



Soviet-era science, translated into English

PHYSICS

B. P. PEREGUD, K. B. ABRAMOVA

1964

SovietRxiv

View the original and related papers at <https://sovietrxiv.org/items/ru-196401.91448>

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.

Abstract

Full Text

PHYSICS

B. P. PEREGUD, K. B. ABRAMOVA

EXPERIMENTAL INVESTIGATION OF AN ELECTRICAL EXPLOSION

(Presented by Academician B. P. Konstantinov on March 30, 1964)

The first work devoted to the investigation of the phenomenon of the electrical explosion of thin metal wires and foils dates back to 1774 ⁽¹⁾. Despite the existence of a number of publications ^(2,3) on this question, up to the present time the process of electrical explosion has still not been studied to a sufficient extent. At the A. F. Ioffe Physico-Technical Institute of the Academy of Sciences of the USSR, an investigation was carried out of the electrical explosion of copper wires. In this work the main attention was directed to the energy aspect of the process and to the behavior of the radiation accompanying the process. The most essential results of the investigation are given in the present communication.

1. None of the works published up to the present time contains information on the threshold regime of electrical explosion. In order to establish under what conditions the process acquires the character of an explosion, a series of experiments was performed with a copper wire 0.5 mm in diameter and 70 mm long in air at atmospheric pressure. The circuit in which the explosion was produced consisted of a capacitor bank connected in series, with capacitance 400 μF , a noninductive resistance, an ignitron, and the wire. The natural frequency of this circuit was 6000 Hz.

With the aid of dual-beam oscillographs, the changes in the magnitude of the voltage drop across the noninductive resistance (current), the voltage drop across the wire, and the change with time of the signal from a vacuum photocell (light) were recorded. The photocell had sensitivity to light in the wavelength range 2200–6000 \AA and a time constant of 10^{-9} sec. The voltage to which the battery was charged, U , was increased from experiment to experiment by 50 V, starting from 800 V. At voltage values up to 1150 V, the phenomena occurring in the wire during the current pulse and in the subsequent time were not similar to an explosion. Characteristic was the ejection from the explosion chamber of large drops of molten metal having a dark-red glow. On glass placed 7 cm from the wire, no scratches or other damage remained. On the light oscillogram there is observed a weak pulse arising at the moment of termination of the current pulse and ceasing after 20 μsec , and then, following it, a prolonged light pulse of the same intensity as the first (see Fig. 1, oscillogram 1). The energy

introduced into the wire is $E = 265$ J. With an increase of the energy to 290 J ($U = 1200$ V), the character of the process changes sharply (Fig. 1, 2). The substance of the wire is strongly dispersed.* After removal of the copper deposit, it is seen that the surface of the glass is chipped and melted. The intensity of the second pulse in this regime is many times greater than the intensity of the first; the second pulse still begins at the moment of termination of the first and continues for 30,000 μ sec (Fig. 1, 3).

It is reasonable to consider that these changes in the character of the development of the process indicate a transition to electrical explosion. It is noteworthy that the energy introduced

* Experiments carried out in vacuum showed that a deposit is formed on the glass which may be regarded as a condensate. When the wire is exploded in air, the glass is destroyed.

energy (290 J) is 2 times less than the sublimation energy of the wire, E_{subl} . The amount of energy expended on destruction of the wire is still smaller, since some fraction of E_{input}^* is carried away by fragments and radiation. Thus, the wire does not evaporate.

A further increase in the input energy does not cause a qualitative change in the course of the process; even if E_{input}^* becomes greater than E_{subl} , only the intensity of the second light pulse increases and the trailing edge of the current pulse becomes increasingly steep. Therefore one may think that complete evaporation does not occur even for $E_{\text{input}} > E_{\text{subl}}$.

Fig. 1. Upper beam of oscillograms 1, 2, 4–10, 12, 14, 15—current; 11—light. Lower beam of oscillograms 1, 2, 6–9, 14—light; 4—voltage; 5—radiation λ 1.68 μ ; 10, 11, 12, 15—infrared radiation λ 1–3.5 μ . Oscillogram 3—light, 13—current. Sweep duration—oscillograms 1, 2, 5, 6, 10, 11, 14, 15—200 μ sec; 3—30,000 μ sec; 4—100 μ sec; 7, 8, 9—500 μ sec; 12—100 μ sec; 13— μ sec.

2. At voltage values $U_{\text{initial}} < 1300$ V, the energy stored in the capacitors is completely expended in the first current pulse. Starting with $U_{\text{initial}} = 1300$ V, the current through the wire ceases before the stored energy has been used up, and the battery remains charged to the voltage U_{res} (Fig. 1, 4). The situation remains unchanged up to $U_{\text{initial}} = 2000$ V. The value $E_{\text{input}} = 550$ J ($U_{\text{initial}} = 2000$ V) approximately corresponds to the sublimation energy of the wire. Under this explosion regime, a detailed time-resolved study of the radiation spectrum of the first flash was carried out. It turned out that the wavelength at which the radiation intensity is maximal is $\lambda = 1.4 \mu$. The radiation detector was a semiconductor photoresistor sensitive in the visible and infrared regions of the spectrum, whose time constant is 10^{-6} sec⁽⁴⁾. The distribution of energy in the radiation spectrum proved not to correspond to the Planck distribution. During the first light pulse the wire is an infrared emitter (λ 2.5–0.5 μ). The radiation intensity at these wavelengths in all subsequent stages of the explosion is small.

An example of an oscillogram for λ 1.68 is given in Fig. 1, 5. With the aid of high-speed photorecording it was established that the diameter of the wire before the beginning of the second light pulse is—

* In work (6) it was noted that E_{input} may be less than the energy required for complete evaporation of the wire.

changes only slightly. This makes it possible to estimate the color* temperature of the wire surface, which proves to be equal to 2000° K and unchanged throughout the entire first light pulse. Direct measurements determined the energy carried away by radiation during this stage of the process. Its value is 0.3 J, which is 150 times greater than the radiation energy of an absolutely black body at $T = 2000^\circ$ K having the dimensions of the wire, but amounts to only 0.05% of E_{input} . Since the second, intense light pulse begins $20 \mu\text{s}$ after the end of the first current pulse, it turns out that the energy introduced, approximately equal to the sublimation energy, is not radiated by the wire during $20 \mu\text{s}$, although thermal equilibrium should have been established in a time of the order of 10^{-12} s (5).

It should be noted that even in the case when $E_{\text{input}} = E_{\text{subl}}$, complete evaporation of the wire cannot occur, since part of E_{input} is carried away by radiation during the second light pulse and by the fragments flying apart. An attempt to estimate the amount of energy carried away by the second radiation pulse did not lead to a reliable result. It turned out that the range λ 2200–6000 Å corresponds to the “tail” of the energy-distribution curve in the continuous spectrum of the second flash. The distribution curves were constructed for 5 instants of time: 10; 450; 1000; 5000; 10 000 μs from the beginning of the second flash. None of them coincided with a Planck curve; one can only suppose that the maximum of the radiation intensity lies in the vacuum-ultraviolet region, near 1000 Å, and that its position changes little over the course of the flash.

3. If the value U_{start} is brought up to 2–2.2 kV, the potential difference on the capacitance remaining after the current pulse proves sufficient for the resumption of current through the interelectrode gap. The current may resume immediately after the end of the first pulse (Fig. 1,7) or after some time, called in the literature the current pause (Fig. 1,6). The duration of the current pause, with the controlled experimental conditions unchanged, fluctuates from one experiment to another. Starting from approximately $U_{\text{start}} = 2500$ V, the current pause does not have time to develop, but however large U_{start} may be, the current at the end of the first stage of development of the process falls to some minimum value (Fig. 1,8 and 9). The current after resumption continues until the stored energy has been completely expended; the curve of current variation is a periodically damped curve. Since the current resumes only if U_{res} is not less than some value, the smallest amplitude value that can be obtained is determined by this value U_{res} .

In all cases a correlation is observed between current and radiation: if the current

is sufficiently large, radiation is absent. Even if the current has the smallest possible value under the given experimental conditions, the second light pulse begins at the end of the first half-period of the current (Fig. 1,6). During the first half-period, i.e., for $80 \mu\text{s}$, the intensity of the light radiation is very small. Increasing the duration of the current half-period does not change the course of the process—the radiation intensity remains small now for $115 \mu\text{s}$ (Fig. 1,7 and 8, $C = 1000 \mu\text{F}$, $f = 4300 \text{ Hz}$) and, for $f = 3000 \text{ Hz}$ ($C = 2000 \mu\text{F}$), for $160 \mu\text{s}$.

4. Radiation can appear immediately after the end of the first current pulse if the current pause is sufficiently long. Then, at the moment the current resumes, the radiation intensity drops sharply and remains small until the end of the first half-period of the current (Fig. 1,6). With a sufficiently large amplitude of the second half-period of the current, the light flash arises only at the end of the second half-period (Fig. 1,9, $f = 4300 \text{ Hz}$). The intensity of the second pulse

* The spectral distribution differs so strongly from the energy distribution in the spectrum of an absolutely black body that, strictly speaking, the concept of color temperature in the present case loses its meaning.

of light depends on the amplitude of the current that preceded it—with an increase in the current, the intensity of the flash increases (cf. oscillograms 7, 8, and 9). This indicates that energy, apparently, can accumulate during the time when the radiation intensity is low. In photographs of the spectra of the explosion flash (integral and time-resolved), emission lines of singly and doubly ionized copper atoms are present.

5. The behavior of the IR radiation (recorded by a photoresistor with a germanium filter, $\lambda = 1 \div 3.5 \mu$) after the resumption of the current depends on its magnitude. If the current amplitude after resumption is 2-3 times smaller than the amplitude of the first pulse, the change in the intensity of the IR radiation corresponds to the changes in the current (Fig. 1, 10). Therefore the time-dependence curves of the visible and IR radiations turn out to be in “antiphase” (Fig. 1, 11). If, however, the current amplitude after resumption is equal to or greater than the amplitude of the first pulse, the IR radiation behaves analogously to the visible radiation—during the first half-period of the current its intensity remains low. In the second half-period, when the current approaches its amplitude value, a dip is observed on the intensity curve of the IR radiation (Fig. 1, 12).
6. When the electrical explosion is carried out in a circuit with a relatively high frequency $f = 100\,000 \text{ Hz}$ ($C = 3 \mu\text{F}$, $U = 25 \text{ kV}$), the course of the process remains essentially the same (the presence of two flashes of light, accumulation of energy, delay of radiation). The current in this case ceases in the third half-period (Fig. 1, 13). Radiation does not have time to arise at the moments when the current passes through zero, and the radiation intensity remains low during the entire time the current flows through the wire (Fig. 1, 14). The IR-radiation pulse, as in the preceding case, appears

approximately at the moment of the abrupt fall in the conductivity of the wire (Fig. 1, 15).

The authors express their deep gratitude to Academician B. P. Konstantinov for his interest in this work and for useful discussions.

Received
3 III 1964

REFERENCES

1. Narine, *Phil. Trans. Roy. Soc.*, London, **64**, 79 (1774).
2. *Exploding Wires*, ed. by W. Chase, H. Moore, **1**, N.Y.—London, 1959.
3. *Exploding Wires*, Russ. transl., ed. by Rukhadze, IDL, 1963. Ed. by W. Chase, H. Moore, **2**, *Exploding Wires*, N.Y.—London, 1962.
4. B. V. Izvozchikov, V. K. Ogorodnikov, A. O. Oleks, K. P. Smekalova, I. A. Taksami, L. K. Diikov, Abstracts of reports at the II All-Union Conference on Photoelectric and Optical Phenomena in Semiconductors, Kiev, 1961.
5. V. P. Shabanskii, *ZhETF*, **31**, no. 4, 657 (1956).
6. I. F. Kvartskhava, A. A. Plyutto, V. V. Bondarenko, *ZhETF*, **30**, no. 1, 42 (1956).

Note: Figure translations are in progress. See original paper for figures.

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.