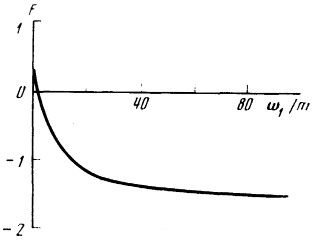

FIG. 5. The function $F(\omega_1)$ in expression (11), which determines the correction to the total cross section.

order of $(\alpha Z)^4$ to the cross section:

$$\sigma(\omega_1)=\sigma_0(\omega_1)[1+(\alpha Z)^2F(\omega_1)]. \tag{11}$$

A plot of the function $F(\omega_1)$, obtained by numerical integration, is shown in Fig. 5. At very large $\omega_1 \gg m$ the function F tends to the limit

$$F(\omega_1)\rightarrow \ln 2-{}^5/_2+O(1/\ln(2\omega_1/m)).$$

We note that the correction of order $(\alpha Z)^2$ in the angular distribution (10) and in the total cross section (11) does not vanish with increasing ω_1.

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1) By virtue of the influence of the wave functions of the initial and final electrons, the Coulomb parameter $\xi=\alpha ZE/p$ in the expansion of the Green's function of the intermediate electron appears in the amplitude of the Compton effect on a bound atomic electron only starting with diagrams that include three Coulomb lines.

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The adiabatic approximation in the problem of the collision of a particle with a bound two-particle system in the case of a separable interaction

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The Faddeev equations are solved in the adiabatic approximation, using separable potentials. The cross sections for dissociative attachment of electrons to diatomic molecules are computed on the basis of the obtained solutions, and a comparison with the experimental data is carried out.

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INTRODUCTION

In this paper we consider the collision of a light particle of mass m_1 with a bound system of two heavy particles (reduced mass $m_{23} \gg m_1$) on the basis of the Faddeev equations.[1] The adiabatic approximation in this problem consists in the use of the solutions of the Faddeev equations for $m_{23}\rightarrow\infty$ to compute the cross sections. If we represent the interaction of the particle m_1 with each of the heavy particles in accordance with the model of zero-range potentials (ZRP), then for $m_{23}\rightarrow\infty$ the Faddeev equations for the problem in question admit of an exact analytical solution, which has been found by Drukarev.[2]

In the present paper we show that the Faddeev equations in the adiabatic approximation also possess an exact analytical solution in the case when the interaction of the particle m_1 with each of the heavy particles is represented by a separable potential.

As a specific example, we consider the reaction involving the dissociative attachment (DA) of an electron to a diatomic molecule:

$$e+\mathrm{AB}\rightarrow\mathrm{A}^-+\mathrm{B}.$$

Although the true interaction of the electron with the atoms constituting the molecule is not expressed by a separable potential, a separable interaction can, under certain conditions,[3] nevertheless serve as a suitable model that is more flexible than the ZRP model.

In §1, we carry out, following the idea of Drukarev's paper,[2] a transformation of the Faddeev equations. In §2 we solve the system of equations for separable potentials exactly. In §3 we present the results of the DA-reaction computations.

§1. THE FADDEEV EQUATIONS AND THEIR TRANSFORMATION

The Faddeev equations[1] in the case of the scattering of particle 1 by the bound pair (2, 3) are formulated for the three parts into which the total wave function

$$\Psi=\Psi_1+\Psi_2+\Psi_3 \tag{1}$$

splits, and have the form

$$\begin{aligned}\Psi_1&=\Phi_1-G_0(Z)T_1(\Psi_2+\Psi_3),\\ \Psi_2&=-G_0(Z)T_2(\Psi_1+\Psi_3),\\ \Psi_3&=-G_0(Z)T_3(\Psi_1+\Psi_2),\end{aligned} \tag{2}$$

where Φ_1 describes the initial state: the free motion of particle 1 and the bound state of the (2, 3) system;

$$G_0(Z)=(H_0-Z)^{-1},\ Z=E+i0,$$

H_0 is the energy operator for the free motion of the three particles, E is the total energy of the three-body system, equal to the sum of the kinetic energy of the incoming particle 1 and the binding energy of the pair (2, 3), and T is the two-particle T matrix.

To describe the three particles in the center-of-mass system, let us use the conventional Jacobi coordinates,[3,4] $\mathbf{k}_i$ and $\mathbf{p}_i$, which are defined as follows:

$$\mathbf{k}_1=\frac{m_3\mathbf{q}_2-m_2\mathbf{q}_3}{m_2+m_3},\quad \mathbf{p}_1=\frac{m_1(\mathbf{q}_2+\mathbf{q}_3)-(m_2+m_3)\mathbf{q}_1}{m_1+m_2+m_3}, \tag{3}$$

where m_i is the mass and $\mathbf{q}_i$ the momentum of the ith particle. The coordinates $\mathbf{k}_2, \mathbf{p}_2$ and $\mathbf{k}_3, \mathbf{p}_3$ are defined in similar fashion. In terms of these variables,

$$\Phi_1(\mathbf{k}_1, \mathbf{p}_1)=\varphi(\mathbf{k}_1)\delta(\mathbf{p}_1-\mathbf{p}_0). \tag{4}$$

Here φ is the wave function of the initial state of the (2, 3) system with energy

$$E_{23}=-\varkappa_{23}^2/2m_{23},\quad Z=\frac{p_0^2}{2n_1}+\frac{\varkappa_{23}^2}{2m_{23}}+i0, \tag{5}$$

where

$$n_1=m_1(m_2+m_3)/(m_2+m_3+m_1),\ m_{23}=m_2m_3/(m_2+m_3).$$

The operators G_0 and T_i are integral operators with kernels of the following form:

$$\begin{aligned}&T_i=t_i(\mathbf{k}_i, \mathbf{k}_i'; Z-p_i^2/2n_i)\delta(\mathbf{p}_i-\mathbf{p}_i'),\\ &G_0(\mathbf{k}_i, \mathbf{p}_i, \mathbf{k}_i', \mathbf{p}_i', Z)=\delta(\mathbf{k}_i-\mathbf{k}_i')\delta(\mathbf{p}_i-\mathbf{p}_i')[k_i^2/2m_{jk}+p_i^2/2n_i-Z]^{-1}.\end{aligned} \tag{6}$$

Following Drukarev,[2] let us set $\Psi_2=-G_0F_2$ and $\Psi_3=-G_0F_3$. Then the system of equations (2) assumes the form

$$\begin{aligned}&[1-T_2G_0T_1G_0]F_2+[T_2G_0-T_2G_0T_1G_0]F_1=T_2\Phi_1,\\ &[1-T_3G_0T_1G_0]F_3+[T_3G_0-T_3G_0T_1G_0]F_2=T_3\Phi_1.\end{aligned} \tag{7}$$

For $m_{23}\rightarrow\infty$ and fixed $\varkappa_{23}$ (i.e., fixed form of φ), the result of the action of the operator $G_0T_1G_0$ on an arbitrary smooth function is zero, as shown in Ref. 2. Taking this into account, we obtain in the limit $m_{23}\rightarrow\infty$ in place of (7) the system of equations

$$F_2+T_2G_0F_3=T_2\Phi_1,\quad F_3+T_3G_0F_2=T_3\Phi_1. \tag{8}$$

The adiabatic approximation consists in determining F_2 and F_3 from the system (8) for finite, but small values of n_1/m_{23}. Let us draw attention to the fact that for fixed $\varkappa_{23}$ all the levels of the (2, 3) system tend to zero as $m_{23}\rightarrow\infty$. Therefore, the application of (8) will be a reasonable approximation only in the case when the presence of the bond in the (2, 3) system does not play an important role in the elastic scattering of the particle 1, and this can be the case when the energy of the impinging particle appreciably exceeds the magnitude of the binding energy.

The neglect of the operator $G_0T_1G_0$ is equivalent to the substitution of Φ_1 for Ψ_1 in the Eqs. (2). It follows from this that the system of equations (8) describes the scattering of the particle 1 as if the momentum distribution for the particles 2 and 3 preserves its initial value φ during the scattering. Such an approximate description of the scattering process underlies the well-known impulse approximation. Taking (3)–(6) into account, let us write the system (8) in the impulse approximation:

$$\begin{aligned}&F_3(\mathbf{k}, \mathbf{p})+2m_1\int d\mathbf{k}'\,\frac{t_3(\mathbf{k}, \mathbf{p}-\mathbf{k}', Z)F_2(\mathbf{p}-\mathbf{k}', \mathbf{k}')}{(\mathbf{p}-\mathbf{k}')^2-p_0^2-i0}=t_3(\mathbf{k}, \mathbf{p}_0, Z)\varphi(\mathbf{p}-\gamma\mathbf{p}_0);\\ &\qquad\gamma=m_3/(m_2+m_3),\\ &F_2(\mathbf{k}, \mathbf{p})+2m_1\int d\mathbf{k}'\,\frac{t_2(\mathbf{k}, \mathbf{p}-\mathbf{k}', Z)F_3(\mathbf{p}-\mathbf{k}', \mathbf{k}')}{(\mathbf{p}-\mathbf{k}')^2-p_0^2-i0}=t_2(\mathbf{k}, \mathbf{p}_0, Z)\varphi(\mathbf{p}+\varkappa\mathbf{p}_0),\\ &\qquad\varkappa=m_2/(m_2+m_3).\end{aligned} \tag{9}$$

§2. SOLUTION OF THE FADDEEV EQUATIONS IN THE ADIABATIC APPROXIMATION WITH THE USE OF SEPARABLE POTENTIALS

In the separable-potential approximation[4]

$$V_i(\mathbf{k}, \mathbf{k}')=-\frac{\lambda_i}{m_{jk}}g_i(\mathbf{k})g_i(\mathbf{k}'),\quad i, j, k=1, 2, 3;\ i\neq j, k. \tag{10}$$

The two-particle T matrices have the form

$$\begin{aligned}&t_i(\mathbf{k}, \mathbf{k}', Z)=-\lambda_i g_i(\mathbf{k})g_i(\mathbf{k}')/m_{jk}d_i(Z),\\ &d_i(Z)=1+4\pi\lambda_i\int\limits_0^\infty\frac{g_i^2(x)x^2\,dx}{2m_{jk}Z-x^2}.\end{aligned} \tag{11}$$

In this approximation the system of equations (9) assumes the following form:

$$\begin{aligned}&F_3(\mathbf{k}, \mathbf{p})+2m_1\Lambda_3g_3(\mathbf{k})\int\frac{g_3(\mathbf{p}-\mathbf{k}')F_2(\mathbf{p}-\mathbf{k}', \mathbf{k}')}{(\mathbf{p}-\mathbf{k}')^2-p_0^2-i0}d\mathbf{k}'\\ &\qquad=\Lambda_3g_3(\mathbf{k})g_3(\mathbf{p}_0)\varphi(\mathbf{p}-\gamma\mathbf{p}_0),\\ &F_2(\mathbf{k}, \mathbf{p})+2m_1\Lambda_2g_2(\mathbf{k})\int\frac{g_2(\mathbf{p}-\mathbf{k}')F_3(\mathbf{p}-\mathbf{k}', \mathbf{k}')}{(\mathbf{p}-\mathbf{k}')^2-p_0^2-i0}d\mathbf{k}'\\ &\qquad=\Lambda_2g_2(\mathbf{k})g_2(\mathbf{p}_0)\varphi(\mathbf{p}+\varkappa\mathbf{p}_0),\end{aligned} \tag{12}$$

where $\Lambda_i=\lambda_i/m_{jk}d_i(Z)$, or

$$\begin{aligned}&F_3(\mathbf{k}, \mathbf{p})=\Lambda_3g_3(\mathbf{k})C_3(\mathbf{p}),\\ &F_2(\mathbf{k}, \mathbf{p})=\Lambda_2g_2(\mathbf{k})C_2(\mathbf{p}),\end{aligned} \tag{13}$$

where

$$C_3(\mathbf{p})=g_3(\mathbf{p}_0)\varphi(\mathbf{p}-\gamma\mathbf{p}_0)-2m_1\int\frac{g_3(\mathbf{p}-\mathbf{k}')F_2(\mathbf{p}-\mathbf{k}',\mathbf{k}')}{(\mathbf{p}-\mathbf{k}')^2-p_0^2-i0}d\mathbf{k}',$$
$$C_2(\mathbf{p})=g_2(\mathbf{p}_0)\varphi(\mathbf{p}+\varkappa\mathbf{p}_0)-2m_1\int\frac{g_2(\mathbf{p}-\mathbf{k}')F_3(\mathbf{p}-\mathbf{k}',\mathbf{k}')}{(\mathbf{p}-\mathbf{k}')^2-p_0^2-i0}d\mathbf{k}'.$$

Thus, in the separable-potential approximation the functions satisfying the system of equations (2) can also be represented in the separable form (13). To derive the system of equations that is satisfied by the functions $C_2(p)$ and $C_3(p)$, let us substitute (13) into (12). We obtain

$$\begin{aligned}&C_3(\mathbf{p})+2m_1\Lambda_2\int\frac{g_3(\mathbf{p}-\mathbf{k}')g_2(\mathbf{p}-\mathbf{k}')C_2(\mathbf{k}')}{(\mathbf{p}-\mathbf{k}')^2-p_0^2-i0}d\mathbf{k}'=g_3(\mathbf{p}_0)\varphi(\mathbf{p}-\gamma\mathbf{p}_0),\\&C_2(\mathbf{p})+2m_1\Lambda_3\int\frac{g_3(\mathbf{p}-\mathbf{k}')g_3(\mathbf{p}-\mathbf{k}')C_3(\mathbf{k}')}{(\mathbf{p}-\mathbf{k}')^2-\mathbf{p}_0^2-i0}d\mathbf{k}'=g_2(\mathbf{p}_0)\varphi(\mathbf{p}+\varkappa\mathbf{p}_0).\end{aligned}\tag{14}$$

The system of integral equations (14) admits of an exact analytical solution for separable potentials with form factors of the form

$$g_2(k)=(k^2+\alpha^2)^{-1},\ g_3(k)=(k^2+\beta^2)^{-1}.$$

In this case, going over to the coordinate representation, we obtain the following system of equations for the determination of the functions $C_2(\mathbf{r})$ and $C_3(\mathbf{r})$:

$$\begin{aligned}&C_3(\mathbf{r})+2m_1\Lambda_2\Phi(\mathbf{r})C_2(\mathbf{r})=g_3(\mathbf{p}_0)\exp(i\varkappa\mathbf{p}_0\mathbf{r})\varphi(\mathbf{r}),\\&C_2(\mathbf{r})+2m_1\Lambda_3\Phi(\mathbf{r})C_3(\mathbf{r})=g_2(\mathbf{p}_0)\exp(-i\gamma\mathbf{p}_0\mathbf{r})\varphi(\mathbf{r}),\end{aligned}\tag{15}$$

where in the case $\alpha\neq\beta$

$$\Phi(r)=\frac{2\pi^2}{r}\left[\frac{\exp(-\alpha r)}{(\alpha^2-\beta^2)(p_0^2+\alpha^2)}-\frac{\exp(-\beta r)}{(\alpha^2-\beta^2)(p_0^2+\beta^2)}-\frac{\exp ip_0r}{(p^2+\alpha^2)(p^2+\beta^2)}\right],$$

and in the case $\alpha=\beta$

$$\Phi(r)=\frac{2\pi^2}{r}\left\{\frac{\exp ip_0r}{(p_0^2+\beta^2)^2}-\left[1-\frac{r}{2\beta}(p_0^2+\beta^2)\right]\frac{\exp(-\beta r)}{(p_0^2+\beta^2)^2}\right\}.$$

The solution to the system (15) has the form

$$\begin{aligned}&C_2(\mathbf{r})=\frac{g_2(\mathbf{p}_0)\exp(i\varkappa\mathbf{p}_0\mathbf{r})-2m_1\Lambda_2g_3(\mathbf{p}_0)\Phi(\mathbf{r})\exp(-i\gamma\mathbf{p}_0\mathbf{r})}{1-\Lambda_2\Lambda_3[2m_1\Phi(\mathbf{r})]^2}\varphi(\mathbf{r}),\\&C_3(\mathbf{r})=\frac{g_3(\mathbf{p}_0)\exp(-i\gamma\mathbf{p}_0\mathbf{r})-2m_1\Lambda_3g_2(\mathbf{p}_0)\Phi(\mathbf{r})\exp(i\varkappa\mathbf{p}_0\mathbf{r})}{1-\Lambda_2\Lambda_3[2m_1\Phi(\mathbf{r})]^2}\varphi(\mathbf{r}).\end{aligned}\tag{16}$$

The components of the total wave function are given by the formulas (13). Notice that the obtained solutions, (16), coincide with the solutions obtained in the second iteration of the Faddeev equations, and possess all the necessary properties of the solutions to these equations.[1,2] Such solutions are of both methodological and practical interest. They can be used in elastic-scattering and reaction calculations in nuclear and atomic physics.

§3. RESULTS OF THE CALCULATIONS

To determine the amplitudes of the various processes in the three-particle system, let us substitute F_2 and F_3 into the expression for the total wave function (1). We obtain

$$\begin{aligned}&\Psi=(1-G_0T_2-G_0T_3)\Phi_1-G_0T_1G_0(F_2+F_3)\\&-G_0T_3G_0F_2-G_0T_2G_0F_3-G_0(T_2+T_3)G_0T_1G_0(F_2+F_3).\end{aligned}\tag{17}$$

Taking account of the fact that the residue of an expression of the type $G_0T_iG_0F_i$ at the poles of T_i coincides up to a factor with the amplitude of one of the possible excitation or redistribution processes, while the residue at the pole of G_0 gives the breakup amplitude,[1,2] we obtain that the second term in (17) gives the elastic-scattering or excitation amplitude,

$$\begin{aligned}&M_{n0}=(2\pi)^2m_1\int\varphi_n^*(\mathbf{r})\\&\times[\exp(i\gamma\mathbf{pr})F_3(\mathbf{r},\boldsymbol{\rho})\\&+\exp(-i\varkappa\mathbf{pr})F_2(\mathbf{r},\boldsymbol{\rho})]d\mathbf{r}\,d\boldsymbol{\rho},\end{aligned}$$

while the cross section is equal to

$$d\sigma_{n0}/d\Omega=|M_{n0}|^2.$$

The third term gives the amplitude of the reaction $1+(2,3)\rightarrow(1,2)+3$:

$$\begin{aligned}&M_{\mathrm{DA}}=(2\pi)^2m_{23}\int\varphi_{12}^*(\mathbf{r})\\&\times\exp(i[m_{23}/m_1]^{1/2}\mathbf{pr})F_2(\mathbf{r},\boldsymbol{\rho})d\mathbf{r}\,d\boldsymbol{\rho},\end{aligned}\tag{18}$$

where $\varphi_{12}(r)$ is the wave function of the (1, 2) system in the separable-potential approximation,[4] while the cross section

$$d\sigma_{\mathrm{DA}}/d\Omega=[m_1/m_{23}]^{1/2}|M_{\mathrm{DA}}|^2.$$

The last term makes contributions to all the amplitudes, and, thus, takes account of the reciprocal influence of all the processes on each other.

On the basis of the solutions, (16), obtained for the Faddeev equations in the adiabatic approximation with the use of the separable potentials (10), we have computed from the formula (18) the cross section for the process of dissociative electron attachment to the molecules H_2, HD, and D_2. As the wave function of the target molecule, we used the wave function of the Morse oscillator. The parameters of the separable potentials were taken from Demkov and Ostrovskiĭ's book.[3] The results of the calculation are shown in Fig. 1. Also shown in the figure are the results of calculations performed in the adiabatic approximation with the use of ZRP,[5] the results of calculations with separable potentials without the adiabatic approximation,[6] and ex-

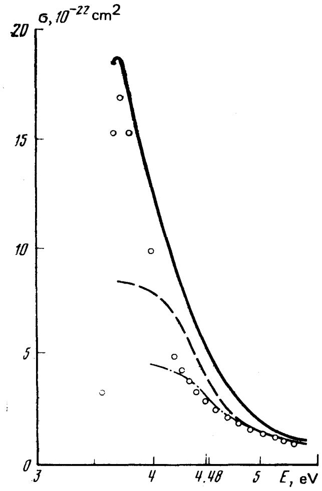

FIG. 1. Total cross section for production of the negative ions H^- in collisions of low-energy electrons with H_2 molecules. ○) Experimental data taken from Ref. 7; the solid curve represents the results of the calculation with the separable potentials (10) without the use of the adiabatic approximation[6]; the dot-dash curve represents the results of the calculation in the adiabatic approximation with the use of ZRP[5]; the dashed curve depicts the results of the calculation carried out in the present paper.

perimental data.[7] It can be seen from a comparison of the calculations that the calculations in the adiabatic approximation with the use of separable potentials reproduce the experimental data on DA cross sections somewhat better than do the calculations in the ZRP approximation, and worse than do the numerical computations without the use of the adiabatic approximation. The DA calculations for the HD and D_2 molecules are similar and are therefore not presented here. It should be noted that, by construction of the adiabatic approximation, the expected region of applicability of the model lies to the right of the point 4.48 eV, which corresponds to the dissociation energy for the H_2 molecule.

In our calculations, as the initial data, we used the two-particle T matrices and the wave functions corresponding to the two-particle bound states, in contrast to the other models proposed by Herzenberg, Mandi, and Firsov and Smirnov,[3] in which it is necessary to know the quasistationary terms of the negative molecular ions AB$^-$, terms whose determination is a fairly difficult problem. In our approach, however, these terms are determined by the imaginary zeros of the denominators of the functions F_l, while the complex zeros correspond to the continuation of the terms into the region of quasistationary states.[2]

In conclusion, I express my gratitude to V. N. Ostrovskiĭ, who drew my attention to the possibility of obtaining an analytic solution to the Faddeev equations for a separable interaction, as well as to I. V. Komarov and S. P. Merkur'ev.

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Absorption of optical radiation in weakly ionized gases

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The influence of atom polarization in an electromagnetic field on the photoabsorption coefficient of a weakly ionized gas is calculated. The effect turned out to be most substantial in the optical band. It is shown that for gases whose atoms have a negative scattering length the photoabsorption coefficient has a deep minimum at certain frequencies.

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In investigations of the properties of a weakly ionized gas in an alternating field it is customarily assumed that the field quanta are absorbed by free electrons when scattered by neutral particles, which play the role of an inert force center.[1,2] Recent studies[3-6] have shown, however, that in many cases an important role is played in this process by the dynamic characteristics of the neutral atoms and molecules. Namely, owing to the polarizability of the atoms and molecules in the external field, they acquire an oscillating dipole moment, and scattering by this moment changes the energy of the free electron by an amount $\hbar\omega$ (ω is the field frequency). This mechanism has explained qualitatively, in particular, the low thresholds of the optical breakdown of alkali-metal vapor by laser radiation.[6]

An analytic formula for the cross section of the bremsstrahlung effect, with account taken of the polarization mechanism, was obtained in Ref. 6 under conditions when the Born approximation was applicable to potential scattering of an electron by an atom. In a weakly ionized gas, the Born approximation cannot be used for electrons with thermal velocities. To take into account the influence of the polarization mechanism of the absorption of radiation we therefore consider in the present paper the scattering of an electron by an atom in the short-range-potential approximation, which was applied to a similar problem earlier.[7,8]