type, can lead to anomalously large diffusion with a coefficient of the order of magnitude of that for Bohm diffusion. [1]

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A MECHANISM ENSURING LEVEL POPULATION INVERSION IN CO_2 LASERS

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Patel [1] has established that the main factor ensuring population inversion of the upper laser level 00^01 of the CO_2 molecules in a CO_2-N_2 laser is resonant energy transfer from the N_2 molecules in the first vibrational level.

His paper, however, does not consider at all the main process that ensures the large population of the first vibrational level of N_2. It was observed recently that the generated power in pure CO_2 can be appreciable. Furthermore, addition of He to a CO_2-N_2 mixture [2] or to pure CO_2 [3] increases the generated power by a factor 5 - 10.

All these facts, which have not yet been explained, can be interpreted in a most natural fashion by using the results of Schulz [4] and Swift [5]. Schulz investigated experimentally inelastic collisions of electrons with N_2 and CO molecules and established that the corresponding effective cross sections have a resonant character and reach a maximum at electron energies 2.3 eV ($\sigma(e, N_2) = 3 \times 10^{-16}$ cm^2) and 1.7 eV ($\sigma(e, CO) = 8 \times 10^{-16}$ cm^2). His results, shown in Figs. 1 and 2, demonstrate that the absolute values of the total cross sections, with allowance for the excitation of the vibrational levels up to the eighth, are very high at electron energies from 1.7 to 3.5 eV in the case of N_2 and from 1.0 to 3.0 eV in the case of CO.

Figure 3 shows the electron energy distribution in a glow-discharge plasma in N_2, obtained by Swift. We see that the electron distribution is clearly not Maxwellian, with a maximum at 1.5 - 2 eV, and that with increasing pressure the maximum shifts toward ower energies and the number of fast electrons is greatly reduced. This result agrees with Schulz's conclusions, since the decrease in the number of fast electrons is due to resonant interaction between the electrons and the N_2.

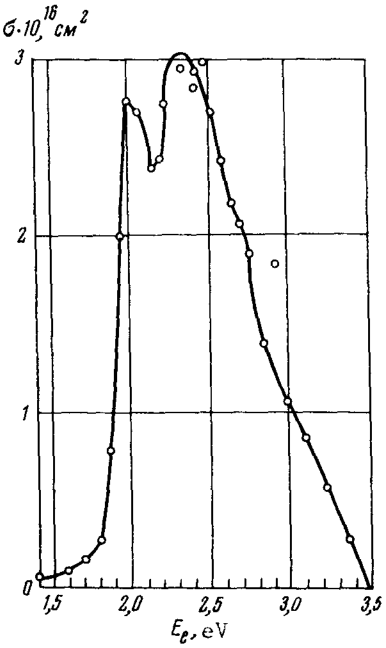

Fig. 1. Total vibrational effective cross section for inelastic collisions between electrons and N_2 molecules vs. electron energy (summation over v = 1 - 8, where v is the vibrational quantum number).

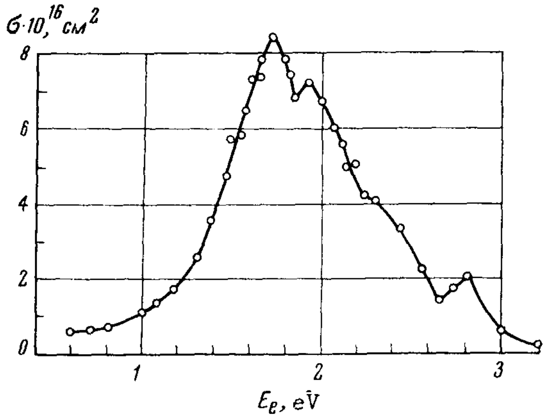

Fig. 2. Effective cross section of inelastic collisions of electrons with CO molecules vs. electron energy (summation over v = 1 - 8).

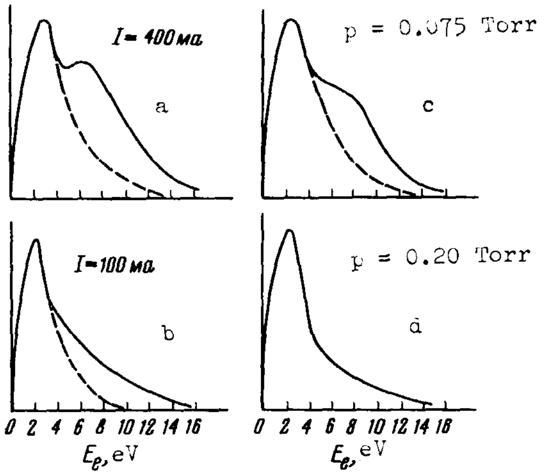

Fig. 3. Energy distribution function (in arbitrary units) of the electrons in the positive column of a glow discharge in N_2: a, b - p = 0.075 Torr, c, d - I = 300 mA.

Proceeding now to the CO_2-N_2 laser, which is usually operated at N_2 pressures higher than used in Swift's experiments, we can assume with sufficient assurance that an increase in the pressure of N_2 to 1 Torr and the addition of CO_2 gas, which has a lower ionization potential, can only reduce the average electron energy. Thus, the average electron energy in the discharge, under conditions close to those prevailing in a CO_2-N_2 laser, will no exceed 1.5 - 2 eV. This in turn denotes, when account is taken of the large value of $\sigma(e, N_2)$, that the main cause of the appreciable concentrations of N_2 in the excited vibrational states is direct electron excitation. We believe, in opposition to Patel, that any vibrational quantum of N_2, not only the first, can go over to the CO_2 molecule. This can occur either directly or via the intermediate process

$$\overset{*}{N_2}(v) + \overset{*}{N_2}(v') \rightarrow \overset{*}{N_2}(v - 1) + \overset{*}{N_2}(v' + 1),$$

which leads, in final analysis, to predominant population of the first vibrational level. The indicated transitions have a high probability, at least up to values of the vibrational quantum number $v \approx 4$ (see, e.g., [6]), for in these cases the anaharmonicity does not yet lead to $\Delta E_{N_2CO_2}$ larger than kT. The possibility that even the high vibrational levels of N_2 can effectively excite the upper laser level of CO_2 explains the large efficiencies and powers of the laser with the CO_2 and N_2 mixture.

To explain the lasing mechanism of a pure-CO_2 laser, it must be borne in mind that owing to the high dissociation energy of the CO_2 (2.8 eV) the electric discharge produces an appreciable number of CO molecules [7]. Taking into account the large excitation cross section of the vibrational levels of CO by electron impact, and also the presence of resonance between the vibrational levels of CO and the 00^01 level of CO_2 ($\Delta E \approx 170$ cm^{-1}), we can propose that the role played by N_2 in the CO_2-N_2 mixture is played by CO in the CO_2-CO mixture. The lower lasing efficiency of pure CO (actually, a CO_2-CO mixture) is also understandable, since $\Delta E_{CO_2,CO} > \Delta E_{CO_2,N_2}$.

The increase in lasing power following addition of He to the CO_2-N_2 mixture or to CO_2 also finds a natural explanation. In fact, He is a gas having the highest ionization potential and the highest gas-discharge electron temperature. Thus, in agreement with the Schottky diffusion theory (see, e.g. [8]), the electron temperature is 22,000°K at a He pressure of 10 Torr in a tube of 2.5 cm diameter, in good agreement with recent probe measurements by Yu. B. Golubovskii and Yu. M. Kagan (private communication). It must therefore be assumed that addition of He to CO_2 or to a CO_2-N_2 mixture leads to an increase in the average electron energy, up to values close to the energies corresponding to the maximum cross sections $\sigma(e, CO)$ and $\sigma(e, N_2)$. An "equalization" of the distribution function, i.e., compensation of the electrons knocked out of the discharge by resonant interaction with the N_2 and CO, is also possible.

In conclusion we note that addition of He to CO_2 or to a CO_2-N_2 mixture not only leads to an increase in the population of the upper laser level, but also to a decrease in the population of the lower laser level. This fact is confirmed by the experimentally observed decrease in the intensity of spontaneous emission from the lower laser level of CO_2 upon addition of He to a CO_2-N_2 mixture. [9]

Thus, the hypothesis of electron excitation of the vibrational levels of CO and N_2, which is well founded, allows us to explain from a unified point of view a large aggregate of experimental facts concerning the operation of CO_2 lasers.

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POSSIBILITY OF IDENTIFYING THE LINES OF THE QUARK-ATOM Mg q II AND Hq IN THE SPECTRUM OF THE SUN

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The possible existence of quarks, stable particles with fractional electric charges $\pm 1/3$ or $\pm 2/3$, has been recently under discussion. It was shown earlier [1] that 10^{-9} - 10^{-10} quarks per nucleon 1) from the initial period of the expansion of the hot Universe could still be extant. The quarks could subsequently become annihilated at a temperature sufficient to overcome the Coulomb barrier, but the negatively-charged quarks could stick to nuclei whose charge protected them against annihilation. At $T \sim 10^{6}$°K the quarks with charge $-1/3$ break away from protons and go over to He, and at $T \sim 10^{7}$°K they go over from He to heavier elements. The same paper raised the question of the possible observation of quark-atom lines in spectra of celestial objects. We now consider this question in greater detail.

Hydrogen emission lines are produced by recombination and by impact excitation. It can be shown that the L_α emissions of hydrogen H and of quark-hydrogen Hq ($\lambda = 2733$ Å) upon recombination are related like $10 N_H/N_{Hq}$ (with allowance for the difference in charge). Impact excitation increases somewhat the Hq radiation - by a factor 7 - 10 at $T \sim 15{,}000$°, but at higher temperatures the Hq is practically fully ionized. Since $N_q/N_H \sim 10^{-10}$, we can state that in none of the emitting objects (planetary and diffuse nebulae, shells of supernovae and quasars, the solar chromosphere, etc.) can the $L_{q\alpha}$ be observed. The same holds for the emission lines of other quark-atoms, even if the quarks are joined only to elements heavier than C.

Observation of the $\lambda = 2733$ Å line in interstellar gas is hindered not only by the small number, but also by the high degree of ionization ($\sim 10^{7}$) of Hq. Conditions are more favorable for the observation of the absorption lines in the atmosphere of the Sun and of the stars, where the number of atoms in the column is larger than in the interstellar gas. If the quarks remain bound to the H, then the Hq 2733.3 ± 0.1 Å line (the uncertainty is due to the unknown mass of the quark) in the Sun's spectrum should have an equivalent width $W \sim 0.03$ Å at a quark abundance of 10^{-10} relative to H. The solar spectrum [2] has absorption-line overlaps in this region, but it can be stated that $W < 0.001$ Å. Consequently the abundance of Hq does not exceed 3×10^{-12}. It must be borne in mind that in the base of the Sun's convective zone the temperature exceeds 10^{6}°K, and the matter is sufficiently thoroughly mixed. Therefore the quarks are probably separated from the H and are joined to He and heavier elements, and possibly only to the latter.