RANGES OF LOW-ENERGY ELECTRONS FOR DIFFERENT ANGLES OF ENTRY INTO A MASSIVE GAS ABSORBER

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The problem of the connection between the initial parameters of an electron beam and its integral (effective) range in an absorbing medium has now been investigated in considerable detail, both theoretically and experimentally, for electrons with energies $E > 1$ keV [1-3]. The data on ranges for electrons with energies of less than 1 keV are inadequate and are not reliable enough to consider the connection between the energy and range as established for $E < 1$ keV [3-9]. Here attention must be drawn to the fact that the dependences between the range and the initial energy obtained in [3-9] pertain only to electron beams with velocity vectors perpendicular to the surface of the absorber.

The aim of the present report is to investigate the influence of the oblique incidence of a primary electron beam on its integral range in a gaseous medium. The transfer process was modeled on the basis of the method of statistical trials within the framework of the scheme of "individual" collisions in a three-component gas mixture (O, O_2, N_2) in the presence of a dipole magnetic field B. A detailed description of the transfer algorithm and the model medium was presented in [10]. Since the motion of the electrons took place in a magnetic field, the angle of entry of the beam into the absorber is the pitch angle (the angle between the velocity vector and the direction of the magnetic field). Here perpendicular incidence of the electron beam corresponds to a pitch angle of zero. The calculations were made for electron beams with initial pitch angles lying in the interval of 0-70°. The trajectories were modeled on an M-40-30 computer in an amount of 6000, which assured the obtainment of a statistical error of no more than 10% at a confidence coefficient of 0.95.

To find the ranges we calculated and analyzed curves of the transmission or, as they are sometimes called, the coefficients of transmission T_N with respect to number of particles,

$$T_N(E_0, \theta_0, z) = n(E_0, \theta_0, z)/N,$$

where n(z) is the number of particles of the primary beam of intensity N whose transverse depth of penetration (along the normal to the surface of the absorber) is equal to a mass z; E_0 and θ_0 are the initial energy and pitch angle of an electron.

Examples of curves of T_N calculated for $E_0 = 0.1$ and 1.0 keV and $\theta_0 = 0$, 20, 40, 60, and 70° (curves 1-5, respectively) are presented in Fig. 1, a and b. The main feature of the evolution of the dependence $T = T_N(z)$ with an increase in θ_0 is a systematic breakdown of the exponential character of this dependence, which was well observed for electron beams with $\theta_0 = 0$ (perpendicular incidence). And whereas a section of the curve of $T_N(z)$ close to straight could be distinguished quite clearly for $\theta_0 = 0$, with an increase in θ_0 such distinguishing becomes impossible. Consequently, the concept that has come to be adopted as the extrapolated range also becomes indeterminate. Only the concepts of the normal and average ranges R_e and $\overline{R}$ remain physically determinate in the entire interval of initial angles of entry of electrons into the absorber. Remember that the normal range R_e is understood as the amount of mass of material after passing through which the intensity of the primary beam decreases by e times. The average range $\overline{R}$ is understood as the mathematical expectation of the distribution density of ranges of the primary electrons:

$$\overline{R} = \int_0^\infty z \frac{\partial T_N(z)}{\partial z} dz \Bigg/ \int_0^\infty \frac{\partial T_N(z)}{\partial z} dz.$$

Before calculating R_e and $\overline{R}$, however, let us consider peculiarities in the behavior of $T_N(z)$ whose causes are effects of reflection of electrons by the magnetic field due to the longitudinal field gradient. For $\theta_0 > 60°$ the latter leads to the fact that some of the electrons, without having undergone a single collision, are reflected by the magnetic field even in the first mean free path. Then a region of a sharp decrease in the intensity of the

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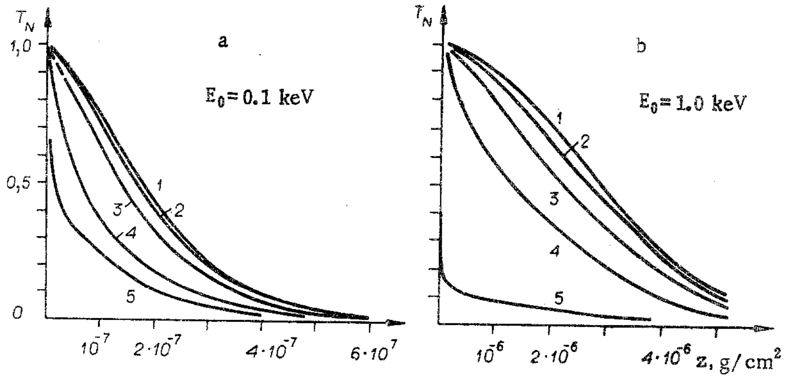

Fig. 1

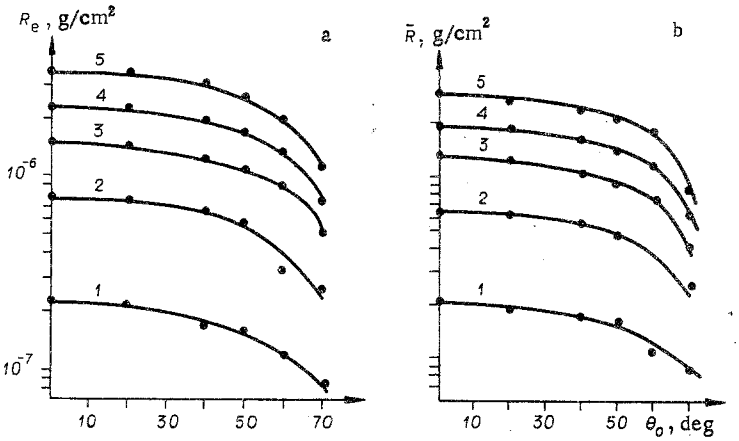

Fig. 2

TABLE 1

E_0, keV \ θ_0	0	20	40	50	60	70
0,1	2,08(—7)*	1,90(—7)	1,73(—7)	1,53(—7)	1,13(—7)	0,895
0,3	6,72(—7)	6,32(—7)	5,53(—7)	4,86(—7)	3,18(—7)	2,48(—7)
0,5	1,35(—6)	1,24(—6)	1,06(—6)	0,932(—6)	0,748(—6)	0,41(—6)
0,7	1,94(—6)	1,89(—6)	1,61(—6)	1,43(—6)	1,18(—6)	0,621
1,0	2,94(—6)	2,73(—6)	2,41(—6)	2,18(—6)	1,76(—6)	0,851

Note. *2.08(−7) = $2.08\cdot10^{-7}$.

TABLE 2

E_0, keV \ θ_0	0	20	40	50	60	70
0,1	2,3(—7)	2,12(—7)	1,72(—7)	1,52(—7)	1,15(—7)	8,40(—7)
0,3	7,85(—7)	7,40(—7)	6,45(—7)	5,65(—7)	3,25(—7)	2,55(—7)
0,5	1,5(—6)	1,40(—6)	1,21(—6)	1,06(—6)	8,85(—7)	5,1(—7)
0,7	2,32(—6)	2,24(—6)	1,91(—6)	1,65(—6)	1,30(—6)	7,22(—7)
1,0	3,47(—6)	3,30(—6)	2,90(—6)	2,5 (—6)	1,95(—6)	1,09(—6)

primary beam lying within limits of $z \le z_1$ is formed on the curves of $T_N(z)$ (z_1 is the mass of absorber material passed through by an electron before the first collision). Therefore, in calculating the normal ranges we will determine them at the level of attenuation of $T_N(z)$ by e times relative to the value of $T_N(z)$ at $z = z_1$,

$$T_N(z_1) = 1 - F(\theta_0),$$

where $F(\theta_0)$ is the fraction of electrons of the unit primary beam which were reflected by the magnetic field before the first collision. Such an approach to the determination of R_e in the case of the presence of a nonuniform magnetic field permits this quantity to be retained as the characteristic energy of the primary electron beam. The calculated R_e and $\overline{R}$ for $E_0 = 0.1$, 0.3, 0.5, 0.7, and 1.0 keV (curves 1-5, respectively) as functions of the initial pitch angles are presented in Fig. 2, a and b, from which it is seen that R_e and $\overline{R}$ undergo a smooth decrease with an increase in the initial angle of entry of the beam into the absorber at all initial energies. The numerical values of the calculated normal and average ranges are presented in Tables 1 and 2 (the values are given in grams per square centimeter).

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LITERATURE CITED

1. L. Katz and A. S. Penfold, "Range—energy relation for electrons and the determination of β-ray and end-point energies by absorption," Rev. Mod. Phys., 24, 28 (1952).
2. S. P. Khare and Y. P. Varshi, "Modified Flammersfeld range energy relation for electrons," Ann. Phys., 7, 220 (1961).
3. J. A. Gledhill, "The range—energy relation for 0.1-500-keV electrons," J. Phys. A, 6, 1420 (1973).
4. G. Anslow, "The total ionization produced in air by electrons of various energies," Phys. Rev., 25, 484 (1925).
5. J. F. Lehmann and T. H. Osgood, "The total ionization due to absorption in air of slow cathode rays," Proc. R. Soc., 115, 609 (1927).
6. J. R. Young, "Penetration of electrons in aluminum oxide films," Phys. Rev., 103, 292 (1956).
7. P. L. Hartman, "New measurements of the fluorescence efficiency of air under electron bombardment," Planet. Space Sci., 16, 1325 (1968).
8. A. Ya. Vyatskii and V. Yu. Khramov, "Laws of interaction of medium-energy electrons with massive solids," Fiz. Tverd. Tela, 17, 3432 (1975).
9. V. E. Ivanov and N. K. Osipov, "Laws of interaction of low-energy electrons with massive gas absorbers," Zh. Prikl. Mekh. Tekh. Fiz., No. 1 (1981).
10. V. E. Ivanov, N. K. Osipov, G. V. Starkov, and L. K. Khvostenko, "The Monte Carlo method in problems of the transfer of low-energy ($E < 1$ keV) electrons in the atmosphere," in: Auroras [in Russian], Nauka, Moscow (1979).

INFLUENCE OF THE CATHODE LAYER ON THE VOLT—AMPERE CHARACTERISTICS OF A DISCHARGE EXCITED BY AN ELECTRON BEAM

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The volumetric discharge with preionization of the gas by an electron beam has found wide application in the creation of powerful laser systems, since it can provide the excitation of large volumes of gas at a pressure $p \approx 1$ atm [1, 2]. However, the physical processes determining the basic laws of energy absorption have clearly been inadequately investigated, and this pertains especially to the electrode layers of the discharge. The importance of studying the cathode and anode potential drops is due to their decisive role in maintaining the current in the discharge at the level assigned by the external source and by the conductivity of the gas of the discharge gap [3], as well as by the influence on the stability of the volumetric discharge [4].

Numerical modeling of the cathode layer (see [5-7]) has been limited to the drift approximation and does not allow for many processes — photoionization, a change in the rate of impact ionization at a high density of absorbed energy, cascade processes, etc. — which can significantly affect its actual parameters.

In the present report the electron concentration n is measured for the first time by the interferometric method, the volt—ampere characteristics (VAC) of the discharge are investigated, and the cathode potential drop is determined as a function of j_c/p^2 in a powerful volumetric discharge at $p = 0.25$-1 atm of nitrogen (j_c is the discharge current density at the cathode).

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