VISIBLE LASER DISCHARGE STUDIES

Quarterly Progress Report

for period December 1, 1976 - February 28, 1977

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Contract No. EY-76-C-02-2922

prepared for

THE U. S. DEPARTMENT OF ENERGY
9800 South Cass Avenue
Argonne, Illinois 60439

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VISIBLE LASER DISCHARGE STUDIES QUARTERLY PROGRESS REPORT

Task I

The following investigations were made in order to establish the accuracy of the Boltzmann code reported earlier;

- (a) Test cases in order to determine the accuracy of the code when electron-electron and superelastic collisions are not included. The code predictions are compared with published results.
- (b) Investigation of the effects of superelastic collisions. An example using krypton and krypton metastables is presented.
- (c) Investigation of the effects of electron-electron collisions. For this case also a typical example of krypton and krypton metastables is presented.

In order to investigate the accuracy of the present code when electron-electron and superelastic collisions are neglected; two cases were investigated. The first case was that of argon and the second case was that of helium. The cross-sections and some experimental data for these gases are readily available from literature. We have used the available cross-sections for argon^(1,2) and helium^(1,3) in our code; in order to predict electron drift velocity as a function of the applied electric field. Figure 1 shows the electron drift velocity in argon for $3 \leq E/P \leq 24$ (V/cm-Torr). Three cases are presented in this figure. The first case indicated by solid lines are those calculated in Ref. 4. This calculation corresponds to a numerical solution of the Boltzmann transport equation. The calculations indicated by broken lines are the predictions of the present code whereas the circles represent a similar calculation using an existing AERL code. The comparisons between the three cases are within $\pm 4\%$ for the whole

Fig. 1 Drift Velocity of Electrons in Argon

range considered. Figure 2 shows a similar calculation for a lower range of $0 \leq E/P \leq 4.0$ (V/cm-Torr) for argon. The results of the present code are compared here with electron drift velocity data⁽⁵⁾ indicated by solid lines and by the existing AERL code. Figure 3 shows a similar comparison for the case of helium. The range of electric field considered was $2 \leq E/P \leq 60$ (V/cm-Torr). The range of electric fields chosen is wide enough to cover most electronic transition laser discharges. The predictions of the present code indicated by broken lines are seen to compare well with calculations of Ref. 6 and existing AERL code. We have also compared the electron temperature in helium predicted by the present code with those of Ref. 6 and existing AERL code. This is presented in Fig. 4. These results indicate that the predictions of the present code is accurate enough for electronic transition discharge investigations. In all the numerical calculations mentioned above the energy step size, $\Delta\epsilon$, were varied till a change of less than one percent in the quantity being compared was observed. This would correspond to $\Delta\epsilon = 0.2$ for the cases examined above. For these cases the energy balance was confined within 1-2%.

In the following text the effect of superelastic collisions will be investigated using the present code. The test gas chosen will be Kr because of recent interest in KrF laser discharge.⁽⁷⁾ It has been determined⁽⁷⁾ that the excited state Kr^* plays an important role in KrF laser discharge. For this reason, the effect of excited state fractional population, Kr^*/Kr , on the electron energy distribution function for a given electric field will be investigated. The cross-sectional data for ground state Kr and excited state Kr^* were taken to be that given in Refs. 7, 8 and 2. In order to

Fig. 2 Drift Velocity of Electrons in Argon

Fig. 3 Drift Velocity of Electrons in Helium

Fig. 4 Electron Temperature in Helium

isolate the effect of superelastic collisions of the excited states with electrons; the electron-electron collisions were neglected in the present investigation. The effect of electron-electron collisions are described later in the report. Two different electric fields of $E/N = 4.23 \times 10^{-16}$ and 1.41×10^{-16} (V-cm²) were chosen for these calculations. This was done to demonstrate the effect of electric field on the electron energy distribution function.

Figure 5 shows the electron energy distribution function when excited state fractional populations are negligibly small ($< 10^{-5}$) for the two electric fields. It is observed that the distribution function for higher electric field is larger than that for the lower electric field at a given energy. This shape, therefore, indicates an overall higher energy associated with the electrons for larger electric field as one would expect. For excited state fractional population less than 10^{-5} the shape of the distribution function was found to be virtually identical. This indicates that energy loss due to ionization and excitation of excited state, Kr^* is negligible at this fractional population. Figure 6 shows the effect of excited state fractional population and superelastic collisions on the distribution function for an electric field of $E/N = 1.41 \times 10^{-16}$ (V-cm²). The explanation of the various excitation processes considered for the calculations shown in this figure is depicted schematically in Fig. 7. The following conclusions seem relevant from Fig. 6:

- (1) The tail of the distribution function is depleted more rapidly when ionization and excitation of the excited state, Kr^* , is an important energy loss. This becomes clear by comparing curves (1) and (3) in Fig. 6. At fractional excited state population of 10^{-3} the electrons at high energy are depleted due to excitation and ionization of excited states.

Fig. 5 Electron Energy Distribution Function in Krypton

Fig. 6

Electron Energy Distribution Function in Krypton Including Superelastic Collisions

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Fig. 7 Details of Electron Impact Processes Shown in Fig. 6

- (2) When superelastic collisions are also included at fractional excited state population of $Kr^*/Kr = 10^{-3}$ and $Kr^{**}/Kr = 10^{-5}$ the electrons gain energy due to de-excitation process. This results in high energy tail of the distribution function as depicted by curve (4) in Fig. 6.
- (3) The de-excitation process indicated by high energy tail of the distribution function is also seen to be important when excitation and ionization of the excited state is ignored. This is depicted through curve (2) for the distribution function.

These results indicate clearly the influence of various excitation processes on the calculated distribution function using the present code. It would appear that excited state collisions have a considerable impact on the electron energy distribution function at fractional excited state populations larger than 10^{-5} .

In order to assess the impact of electron-electron collisions on the distribution function; numerical predictions were obtained using the total number of electrons (cm^{-3}) of 10^{14} and 10^{16} for krypton. All other effects such as excitation and ionization from excited state and superelastic collisions were neglected. Figure 8 shows the distribution function for these cases for an electric field of $E/N = 1.41 \times 10^{-16} \text{ (V-cm}^2\text{)}$. It is observed from this figure that the electron distribution function changes markedly when the electron density is increased by a factor of 100. This indicates that the electron-electron collisions are apparently of significant importance, at least under the conditions modeled here. In any discharge calculations, therefore, an assessment of the impact of electron-electron collisions must be made.

Fig. 8 Influence of Electron-Electron Collision on Electron Distribution Function in Krypton

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