EXPERIMENTAL VERIFICATION OF THE FANO EFFECT

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An absolute measurement of the electron polarization obtained by photoionization of cesium by circularly polarized light is reported. The measured polarization of 65 ± 15 % confirms the prediction made by Fano and the assumptions of Seaton on spin-orbit interaction in photoionization of alkali atoms. They also show that it is possible to construct a photoionization source of polarized electrons without using a polarized atom beam.

Recently Fano[1] predicted an effect which is very interesting from a theoretical viewpoint as well as for practical purposes: Photoelectrons emitted by alkali atoms exposed to circularly polarized light should be highly polarized if the wavelength of the light falls within a broad spectral band around the minimum of the photoabsorption cross section. Fano made a numerical analysis for cesium resulting in a polarization ≳85 % for $2750 \lesssim \lambda \lesssim 3150$ Å.

The basic idea of the Fano effect can be illustrated as follows: The unpolarized cesium-atom beam is considered as a mixture of equal numbers of ground-state atoms with spins parallel ("spin up") and antiparallel ("spin down") to the direction of the incident light. In Fig. 1 the transitions from the ground state to the continuum P states[2] due to σ^+ light are indicated, showing that there is a certain probability for spin flip $m_s = -\frac{1}{2} \rightarrow m_s = +\frac{1}{2}$ in the transitions 2 and 3. The cross section for producing spin-up and spin-down electrons by these transitions can be shown to be proportional to $\frac{2}{9}(R_3-R_1)^2$ and $\frac{1}{9}(R_3+2R_1)^2$, respectively. R_1 and R_3 are the radial parts of the matrix elements for transitions to the $j=\frac{1}{2}$ and $\frac{3}{2}$ states; they differ slightly due to spin-orbit interaction. The cross section for transition 1 which results in spin-up electrons is proportional to R_3^2.

The polarization of the photoelectrons is therefore given by

$$P = \frac{\sigma^{\uparrow}-\sigma^{\downarrow}}{\sigma^{\uparrow}+\sigma^{\downarrow}} = \frac{R_3^2+\frac{2}{9}(R_3-R_1)^2-\frac{1}{9}(R_3+2R_1)^2}{R_3^2+\frac{2}{9}(R_3-R_1)^2+\frac{1}{9}(R_3+2R_1)^2}. \quad (1)$$

Since spin-orbit coupling is a small interaction, one finds $R_1 \approx R_3$; thus the cross sections for producing spin-up and spin-down electrons are not very different from each other. Significant polarization of the photoelectrons can therefore only be expected near the minimum of the photoionization cross section $\sigma^{\uparrow}+\sigma^{\downarrow}$, since only there is the relative difference of spin-up and spin-down electrons appreciable, analogous to the circumstances in electron scattering.[3]

An indirect experimental verification of Fano's ideas was given by Lubell and Raith.[4] These authors did not observe the electron polarization, but they measured the ion intensities I^+ and I^- obtained by ionizing polarized cesium atoms by circularly polarized light with positive and negative photon helicities. Transitions 1′ and 2 + 3 in Fig. 1 were observed. With the results for the cross sections given above we therefore obtain (for completely polarized Cs atoms)

$$\delta = \frac{I^+-I^-}{I^++I^-} = \frac{R_3^2-\frac{2}{9}(R_3-R_1)^2-\frac{1}{9}(R_3+2R_1)^2}{R_3^2+\frac{2}{9}(R_3-R_1)^2+\frac{1}{9}(R_3+2R_1)^2}, \quad (2)$$

which differs from Eq. (1) by a minus sign. The authors made a relative measurement of δ after determining their atomic-beam polarization from the difference of the ion intensities. Eq. (2) was confirmed.

In the present paper an absolute measurement of the electron polarization, Eq. (1), is reported. Figure 2 gives a schematic diagram of the apparatus. A cesium-atom beam is crossed by a beam of circularly polarized light. The photoelectrons are extracted by a weak electric field of about 10 V/cm perpendicular to the plane defined by the two beams and pass through an electron-optical focusing system which also removes

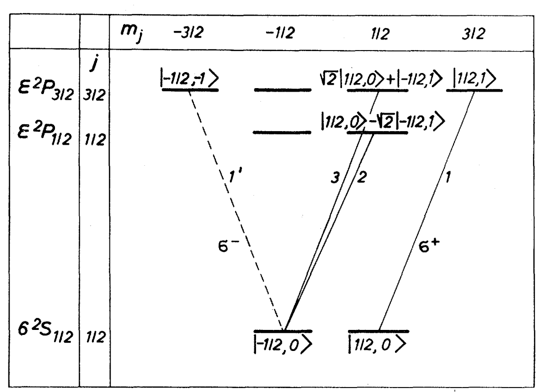

FIG. 1. States, wave functions $|m_s m_l\rangle$ [cf. L. Schiff, Quantum Mechanics (McGraw-Hill Book Company, Inc., New York, 1955), p. 291], and transitions connected with photoabsorption in cesium.

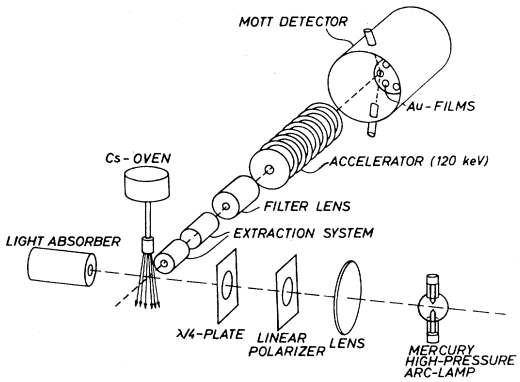

FIG. 2. Schematic diagram of the apparatus.

spurious electrons. After postacceleration to 120 keV they enter a Mott detector where their polarization is analyzed.

For the production of the cesium atom beam the oven described by Eitel, Jost, and Kessler[5] was used after making a few modifications. As light source a mercury high-pressure arc lamp was used together with a polarizing foil and a quarter-wave plate, but without a filter. The main intensity of the lamp is concentrated in the spectral range where Fano's theoretical polarization is between 90 and 100%. Correcting the theoretical polarization curve for the intensity distribution and circular polarization of the incident light yields an average value of 80% for the spin polarization to be expected.

Before the results proved to be reliable, several difficulties had to be overcome. The measured electron polarization turned out to depend on the temperature of the cesium oven, i.e. the density of the beam, unless this temperature was chosen lower than about 140°C. According to the results of Popescu et al.,[6] this is due to spurious electrons resulting from photoionization of Cs_2 and from collisions of ground-state atoms with those in excited states which are produced by irradiation with our broad spectral band. These processes depend strongly on the beam density. Another serious problem was the electrons originating from inner walls of the apparatus. They gave rise to polarization values which were unreproducible and too low. Finally a design of the electron optical system was found which satisfactorily suppressed these electrons.

Due to the low oven temperature only about 10^4 photoelectrons were produced per second. The average value of the polarization was $(65 \pm 15)\%$. The measured values (10 runs) varied between these limits of error because of the spurious effects described in the last paragraph. (The statistical error is much smaller, since 4.2×10^4 electrons were counted). The experiment confirms Fano's prediction on the possibility of producing highly polarized electrons by photoionization of unpolarized atomic beams. All the sources of polarized electrons constructed so far on the basis of photoionization[7] start from polarized atomic beams.

Measurements of the Fano effect along the spectrum with good resolution and with an improved apparatus are now being made. The observed electron polarization will provide a detailed check of the theoretical assumptions made in describing the influence of spin-orbit coupling on photoabsorption by cesium vapor.[8,9]

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