Signal of collisional photoionization spectrometer of radiation in the presence of inelastic electron-atom interactions. Diffusion approximation

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A collisional photoionization radiation spectrometer is dedicated to absolute emission spectroscopy in the VUV region. In distinction from the usual photoionization spectrometers it has a greater sensitivity by 2–3 orders of magnitude.

Well-known calculations of the spectrometer signal have been performed only for elastic electron-atom collisions, which imposes limitations on the spectral range investigated (the energy of the photoelectron cannot exceed the first excitation potential of the atom of the working gas). If this condition is not fulfilled, the energy spectrum of the photoelectrons is complicated considerably. In it, besides the initial lines formed by photoelectrons not undergoing a single inelastic collision with atoms, collateral lines appear (secondary, tertiary, etc.) due to electrons that have undergone several (one, two, etc.) inelastic collisions.

In this work a calculation of a collisional spectrometer signal was performed for the case where the energy of the photoelectrons considerably exceeds the first excitation potential of the atoms of the working gas.

The well-known collision photoionization spectrometer consists of a limited volume filled with a monoatomic working gas within which two electron mirrors are mounted opposite each other. A homogeneous magnetic field is created between the electron mirrors parallel to their axis, which impedes the photoelectrons from reaching the side walls. Behind each of the mirrors an energy analyzer and detector is mounted. The radiation investigated illuminates the working gas between the electron mirrors and ionizes it. The energy of the photoelectrons formed is unambiguously connect-
ed with the energy of the radiation quanta, while the rate of generation of photoelectrons is proportional to the number of quanta, the number of atoms of the working gas, and the partial photoionization cross section.

Let us examine the behavior of one of the groups of monoenergetic electrons formed as a result of photoionization of the atoms of the working gas by monochromatic radiation. The investigation of the energy of the electrons was performed by scanning of the retarding potential \( V \) [eV] supplied to the mirror. If the retarding potential is greater than the energy of the electrons \( E \) [eV] all these electrons will persist in the space between the mirrors as a result of various kinds of losses. When the retarding potential is equal to or somewhat less than the energy of the electrons, some part of them reaches the mirrors, creating a current. This current of the electron mirrors is the subject of our investigation.

To pass through an electron mirror a magnetized electron must diffuse into the working gas to the mirrors and make an attempt to pass through it. If the component of the vector of the electron velocity parallel to the axis is sufficient to overcome the potential barrier of the electron mirror, the electron passes through it. If the electron is reflected by the mirror, it undergoes a collision with a gas atom. Elastic collisions change the energy of the electron inconsiderably, changing the direction of its motion in a random way. After each elastic collision the electron can pass through the mirror. If even one inelastic collision of an electron with an atom occurs, it considerably changes its energy, the electron mirror will be closed to it, and the electron perishes.

Let us find the current of the electron mirrors, neglecting the change of the electron energy in elastic collisions, the transverse displacement of the electrons relative to the axis of the mirrors (the case of an infinitely large magnetic field), and absorption of radiation (the condition of equivalence of generation of electrons in the direction transverse to the mirror axis). The concentration of atoms of the working gas \( n_a \) [cm\(^{-3}\)] is such that the condition of the diffusion approximation is fulfilled. \( n_a Q_a L > 3 \) [Q_a [cm\(^{-2}\)] is the total scattering cross section of photoelectrons by atoms of the working gas, \( L \) [cm] is the distance between the electron mirrors].

Using these assumptions we solved the diffusion equation analogously to the equation in Ref. 2, which describes the distribution of the linear concentration \( n \) [cm\(^{-1}\)] of the electrons along the axis of the mirror of the electron mirrors depending on the value of \( U \), \( Q_a \), and the inelastic scattering cross section \( Q_a \) [cm\(^{-1}\)] of the electrons by the atoms of the working gas. Let us choose the coordinate origin at the midpoint between the mirrors.

The distribution of the electron concentration is described by the expression

\[
n(x) = 1.69 \times 10^{-6} \frac{J \cdot \sigma_p}{Q_a L} \left[ \left( 1 + x \tanh \frac{L}{x_a} \right) \sqrt{3(2Q_a - Q_1)} \right] \left( x + \sqrt{\frac{Q_1}{Q_2}} \tanh \frac{L}{x_a} \right) \frac{1}{2} \tanh \frac{x}{x_a} \tanh \frac{2x}{x_a} \tanh \frac{2x}{x_a} \tanh \frac{x}{x_a} \right),
\]

where \( J \) [quanta/cm\(^2\) sec] is the intensity of the radiation investigated, \( \sigma \) [cm\(^2\)] is the area of the transverse cross section of the electron mirrors, \( a \) [cm] is the length of the illuminated region, \( Q_a = 3n_a \sqrt{2Q_1(Q_2 - Q_1)} \),

\[
x = \begin{cases} \frac{a}{4} & \text{at } U > E, \\ \frac{a}{4} (1 - \frac{U}{E}) & \text{at } U \leq E, \\
1 & \text{at } \frac{a}{2} < s < \frac{a}{2}.
\end{cases}
\]

We have shown that the distribution of the electrons between mirrors \( n(x) \) approaches equivalence in the following cases: on a value of the retarding potential close to \( E \) and \( a \rightarrow L \) or on a decrease in the concentration of the atoms of the working gas.

The distribution obtained permits finding the current \( I \) [electrons/sec] of the electron mirrors

\[
I = 2 \pi Q_p \sinh \frac{a}{Q_a L} \frac{1}{2} \cosh \frac{L}{Q_a L}.
\]

With \( a = L \) and small \( x \) Eq. (2) changes to

\[
I = 2 \pi Q_p \frac{Q_a L}{Q_a L}.
\]

As is seen from Eq. (3), the monoenergetic group of photoelectrons dictates a linear increase of the current of the electron mirrors. The increment of the current of the electron mirrors on scanning of \( U \) with the step \( \Delta U \) for a monoenergetic electron group has the form of a step function of height

\[
S = 2 \pi Q_p \frac{Q_a L}{Q_a L} \Delta U.
\]

The value \( 2 \Delta U \) determines the resolving capacity of the spectrometer.

The most important of the results obtained by us is the independence of the value of \( S \) of the concentration of atoms of the working gas on full illumination of the volume between the electron mirrors in the case of inelastic electron-atom collisions at values of \( n_a \) sufficiently large for fulfillment of the conditions of the diffusion approximation. This makes possible: measurement of the absolute intensity of the spectral lines without determination of the absolute concentration of the atoms of the working gas; application of the method of collisional photoionization spectroscopy to measurement of the scattering cross sections of electrons by atoms.

K. E. Mishchenko, Ya. N. Turmakov, and A. B. Utkin, Sixth All-Union Conf. on VUV Spectroscopy and Interaction of Radiation with Matter, Abstracts of Reports (Moscow, 1979).