Production of low-energy polarized electrons

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A new method is proposed for experimentally obtaining highly polarized low-energy electrons. The idea of the method is based on transferring the spin orientation of the atomic electron to the free electron by inelastic collision of the atoms, as a result of which the electron is detached. The particular processes considered in the article, as shown by estimates, can be used to obtain polarized electron beams of sufficiently large "brightness".

The production, scattering, and detection of polarized electron beams is one of the most promising problems of modern experimental and theoretical physics of electron-atom collisions.[1,2] So far, however, no experiments have been organized on the scattering of slow polarized electrons (at electron-volt energies), owing to the insufficient "brightness" of the polarized electron beams obtained in the present-day experimental procedure.[1)] The scanty theoretical calculations of the scattering of polarized electrons by oriented atomic-molecular targets yield therefore only preliminary predictions.

We propose in this paper a new method of obtaining free highly-polarized electrons of almost zero energy. The idea of the method is to transfer the prepared polarization of the atomic electron to a free electron via an inelastic process such as Penning ionization, or by level crossing. By specially chosing the partners it is possible to make the free electrons have almost zero energy and an appreciable degree of polarization. The first of these circumstances makes it possible to effectively shape polarized-electron beams with the aid of an electric field. The intensities of these beams depend on the energy-transfer cross section, which is relatively large under conditions of almost resonant transition (for estimates see below).

We consider the inelastic scattering

$$O(^1S_0) + Cs(^2S_{1/2})\uparrow \to O(^3P_0) + Cs^+(^1S_0) + e(\uparrow), \tag{1}$$

in which the Cs atom is oriented; the resonance defect is $\Delta E = 2169$ cm^{-1}. Let us find the degree of polarization P of the electron and estimate the energy-transfer cross section in the channel $O(^3P_0) + Cs^+(^1S_0) + e(\uparrow)$.

If the atoms approach each other slowly, when only s-scattering takes place, the total angular momentum of the system (J) and its projection on the selected direction (M_J) are $J = 1/2$ and $M_J = 1/2$ (total initial polarization is assumed). In the output channel, the total angular momentum and its projection are determined by the angular momentum of the free electron. Since J and M_J are conserved in the collisions, the s electrons produced in the reaction (1) are fully polarized. An energy filter can be used to separate these electrons from those produced in other allowed channels of the reaction $O(^1S_0) + Cs(^2S_{1/2})\uparrow$.

Let us estimate the cross section (1), regarding this process as almost resonant energy transfer. In the two-state approximation the system of equations for the transition coefficients is (we use the atomic system of units)

$$i\dot{a}_{2,1} \approx V \exp(\mp i\Omega t) a_{1,2}, \tag{2}$$

where $\Omega t = \omega t - \int_{-\infty}^{t} (V_{22} - V_{11})\, dt'$. The matrix element of the transition is $V_{12} = V \exp(i\omega t)$, ω is the transition frequency, and $V_{11,22}$ are the diagonal elements of the interaction in the atomic basis. It is easy to show that under the condition $\Omega t_0 \ll \pi/2$ (t_0 is the characteristic interaction time) the transition probability is equal to

$$W = \sin^2 (2 \int_0^\infty V \cos \Omega t\, dt). \tag{3}$$

For a transition of the exchange type, which takes place in (1), the operator for straight-line trajectories is $V = V_0 \exp\{-\alpha [p^2 + (vt)^2]^{1/2}\}$ (p is the impact parameter and v is the collision velocity). Making, for the sake of estimates, the substitution $\Omega t \to \Omega_0 t = \omega t - \int_{-\infty}^{\infty} (V_{22} - V_{11})\, dt'$, we obtain

$$W = \sin^2 \left\{ \frac{2V_0 \alpha p}{[\Omega_0^2 + (v\alpha)^2]^{1/2}} K_1\left(p[\Omega_0^2 + (v\alpha)^2]^{1/2}/v\right) \right\}, \tag{4}$$

where K_1 is a Macdonald function. The energy-transfer cross section $\sigma = 2\pi \int_0^\infty Wp\,dp$ at $\alpha v < \Omega_0$ is given by

$$\sigma = 8\pi^2 (V_0 \alpha v^2 / \Omega_0^3)^2. \tag{5}$$

The maximum cross section is reached at $\alpha v_0 \sim \Omega_0$ and is equal to

$$\sigma_{max} = \frac{\pi}{4\alpha^2} \ln^2 \left(\frac{V_0}{\Omega_0}\right) \tag{6}$$

(we assume the natural condition $V_0/\Omega_0 > 1$). We see that σ_{max} does not depend critically on the parameters V_0 and Ω_0, and is of the order of the gas-kinetic cross section. For the system $O(^1S_0) + Cs \to O(^3P_0) + Cs^+ + e$ we obtain in accordance with (6) the value $\sigma_{max} = 6 \times 10^{-16}$ cm^2 at $v_0 \approx 2 \times 10^6$ cm/sec. At $v = 10^5$ cm/sec, we have $v\sigma = 5 \times 10^{-12}$ cm^3/sec.

Realistic values of the densities of $O(^1S_0)$ and $Cs(^2S_{1/2})\uparrow$ in the gas discharge at the indicated value of $v\sigma$ makes it possible to estimate an electron current on the order of a microampere and more, and accordingly $I_0 \approx 10^{-6}$ A. In the stationary regime we have $I < I_0$, owing to the decrease of the population of $O(^1S_0)$, the depolarization of $Cs(^2S_{1/2})\uparrow$, the electrons produced in collisions, and other causes, i.e., the final value of I is an experimental characteristic. We indicate for comparison that in an optically pumped helium discharge, which is used as a source of polarized electrons, the best value is $I=4\times10^{-9}$ A,[3,2] and in the Fano effect $I=4\times10^{-10}$ A.[2]

It can thus be assumed that the considered process is an effective experimental way of obtaining slow polarized electrons.

In addition to (1), practical and theoretical interest attaches to the reaction $O(^1S_0)+Rb(^2S_{1/2})\uparrow \rightarrow O(^3P_0)+Rb^+(^1S_0)+e(\uparrow)$ with a defect $\Delta E=-115$ cm^{-1}. The electron is detached in this case because of the crossing of the levels at a point close to the turning point.

We note in conclusion that if we lift the limitation that the electrons be produced with almost zero energy, then many processes of the Penning-ionization type can yield a total transfer of the polarization to the free electron (for example, $He(2^3S_1)\uparrow + Cd(^1S_0) \rightarrow He(^1S_0) + Cd^+(^2S_{1/2}) + e(\uparrow)$ (see[4,5]) or $He(2^1S_0) + Cs(^2S_{1/2})\uparrow \rightarrow He(^1S_0) + Cs^+(^1S_0) + e(\uparrow)$.

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1)The "brightness" of a beam of polarized electrons is characterized by the quantity $I=Pi_e$ (P is the degree of polarization and i_e is the electron current) (see[2]).

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