# ELECTRONS EMISSION OF FROM COLD CATHODES IN A GAS DISCHARGE AND ITS INFLUENCE ON CURRENT-VOLTAGE CHARACTERISTICS

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The work was supported by the Russian Science Foundation under grant 19-19-00069

The mechanisms of electron emission in a gas discharge are still the subject of debate. The author's concept is that emission properties are determined by a modified surface layer of cold cathodes. The modification consists in its saturation with particles of the working gas to a density comparable to the packing density of particles in a liquid working gas [O. V. Dudka, et al. *Tech. Phys. Lett*. **39**, 960 (2013)]. As a result of the modification under the influence of fast heavy particles accelerated in the region of the cathodic potential drop and VUV resonance photons, various emission mechanisms are realized upon discharge in noble gases and molecular gases. In turn, the emission mechanism in light and heavy noble gases also varies.

In helium and neon, fast atoms $A_f$ and ions produce mainly the excitation of embedded atoms. Excited atoms in the Penning process ionize the atoms of the matrix, which leads to the appearance of a fast electron emitted from the cathode (Auger effect):

$$A + h\nu \longrightarrow A^{*}$$
$$A^{*} + M \longrightarrow A + M^{+*} + e$$

Heavy noble gases with high efficiency produce both excitation with the subsequent Auger effect, and ionization with the release of an electron:

$$A_f + M \longrightarrow Af + M^{+*} + e$$
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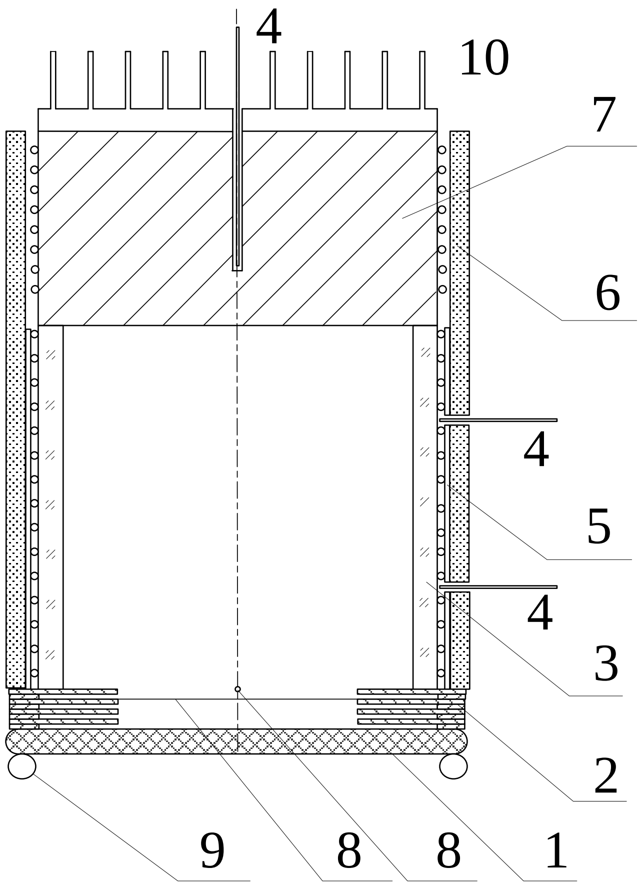
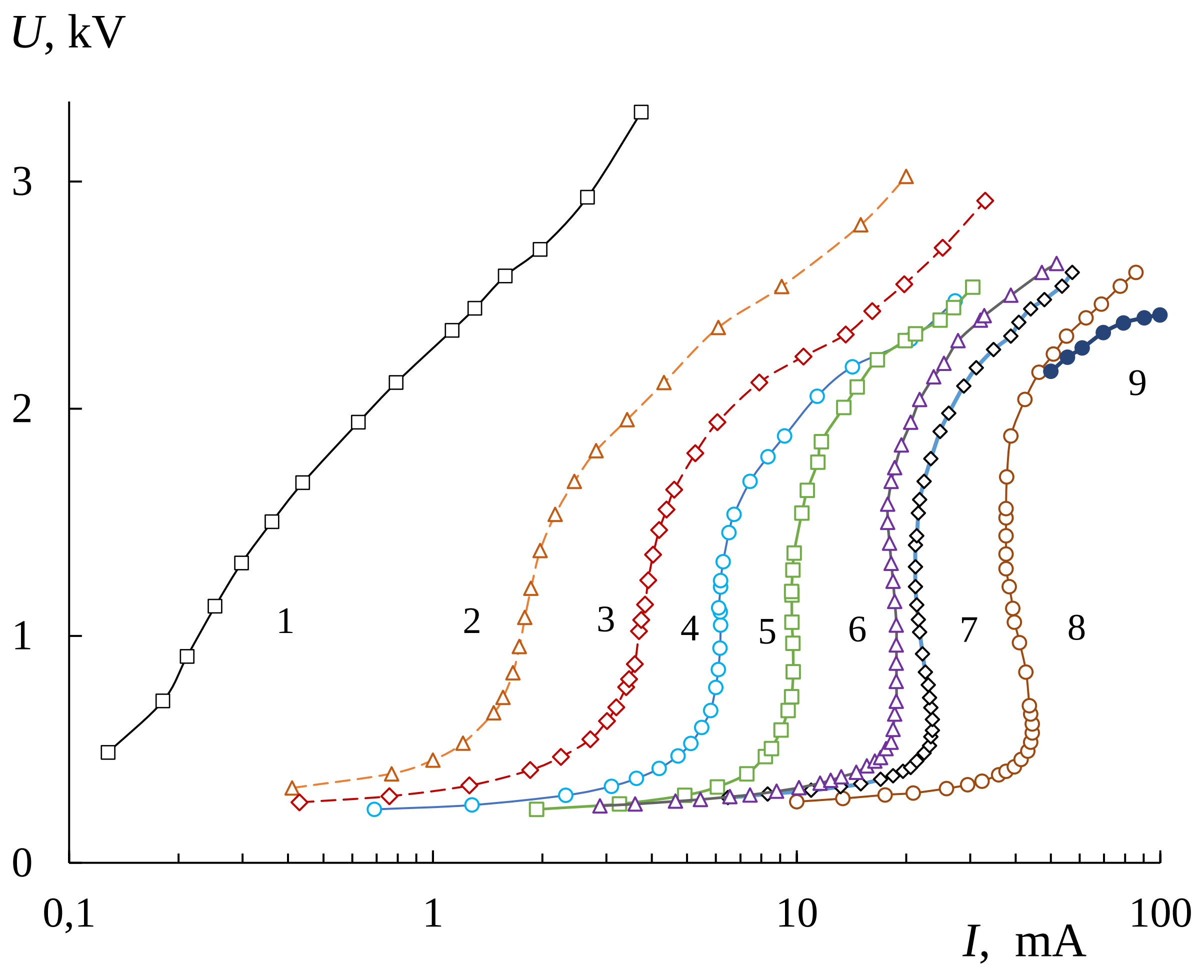


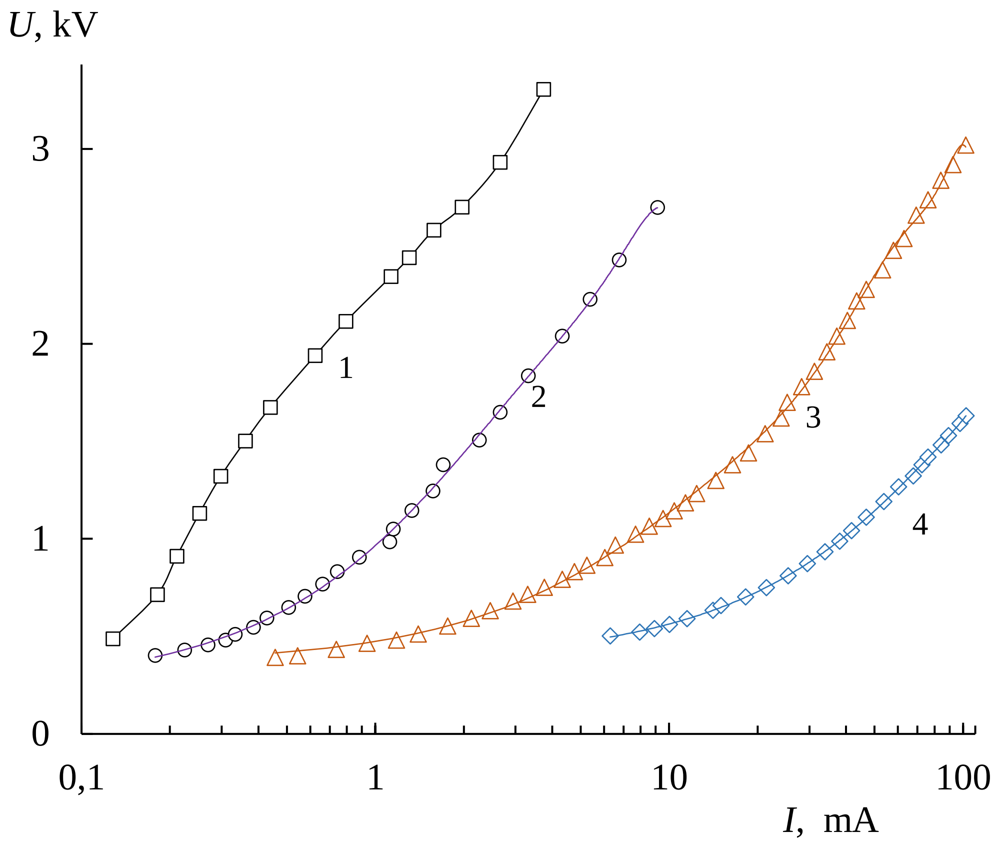

Design of the gas-discharge cell: (1) *Ti* - cathode *d*=12mm, (2) insulator, (3) drift tube *L*=20mm, (4) thermocouple, (5) copperplates, (6) heat insulator, (7) anode (collector), (8) probes, (9) water cooling system, and (10) heat radiator.

This cell makes it possible to measure current-voltage characteristics and electron beam generation efficiency



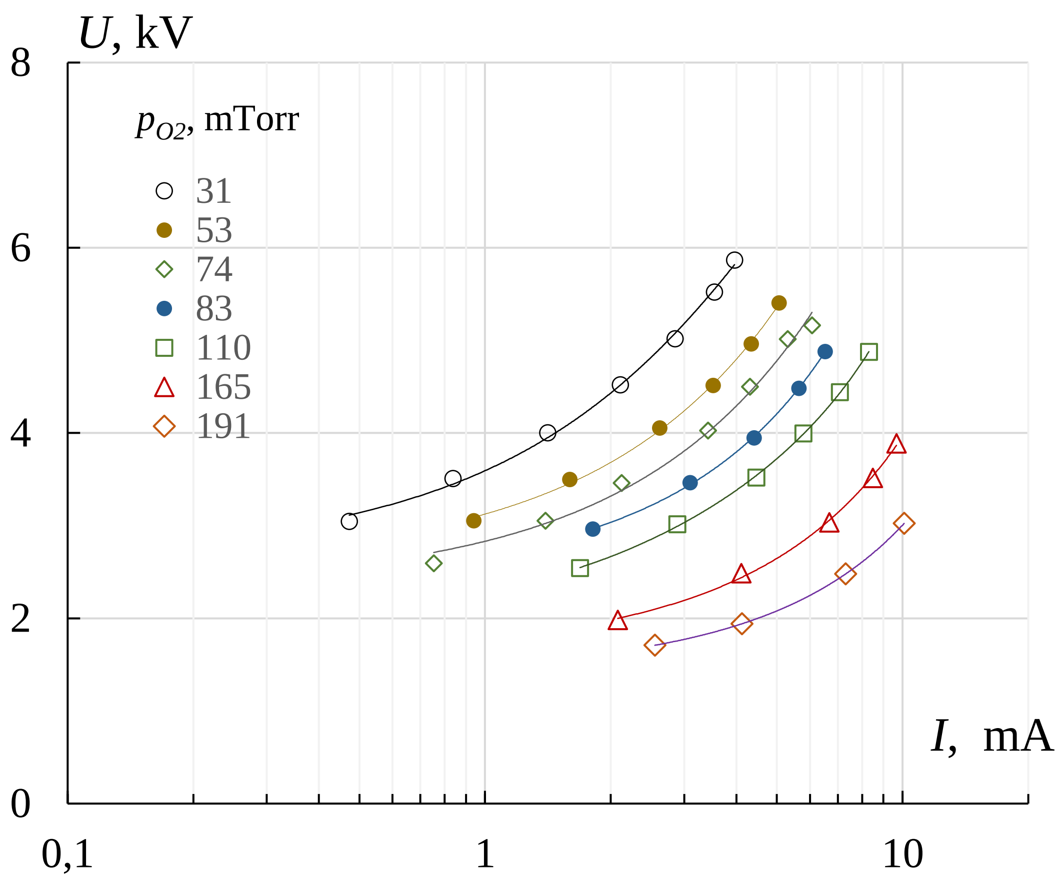

Current-voltage characteristics of continuous (1–8) and quasi-continuous (9) discharges in *He* at $p_{He}$ = (1) 4, (2) 6, (3) 8, (4)10, (5) 12.5, (6) 16, (7) 20, and (8, 9) 28 Torr.

Absolute value of the current density $j$ at $p_{He}$=28 Torr and $U$=2.4kV is ~ 275 times lower than that calculated for $j=2.5\times10^{-12} p_{He}^{2} U^{3}$ [A/cm$^2$], where $p_{He}$ [Torr] - pressure of helium; $U$ [V] is the cathodic potential drop [K. A. Klimenko et al. Sov. Phys. Tech. Phys. **35**, 1084 (1990).] .

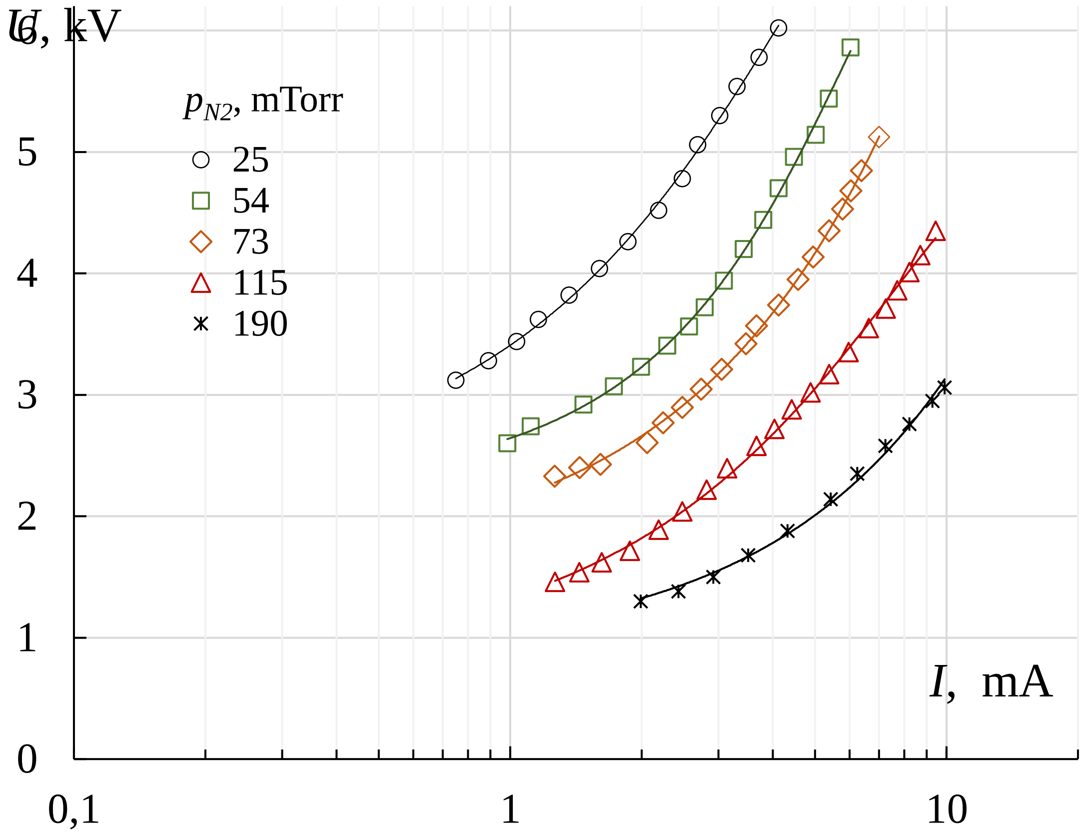



Current-voltage characteristics of continuous discharges in pure *He* (1) and *He*–$O_2$ mixtures (2–4) at $p_{He}$ = (1–4) 4 Torr and $p_{O2}$ = (2) 8, (3) 25, and (4) 65 mTorr.

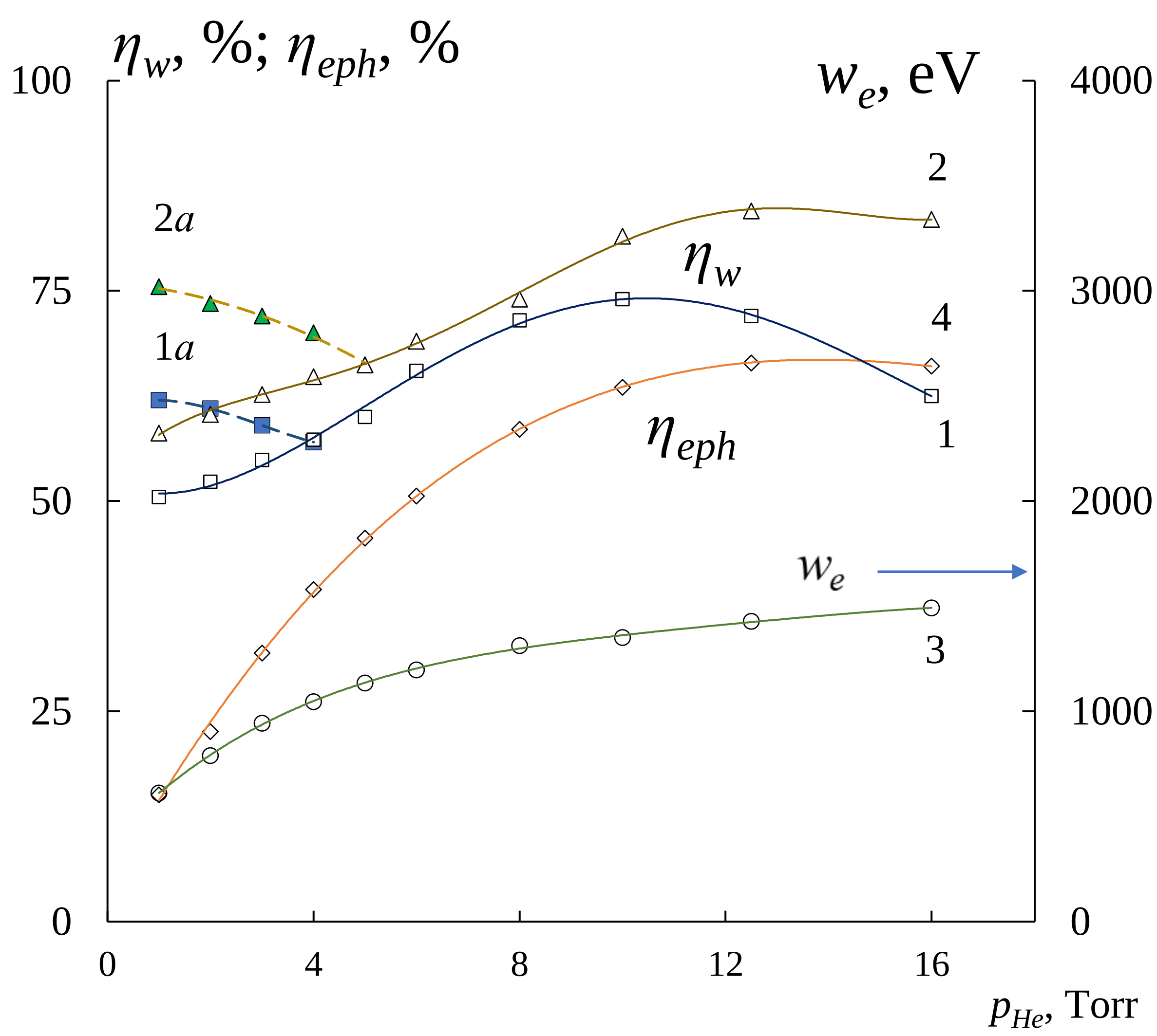
Only at O2 admixture ~ 1.6% current-voltage characteristics became comparable with relation $j=2.5\times10^{-12} p_{He}^2 U^3$ [A/cm$^2$].




Current-voltage characteristics of continuous discharges in $O_2$ at $p_{O2}$ = 31; 53; 74; 83; 110; 165 and 191 mTorr.




Current-voltage characteristics of continuous discharges in $N_2$ at $p_{N2}$ = 25; 54; 73; 115 and 190 mTorr.




In pure *He* photoemission prevails

EB generation efficiency $\eta_w$ in pure *He* (*1,2*) and *He–O*$_2$ mixtures (*1a,2a*) at $p_{O2}$=15 mTorr as a function of the helium pressure $p_{He}$.

Curve 3 shows the energy $w_e$ which dissipated by one fast electron in the drift space,

Curve 4 shows the fraction of photoelectric current $\eta_{eph}$ in the discharge current at $U$ = 2.5 (*1,1a,3,4*) and 3.5 kV. (*2,2a*)

$$n_{eph}=\eta_{ex}w_e\gamma_{ph}R/h\nu$$

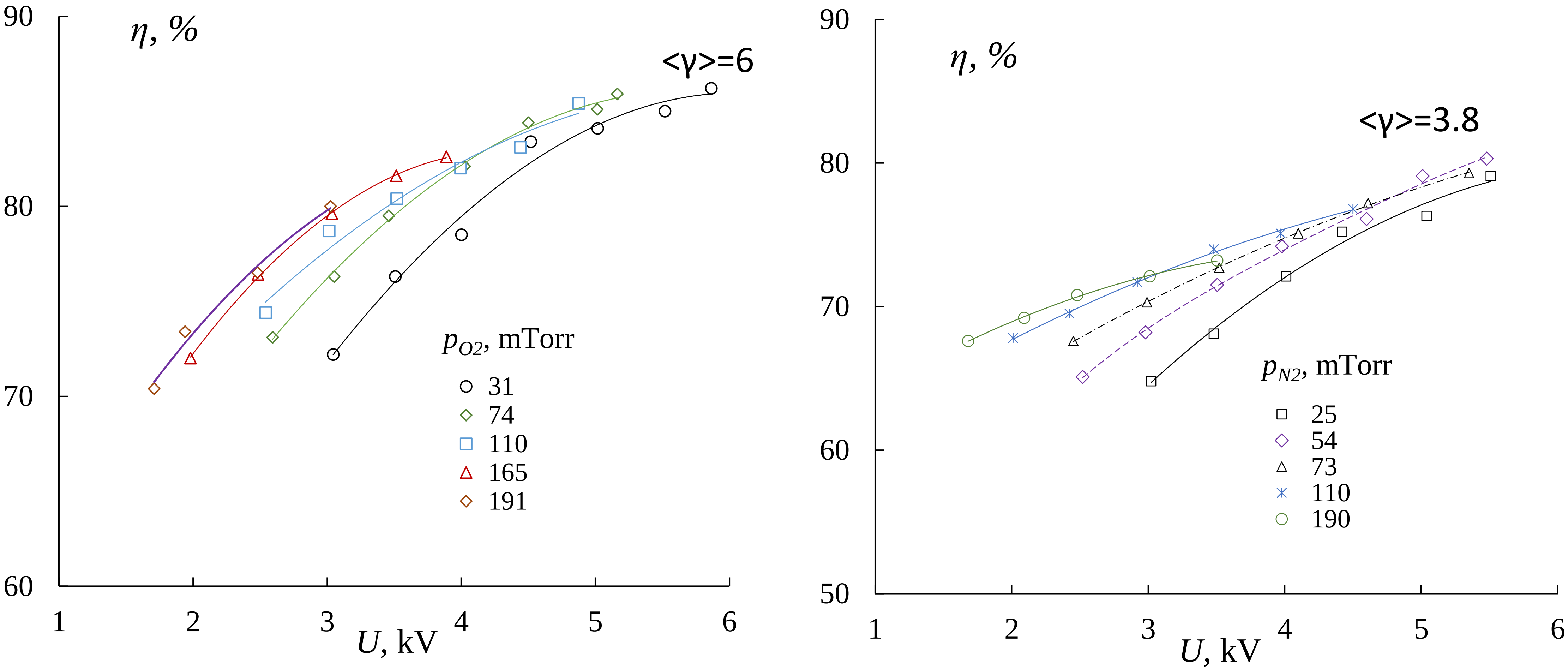
$n_{eph}$ the number of photoelectrons emitted as a result of deceleration of EB - electron in the DS

$\eta_{ex}$=0.3 the fraction of the EB energy contributed to excite the resonance states

$R$=0.17 the fraction of the vacuum UV radiation intercepted by cathode

$\gamma_{ph}$ =0.3 the photoemission coefficient

# EB generation efficiency η*w* in $O_2$ (*a*) and $N_2$ (*b*) as functions of the voltage *U*




$$\eta = \frac{\langle\gamma\rangle}{\langle\gamma\rangle + 1}$$

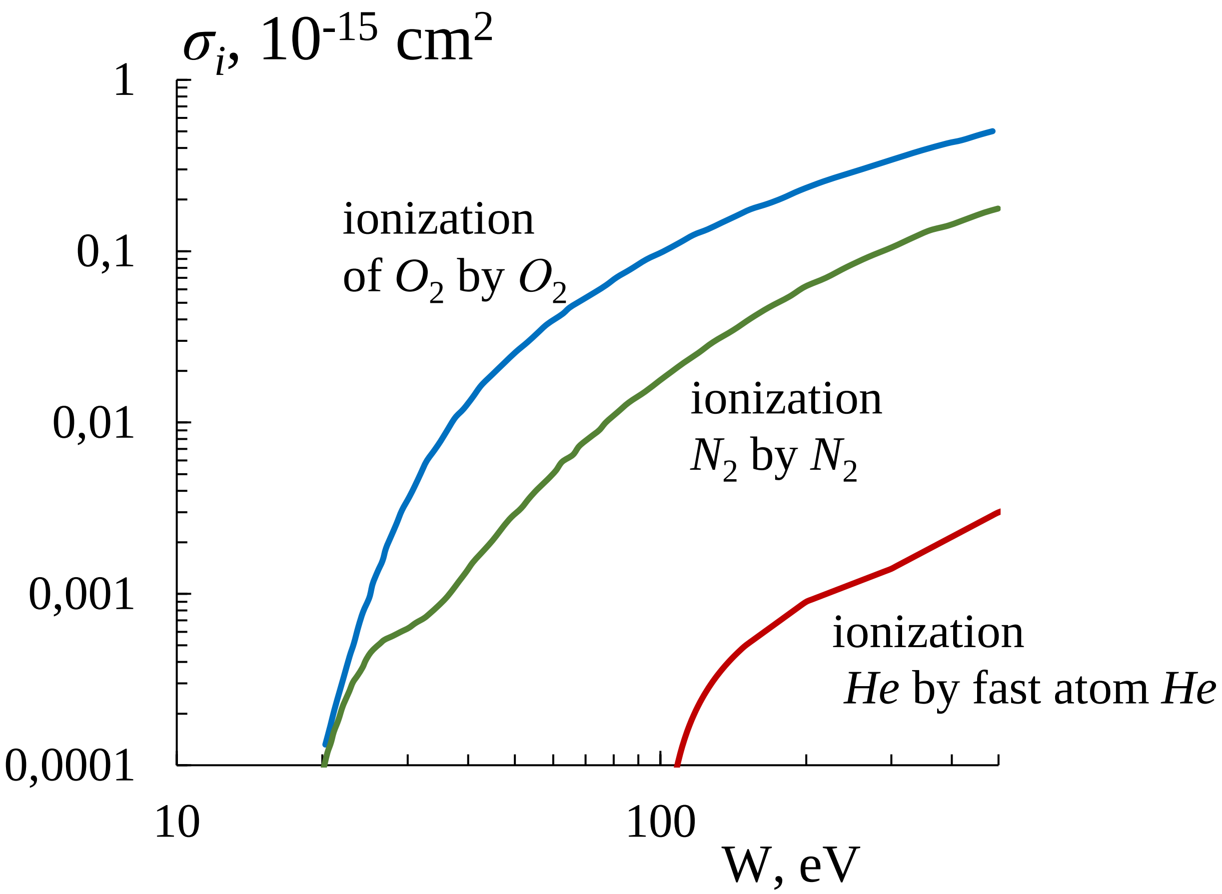
$\gamma_i$ – emissive coefficient under action of molecular ions,

$\sum \gamma_m$ - emissive coefficient due to fast molecules.

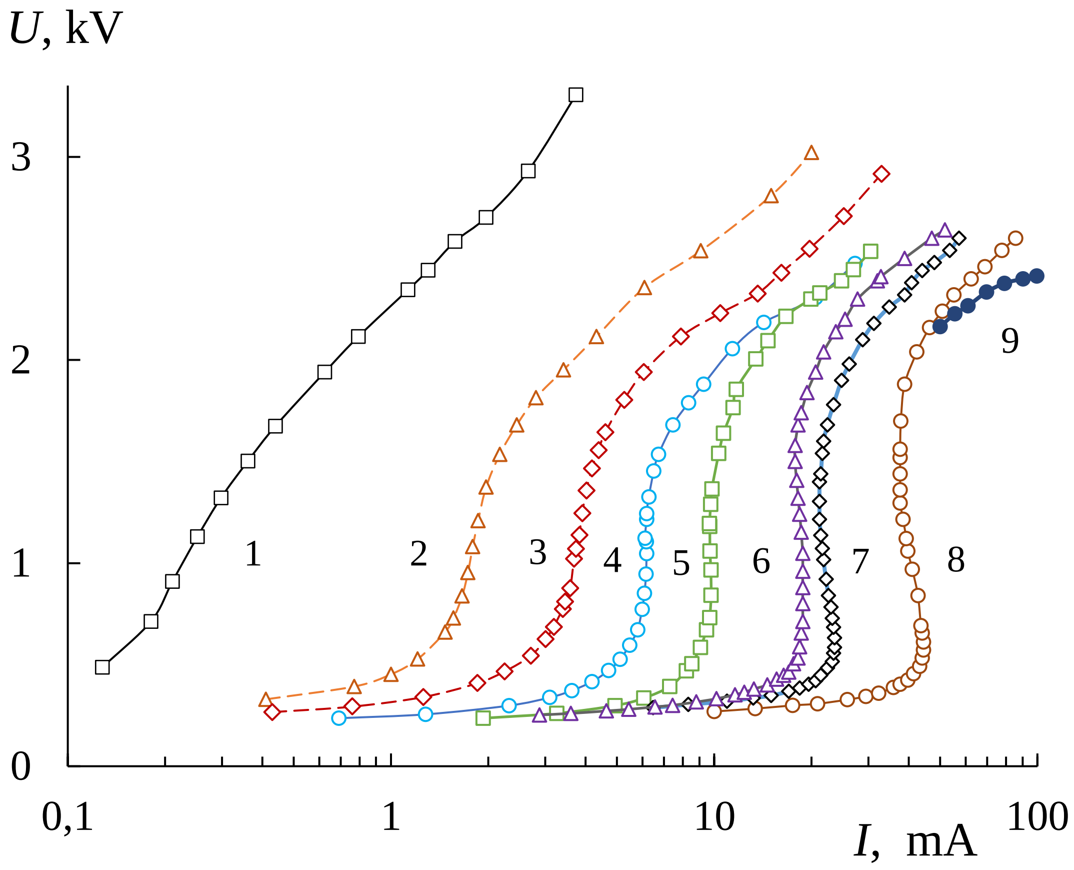
$$\langle\gamma\rangle = \gamma_i + \sum \gamma_m$$

In $O_2$ and $N_2$ emission under bombardment by heavy particles prevails

# Discussion



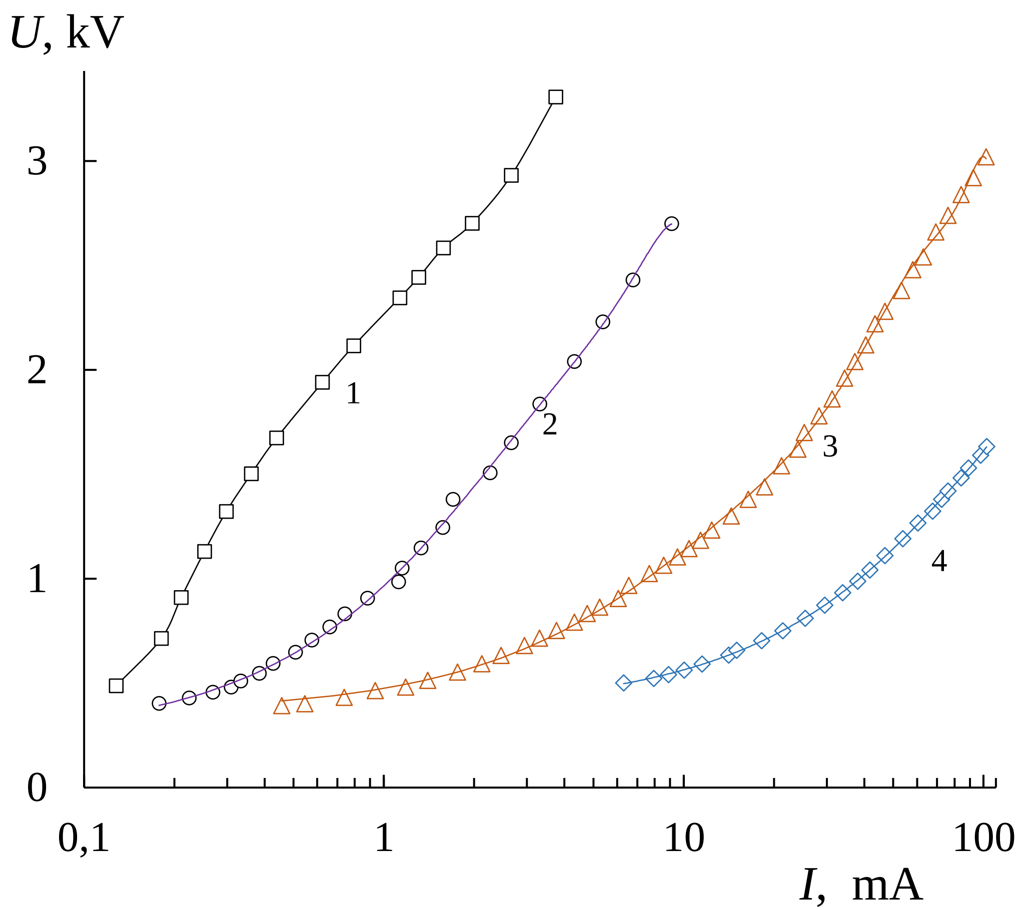

Cross sections for ionization of atoms by fast atoms as functions of the colliding particles energy




CVC of discharge in *He* at $p_{He}$ = (1) 4, (2) 6, (3) 8, (4)10, (5) 12.5, (6) 16, (7) 20, and (8, 9) 28 Torr.

w=500eV, $\gamma=4.1\times10^{-1}$ for $N_2$ [Utterback, 1961]

$\gamma=3\times10^{-3}$ for He [Lakits, 1990]




Current-voltage characteristics of continuous discharges in pure *He* (1) and *He*–$O_2$ mixtures (2–4) at $p_{He}$ = (1–4) 4 Torr and $p_{O2}$ = (2) 8, (3) 25, and (4) 65 mTorr.

$He^+ + O_2 \rightarrow O_2^+ + He$. Oxygen ions are accelerated in the cathode fall region CFR up to energy closely to $w_i = eU_c$. $O_2^+$ has much higher $\gamma$ in comparison with $He^+$. In addition $O_2^+$ effectively ionizes *He* in the *CFR*

# Conclusion

The experimental studies of gas discharges in pure He, $O_2$, $N_2$, and He–O2(N2) have shown that the purity of He has a strong effect on the discharge characteristics. Under insufficiently pure (in fact, uncontrolled) conditions of technical vacuum, different shapes of the CVC can take place. Therefore, the mechanisms sustaining the discharge and responsible for EB generation cannot be reliably analyzed under these conditions.

In pure helium $p > 4$Torr and $U > 1.5$ kV, the current caused by cathode photoillumination from the space between the cathode and the anode, where most energy of the electrons accelerated in the cathode sheath is dissipated. Under these conditions, the energy efficiency of EB generation reaches a high value (up to 85%) at a low cathode sputtering and the shape of the CVC differs substantially from those previously observed by other authors.

In pure $O_2$ and $N_2$, kinetic emission is the main source of electrons in the discharge. Due to the high value of $\langle \gamma \rangle$ under bombardment by heavy particles highly efficient EB generation was achieved in $O_2$ and $N_2$, with efficiencies of 86 and 80%, respectively. However, the sputtering of the cathode under these conditions is much stronger than in a discharge in pure He.

*Thank you for the attention*