Phys. Rev. 92, 452 (1953).

[5] E. Fermi, Phys. Rev. 93, 143 (1954).

[6] S.Z. Belen'kii and A.I. Nikishov, J. Exptl. Theoret. Phys. (U.S.S.R.) 28, 744 (1955); Soviet Phys. JETP 1, 593(1955).

[7] I.L. Rozental', J. Exptl. Theoret. Phys. (U.S.S.R.) 28, 118 (1955); Soviet Phys. JETP 1, 166 (1955). G.V. Lepore and R.N. Stuart, Phys. Rev. 94, 1724 (1954).

[8] V. Veivin and de Shalit, Nuovo Cim. 1, 1146(1955).

[9] I. Kobzarev and I. Shmushkevich, Dokl. Akad. Nauk SSSR 102, 929 (1955); I. Shmushkevitch, Doklad. Akad. Nauk SSSR 103, 235 (1955).

[10] D. Amati and B. Vitale, Nuovo Cim. 11, 4, 719 (1955).

[11] M.I. Podgoretski and I.L. Rozental', J. Exptl. Theoret. Phys. (U.S.S.R.) 27, 129 (1954).

Translated by J.L. Herson
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Concerning Papers of S. E. Khaikin, S. V. Lebedev and L. N. Borodovskaia Published in the J. Exptl. Theoret. Phys. (U.S.S.R.) in 1954-1955

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IN the works of S. E. Khaikin, S. V. Lebedev and L. N. Borodovskaia, a presentation was given of the results of experiments in which processes occurring in metallic wires during the passage through them of large impulsive currents were studied. From an analysis of the results obtained, the authors came to two conclusions of significance in the physics of metals:

1. With an impulsive current density of 10^6-10^7 A/cm^2, the substance of the wire passes into an abnormal nonmetallic state, differing "by a sharp change of the character of the dependence of the resistance R of the wire on the energy E introduced into it."

2. In a series of experiments conducted on tungsten and iron wire in vacuum, an "abnormally high electronic emission" from the surface of the wire was discovered, accompanied "by the violation of the law of Boguslovskii-Langmuir" and associated, in the opinion of the authors, with the transition of matter into an abnormal state.

In the first three articles[1-3], the character of the abnormal state of matter was not made precise. In succeeding articles[4,5], it was surmised that this state bears a purely electronic character. Characterizing this new state, Lebedev asserts[4] that "the existing theory of metals not only did not predict the results of our experiments, but apparently cannot generally explain them without adding a new physical hypothesis to the theory."

Careful scrutiny of the above-mentioned works leadsus to the conclusion that the evidence put forward by the authors is not sufficiently convincing.

The first conclusion of the authors (concerning an abnormal state of matter) is based on the fact that the amount of energy introduced into the wire during various durations of passage of the impulsive current, calculated on the basis of oscillographic data, appeared to be greater than the wire could take up, while being in the usual state for metals. For example, according to the authors' calculations, the wire, maintaining a solid state during theimpulsive heating, can take up an amount of energy considerably greater than the energy of fusion.

Similar experiments were conducted by a group of co-workers together with the author of this letter, in order to study the properties of the substance of a wire during the passage through it of impulsive currents of great power[6,7]. The experimental method was similar to the method used in the works under discussion here, the only difference being that simultaneously with oscillography, shadow photographs were taken of the wire in various stages of explosion, and particular attention was paid to decreasing to a minimum the inductive distortion of the oscillograms. The current impulses were shorter, and accordingly, the current densities achieved were greater than in Refs. 1-5. As a result of these experiments, it was possible to show that Ohm's law for the solid state is maintained up to current densities $\sim 10^7$ A/cm^2.

With relatively low voltages on the condenser (< 5 kv), within the accuracy of the measurements, no particular abnormalities in the behavior of the substance of the wire was observed, and up to the first current maximum the energy introduced completely corresponded to the resistance of the wire. The contradictory results obtained in Refs. 1-3 can be explained, apparently, by the fact that the oscillograms from which the authors calculated the energy reveal considerable inductive distortion. In Ref. 1, in the calculation of the energy introduced into the wire according to Eq. (2), no correction to the magnitudesof the voltages V_R and V_r were made for the inductive fall of the voltage, amounting to several tens of percent of their maximum value (see, for example, the oscillograms in Fig. 7). Since the product of V_R and V_r occurs under the integral sign in Eq. (2), exaggerated values are found for the energy. The apparent surpluses of energy are greater, the greater the derivative of current with respect to time, i.e., the greater the amplitude of the impulsive currents. Similar inaccuracies occur also in Ref. 8, which is referred to by the authors as a work confirming their results. But as regards the calculation of the resistance of the wires according to Eq. (1)[1], sufficiently correct values are given, since in this equation the ratio of V_R and V_r enters, and their percents of inductive distortion are approximately the same.

Also considered in Ref. 1 is the question of the abnormal trend of the dependence of the resistance R of the wire on the amount of energy E introduced into it. According to the data of our experiments, such a dependence always occurs only at the end of the region of impulsive current before its so-called pause, and is associated with the intensive motion of matter arising as a result of the rapid thermal expansion of the wire, the strong compression of separate parts of it in a radial direction (caused by the action of the magnetic field of the current), the very rapid evaporation of these parts, etc. In this region, the wire is capable of taking up a considerably greater amount of energy than is necessary for its complete evaporation. Thus, that state of matter which the authors call abnormal, in actuality evidently represents the beginning of the stormy process of destruction of the wire. In the epxeriments in vacuum with refractory wire, in view of thermoelectronic emission from the surface of the wire, particularly from its superheated parts, and the associated shunting discharge, the wire may not obtain sufficient energy for explosion or even for fusion. Therefore, during the impulsive regime of heating in vacuum, the wire frequently remains unmelted.

The second conclusion of the authors (regarding abnormal electronic emission from the surface of refractory wires) is based on the fact that during heating by a large impulsive current, and in the presence of a certain anode voltage, the anode current is hundreds of times greater than the emission current of the wire at its fusion temperature in a stationary regime of heating, while the same wire here frequently remains unmelted. The authors make numerous attempts to prove that the abnormal increase of emitted current is not associated with some manifestation of a discharge in the gas or other secondary currents. Resting on these proofs, they concluded that the abnormal emission is due to an abnormal state of the substance of the wire. It should be noted that here, no account is taken of two circumstances which might be essential for the correct understanding of the appearance of abnormal electronic emission:

1. During impulsive heating almost to the temperature of fusion, occluded gases and part of the substance of the wire are evaporated from its surface. The mean thermal velocities of molecules and atoms at the temperature of fusion, for example, of tungsten ($\sim 3400°$) is of the order of 10^5 cm/sec. Therefore, during several microseconds (duration of the impulse for the greatest currents) the majority of them are able to fly only several millimeters from the surface of the wire. In view of this, in distinction to a stationary regime of heating, in the regime of impulsive heating a nonuniform distribution of gas pressure arises between the anode and cathode, with maximum pressure on the surface of the wire. With such a pressure distribution, in the presence of a sufficiently great electric field along the wire (several hundred volts per centimeter) and a magnetic field perpendicular to it, there exist, evidently, suitable conditions for the occurrence of discharges with large currents shunting the wire. In experiments on the explosion of wire in vacuum we visually observed that with a tungsten wire with a diameter of 0.1 mm and with a current of several thousand amperes, the visible diameter of the discharge does not exceed 4-5 mm, which evidently indicates the presence of a pressure gradient in the direction of the radius. Moreover, in this case the untwining of the discharge is also possible, caused by the action of the current's own magnetic field. Hence, it follows that in the comparison of the results of experiments in the impulsive and in the stationary regimes, disregarding the above-mentioned statements may lead to incorrect conclusions.

2. Certain deviations from the law of Boguslovskii-Langmuir in the initial part of diode characteristics are known, caused by the action of the magnetic field of the current of the incandescent cathode on the motion of the electrons. Here, there exists a critical value of anode voltage U_{kp}, below which the electrons in general do not strike the anode. In the case of a cylindrical anode with a coaxial wire cathode, U_{kp} is associated with a heating current i by the relation (see Ref. 9, p. 125):

$$U_{\text{кр}} = 188 \cdot 10^{-4}\, i^2 \left(\lg \frac{r_a}{r_\text{к}}\right)^2 ;$$

where U_{kp} is expressed in volts, i in amperes and r_a and r_k are the radii of the anode and cathode. Under the conditions of the experiments considered herein, $i \sim 10^3 A$, $r_k \leq 0.05$ mm, the anode is plane with area $\sim 1\ \text{cm}^2$ and is at a distance of 1 cm from the cathode. If a cylindrical anode is taken in place of a plane, the magnitude of U_{kp} is evidently not decreased. Therefore, a magnitude of 1 cm may be assumed for r_a. Then the above equation gives $U_{kp} \sim 100$ kv, and with a current of $i \sim 10^2 A$, $U_{kp} \sim 1$ kv. Thus, in the experiments considered, the authors would not have obtained electron currents differing from zero had the emission been normal, since the anode voltage in these experiments did not exceed 1 kv. In that case, in order to explain the abnormal emission, it is necessary to assume the existence of initial velocities of thermoelectrons sufficiently large to surmount the magnetic field of the current. A calculation of electron trajectories under the condition considered indicates that an initial electron energy < 10 ev is insufficient to surmount the magnetic field of the current. The assumption of significantly higher energies is not physically justifiable; therefore, evidently, it is fitting to acknowledge the basic role of a discharge shunting the wire. The abnormal electron emission could be easily understood if it were assumed that in the process of the impulsive regime of heating, an increase in the emitting surface occurs with a simultaneous decrease in the magnetic field on this surface. Both of these conditions are satisfied if a shunting discharge with a large shunting current develops along the wire. Here, the emitting surface is increased, and simultaneously the magnetic field of the current is decreased because of the decreased current density. From this, evidently, there is also associated the possibility of drawing off large electron currents

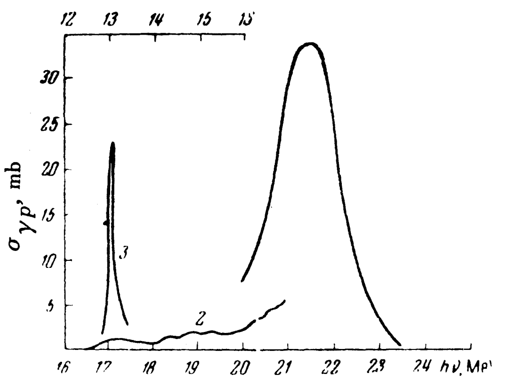

FIG. 1. (γ, p) excitation function for C^{12} and O^{16}. *1*--$C^{12}(\gamma, p)B^{11}$-- "giant" resonance (see Ref. 12), σ_{int} = 63 mev mb; *2*--$C^{12}(\gamma, p)B^{11}$ (see Refs. 5, 9 and 10), Q = 15.95 mev, σ_{int} = 8.2 mev mb; *3*--$O^{16}(\gamma,p)N^{15}$ (see Ref. 13), Q = 12.11 mev, σ_{int} = 4.4 mev mb. Lower scale for *1* and *2*; upper scale for *3*.

photonuclear studies, which are, as a rule, carried out over broad spectral ranges of the γ-rays. It would be of particular interest to study such reactions in the "giant" resonance region.

An anlysis of the data on (p, γ) reactions without cascade emission of γ-rays enables us to draw definite conclusions as to the predominance (although it is not overwhelming) of $E1$ γ-ray absorption in this energy region. In some instances such data also provide definite information concerning the cross sections for anisotropic proton emission in (γ, p) reactions. For example, the integral cross section for levels 3, 5 and 6 in the $S^{32}(\gamma, p)P^{31}$ reaction, which levels correspond to the emission of protons in the p-state, is σ_{int} = 4.5 mev mb. One must keep in mind the contributions of individual levels to the anisotropic emission of photonucleons in comparing the spectrum and angular distribution of these nucleons with calculations from statistical theory.

TABLE

Reaction	Threshold in mev	Energy interval $\Delta h\nu$ in mev	Levels and type of gamma absorption	σ_{int} in mev mb		References to the literature
$B^{10}(\gamma p)Be^{9}$	6.58	6.58 — 11	6.89($M2$)	~1.1	1.4	5-8
			7.48($E1$)			
			8.89($M1$)	0.3		
			10.83(?)			
$C^{12}(\gamma p)B^{11}$	15.95	15.95 — 21	16.10($E2$)		8.2	5,9,10
			16.57($M2$)			
			17.22($E1$)			
			18.39($E2$)			
			18,86(?)			
			19.25(?)			
			20.25(?)			
			20.49(?)			
$N^{14}(\gamma p)C^{13}$	7.54	7.54 -- 9,2	8.06($E1$)	~0,6	2	5,11
			8.62($M1$)			
			8.70($E1$)			
			9.18($E1$)			
$S^{32}(\gamma p)P^{31}$	8.85	8.85—11,2	9.65($M1,E1$)	0,003	10,3	14,16
			9.93($M1,E1$)	0.01		
			10.68($E1$)	2.3		
			10.77($E1,M1$)	0.8		
			10.81($E1$)	1.8		
			10.90($E1$)	0.4		
			11.10($M1,E1$)	1.3		
			11.12($M1,E1$)	3.5		

In conclusion, I wish to thank Iu. K. Khokhlov and E. M. Leikin for discussions of the problem treated in this note.

[1] A. B. Migdal, J. Exptl. Theoret. Phys. (U.S.S.R.) 15, 81 (1945).

[2] Haslam, Katz, Horsley, Cameron and Montalbetti, Phys. Rev. 87, 196 (1952).

[3] Katz, Haslam, Horsley, Cameron and Montalbetti, Phys. Rev. 95, 464 (1954).

[4] J. Goldemberg and L. Katz, Phys. Rev. 95, 471 (1954).

during the explosion of a wire in vacuum. The ionic currents drawn off from such a discharge must be hundreds of times smaller than the electronic currents, because the ratio of these currents with the same anode voltage is determined by the square root of the inverse ratio of the masses bearing the charges, which is also confirmed in the works considered.

[1] S. V. Lebedev and S. E. Khaikin, J. Exptl. Theoret. Phys. (U.S.S.R.) **26**, 629 (1954).

[2] S. V. Lebedev and S. E. Khaikin, J. Exptl. Theoret. Phys. (U.S.S.R.) 26, 723 (1954).

[3] S. V. Lebedev, J. Exptl. Theoret. Phys. (U.S.S.R.) **27**, 487 (1954).

[4] S. V. Lebedev, J. Exptl. Theoret. Phys. (U.S.S.R.) **27**, 605 (1954).

[5] L. N. Borodovskaia and S. V. Lebedev, J. Exptl. Theoret. Phys. (U.S.S.R.) (no page no., n.d.).

[6] Bondarenko, Kvartskhava, Pliutto and Chernov, J. Exptl. Theoret. Phys. (U.S.S.R.) **28**, 191 (1955); Soviet Phys. JETP **1**, 221 (1955).

[7] Kvartskhava, Pliutto, Chernov and Bondarenko, J. Exptl. Theoret. Phys. (U.S.S.R.) **30**, 42 (1956).

[8] J. Wrana, Arch. f. Elecktrotechn. **33**, 656 (1939).

[9] F. Vlasov, *Electro-vacuum systems*, Sviaz'izdat, Moscow, Leningrad, 1949.

Translated by D. Lieberman and M. Mestchersky
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(γ, p) Reactions Associated with the Formation of Ground State Nuclei

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DURING the last few years a great deal of confirmation has been obtained for the existence of the so-called "giant" resonance in photonuclear reactions [such as (γ,n) and (γ,p) reactions] which is caused by the location between 15 and 25 mev of the center of gravity of dipole levels excited through nuclear absorption of $E1$ γ-quanta.[1] Beginning in 1952, a group of Canadian physicists[2-4] have distinguished an entire series of separate resonance levels in the "giant" (γ, n) resonance of a few light nuclei (Li^7, C^{12}, O^{16}, F^{19}). The study of the photonuclear excitation function fine structure is of decided interest both for nuclear spectroscopy and for the determination of the character of γ-ray absorption by nuclei. In connection with the latter question it is especially important not only to determine the contribution of any of the individual levels to the observed yield but also to reveal the nature of the final nuclear state [which is not usually done in the study of (γ, p) and (γ, n) reactions] as well as the angular distribution of the emitted particles.

In the present note we wish to estimate the contribution of individual levels to photonuclear (γ, p) reactions, which can be obtained from experimental data regarding the cross sections of reverse (p, γ) reactions that take place without cascade emission of γ-rays ($\sigma_{p\gamma}$). The cross sections $0_{\gamma,p}$) reactions connected with the formation of ground states in the final nuclei are related to the (p, γ) cross sections by the simple relationships of detailed balancing; for example, in the case of O^{16} (γ, p) N^{15} we have:

$$\sigma_{\gamma 0} = \sigma_{pN} 2 \frac{16}{15} \frac{mc^2 (h\nu - Q)}{(h\nu)^2} \frac{2I_N + 1}{2I_O + 1}.$$

Here $I_N(=\frac{1}{2})$ and $I_O(=0)$ are the spins of N^{15} and N^{16}, m is the proton mass, $Q(=12.11$ mev) is the energy released by the reaction, $h\nu$ is the energy of a γ-quantum associated with the proton energy (E_p) in the (p, γ) reaction by the relationship $h\nu = Q + (15/16)E_p$. From an analysis of the data in the literature, considerable information can be obtained concerning (γ, p) reactions associated with the formation of ground state final nuclei in the case of five light nuclei: B^{10}, C^{12}, N^{14}, O^{16} and S^{32}. The results are summarized in the Table and Figure.

As can be seen from the Table and Figure, the maximum cross sections for (γ, p) reactions connected with the formation of ground state final nuclei associated with individual levels, sometimes exceed by a large factor the maximum cross sections in "giant" resonance. The integral cross sections of such reactions which are associated with individual levels amount to about 10% of the integral cross sections in "giant" resonance, which encompass all possible states of the final nuclei. Consideration of this fact leads to some increase in the experimental values of the gamma absorption cross sections (σ_γ) and to reduction of the difference between the theoretical and experimental values of $\sigma_{\gamma\,int}$ for light nuclei as has been noted in Ref. 15, for example. It will be necessary to use extensive experimental data concerning (p, γ) and (n, γ) reactions in order to make an independent check of the results from