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Abstract. An unknown type of phase transition of a metal from the solid state to a liquefaction one at a temperature T<740 K is established, which is much lower than the melting point of the investigated Ni. This effect we called an electronic ricochet. The transition arises in the ordinary lamp inside its nickel wire due to an electric explosion of the tungsten filament connected to it. The medium of its propagation was quasi free electrons, which removed the ricochet far from the site of the explosion. The ratio of the volume V_d of the formed Ni drops to the volume V_c of the solid conductor from which these droplets increased was V_d/V_c≈0.2. This means that at least 20% of the mass of the solid metallic conductor was subjected to such an unusual phase transition. The result of the action of the electronic ricochet was found in six lamps out of hundreds of tested samples.

1. Introduction
Electronic ricochet is a rare phenomenon [1-3]. It occurs in one of the ~70 lamps, in which the tungsten filament explodes when the lamp is turned on. The examined lamps had a power of 60…150 W, ac voltage 220…240 V. The ricochet of a 75-watt lamp (nominal current I=0.34 A) is able to turn off the circuit breaker, in which the overload current I_{max}=80…160 A, and off time t_{off}=0.01…0.005 seconds. Our data are obtained from the already burned lamps. Therefore, their form illustrates only the result of an electronic ricochet and does not show development in time of this process. However, separate photos of deformed conductors give information about the effect of a ricochet at the intermediate stages of this unusual phenomenon.

2. The description of the experiment
In figure 1 shows an electric incandescent lamp with a power of 60 W. In it two nickel hooks 4 and 7 with a diameter of 0.5 mm are connected in series with a tungsten filament 5 and 6 with a diameter of 30 μm. The diameter of the filament is 30…40 μm in lamps with a power of 60…75 W, 220 V. In more powerful lamps – 50 μm. The filament is twisted into a spiral (figures 1a and 2). Under normal operation, the electric current heats the tungsten filament to a temperature of T_5≈1500 K in section 5 and to T_6=2200…2400 K in section 6.

Also close to the cold nickel hook 1 is usually located the place 5 of explosion of the tungsten spiral in the lamp (figure 1a). Here, the tungsten spiral is pressed into a "massive" nickel hook blades and is well cooled by thermal conductivity. The temperature gradient along the length W of the filament in 5 is 1.4×10^6 K/m [1]. Sometimes the W filament explodes in the contact zone with the molybdenum loop. And very rarely such an explosion leads to an electronic ricochet (figure 1b),
capable of uncovering the blades of the nickel hook-holder. The ratio of the diameters of the hook and the filament is $f_W = 0.5/0.03 \approx 17$.

![Figure 1](image1.png)

**Figure 1.** Exploding wires: a – filament lamp, 1, 2, 4, 7 – nickel hook-holder, 3 – molybdenum loop, 5 – usual place of explosion of tungsten filament, 6 – maximum temperature of tungsten filament; b – electronic ricochet of explosion W filament uncovered Ni hook blades.

3. Result of researches

At the initial stage of the ricochet, Ni bulge 2 grows out of the cold top of the hook (figure 2). Its height is 0.28 mm, that is, more than half the diameter of the hook 7 (figure 1). The bulge is multilayered (figure 2b). During its birth and growth, the temperature of the hook top is less than 740 K, which corresponds to the minimum glow temperature of the metal. The bulge appears due to the explosion of the W filament and its melting in the form of a ball 1. The reaction to the explosion does not extend to the free end of the W spiral (figure 2a).

![Figure 2](image2.png)

**Figure 2.** Initial stage of Ni hook ricochet: a – bulge at the top of the hook, W ball – left, the technological end of the W spiral – on the right, magnification of 1 mm per large division; 1 – a ball that absorbs the metal of the four coils of the W spiral; 2 – traces of layered growth of the nickel bulge; 3 – the top of the bulge (b).
The final stage of the hook’s ricochet takes a fantastic view (figure 3a). The spherical shape and the smooth shiny surface of the droplets indicate their origin from liquid nickel. However, the temperature of the top of the hook (less than 740 K) excludes this possibility.

**Figure 3.** Final stage of the ricochet of the top of the Ni hook: a – magnification of 0.25 mm per large division; b – the diameter of the large ball is 176 μm; diameter of a small ball 30 μm.

The hook body (see below figure 3b) and the Ni ball with 176 μm diameter grown from it are connected by a massive jumper. Judging by its surface, the jumper was deformed from a hard metal. On the right side of the jumper a small ball begins to grow, like a branch parallel to a large ball in the top of the jumper.

In addition to the top of the hook, the ricochet can cover a relatively large part of the surface of its blades (figure 4). In one case, this is a shallow deformation of the hook surface from the side of the exploded W filament (figure 4). In another case, the thermal radiation of the W spiral does not fall at all on the deformed surface (figure 4b).

**Figure 4.** Initial stage of the ricochet on pressed Ni hook blades: a – view from the side of the blown W filament, W ball under the hook top; b – view along the normal to the spiral axis, both magnification of 0.25 mm per large division.
The final stage of the ricochet of the hook blades (figure 5) looks like the deformation of the top of the hook (figure 3a). But, firstly, it covers a large area. Secondly, it extends far from the site of the explosion of the W filament. Thirdly, droplets of deformed metal are arranged in a periodic order, as if they had grown along the boundaries of solid crystals (figure 5a). The average step of this order is $\lambda \approx 0.37 \text{ mm}$. The step size is approximately the same along the length of the hook and along the circumference of its surface.

![Figure 5](image)

**Figure 5.** Final stage of the ricochet of the Ni hook blades: a – magnification of 1 mm per large division; b – the maximum droplet diameter is 152 $\mu\text{m}$ (second from the bottom), its height is 247 $\mu\text{m}$ (from break of jumper to the droplet top).

4. Discussion of results

The low-temperature phase transition of nickel in ordinary lamp can not be called unexpected [2, 4]. There is no doubt that it is caused by a flow of quasi-free electrons in metallic W and Ni conductors. A lamp burned out when the ac was turned on that is when the electrical resistance W filament was minimal. In two cases, the switch was the same and created, possibly, an over voltage in the electrical circuit. These circumstances initiated an electric explosion of a W filament, which causes quantum effects in lamp’s metallic conductors [1].

Let us discuss whether it is possible to melt Ni in such a way that it takes the form shown in figure 5. In this case, only the electric energy entering the hook 7 from an external source (figure 1a) can be a source of heat. Let’s compose the balance of thermal energy $Q$, necessary for melting the volume $V_d$ of the formed droplets, and the electric energy $P=Wt$, which entered the volume $V_c$ of the conductor, from which these droplets grew, $Q=Wt$. Now we can determine the time $t$, during which the electric current could melt the volume $V_c$ and squeeze out the volume of the liquid $V_d$ from it. The time required for such an operation is defined as:

$$t \geq \frac{Q}{P} \geq \frac{c_p \Delta T + \Delta H}{j^2} \frac{V_d}{\sigma \rho V_c}. \quad (1)$$

Here: $c_p=442 \text{ J/kg}$ is the heat capacity of Ni; $\Delta T=1728–300=1428 \text{ K}$ – temperature and $\Delta H=3\times10^5 \text{ J/kg}$ – heat of fusion Ni; $\sigma=1.63\times10^7 \Omega^{-1} \text{ m}^{-1} (T=273 \text{ K})$ and $\rho=8910 \text{ kg/m}^3$ are the electrical conductivity and density of Ni, respectively [5]. The electrical conductivity of Ni decreases with increasing temperature and amounts to $\sigma=3.33\times106 \Omega^{-1} \text{ m}^{-1}$ at $T=773 \text{ K}$, when the metal begins to glow, but it is still very far from melting. The nickel conductor remained dark during the experiments. The current
density \( j \) in the hook is taken equal to the average overload current \( I_{\text{max}}=120 \, \text{A} \) of the fuse in the lamp supply circuit, see above. After substituting these parameters into (1), we obtain

\[
t \geq \left( 0.36 \ldots 0.07 \right) \frac{V_d}{V_c}.
\]  

(2)

Depending on the distance from the site of the W filament explosion (see 5 on figures 1a and 5a), the hook surface is covered with Ni droplets of various sizes. The largest of them grow near the cross-section 5. The further from 5, the drops become smaller. At a distance from the mark 8 to the mark 10, the average volume of the large drop is \( 2.32 \times 10^{-3} \, \text{mm}^3 \), and the small \( 4 \times 10^{-4} \, \text{mm}^3 \). Here, the ratio of the volume of all droplets to the volume of Ni wire lying below them is \( f_i=(V_d/V_c)=0.159/0.78=0.204 \). In the area from mark 10 to mark 13 (\( L=3 \, \text{mm} \)), large drops disappeared. Here, the average droplet volume is \( 3.17 \times 10^{-4} \, \text{mm}^3 \). At a distance \( L=4 \ldots 7 \, \text{mm} \), all the drops disappear. Thus, the appearance and size of droplets are not related to the current density \( j=\text{const} \) in the hook 7, but to the removal of \( L \) from the place of the electric explosion W.

According to (2), the required melting time \( t \geq 0.36 f_i \geq 0.07 \, \text{s} \) at the closest hook segment to the explosion. This value is much longer than the automatic tripping \( t_{\text{off}}=0.01 \, \text{s} \). This means the hook will stop heating long before Ni melts and there is nothing to heat the solid metal.

Consequently, for the deformation shown in figure 5, nickel should have become fluid within the solid metal, and had to go to the surface of the hook for a different reason than the usual melting [6, 7]. This reason we associate with the quantum phenomena arising in a metallic conductor with a sharp breakage of the electric current in it [1]. The result of the ricochet is a deep deformation of the metal, due to the extensive decay of crystalline nickel, as if the crystal had passed through a state of liquid metal [8, 9].

5. Conclusion

An unknown type of phase transition of a metallic (nickel) conductor from a solid state to a liquefied state at a temperature below the melting point is established. The final structure of the metal is not called a liquid, because the large difference between the transition temperature (about 740 K and below) and the melting point of nickel (1728 K) contradicts the generally accepted word “melting”. The considered phase transition is a quantum effect caused by the reaction of crystalline nickel to an electric explosion in a series-connected electrical link. This effect we called an electronic ricochet.

References

[1] Marakhtanov M K and Marakhtanov A M 2013 Quantum macroelectronics: experiment and theory (Moscow: Krasand) [in Russian]
[2] Marakhtanov M K and Marakhtanov A M 2010 Unexpected quantum effects in well-known electrical processes: experiment and theory (Moscow: Krasand) [in Russian]
[3] Marakhtanov M K 2018 Unknown properties of metal BIT’s Annual World Congress of Smart Materials-2018 (Osaka, Japan) 433 p
[4] Duhopelnikov D V, Bulychev V S and Vorobyev E V 2018 Magnetron discharge with liquid-phase cathode Herald of the BMSTU, Series Natural Sciences 1 95 [in Russian]
[5] Grigoryev I S and Meilihov E Z 1991 The physical magnitudes (Moscow: the Energoatomizdat), in Russian
[6] Belodedov M V and Ichkitize L P 2017 Journal of Siberian Federal University-Mathematics and Physics 10(2) 239 [in Russian]
[7] Makeev M O, Ivanov Y A, Meshkov S A, Sinyakin V Y and Ivanov A I 2015 5th International Workshop on Computer Science and Engineering: Information Processing and Control Engineering, WCSE 2015-IPCE
[8] Makarov A M, Lunyova L A and Makarov K A 2016 Herald of the BMSTU, Series Natural Sciences 1 45 [in Russian]
[9] Fedorov S V, Selivanov V V and Veldanov V A 2017 Alta Astronautica 135 44