# INFLUENCE OF LAMB SHIFT ON THE INTERFERENCE OF EXCITED STATES OF HYDROGEN ATOMS

Yu.L. Sokolov
Submitted 24 April 1970
ZhETF Pis. Red. 11, No. 11, 524 - 528 (5 June 1970)

Since the conclusion of the extensive series of experiments by Lamb and co-workers, a large number of theoretical and experimental papers have been devoted to the study of the fine structure of the levels of the hydrogen atom and hydrogenlike ions. The increased interest in research of this type is due primarily to the presence of very slight but in all probability actual discrepancies between experiment and theory [1]. In view of the fact that a clarification of the nature of such a disparity is of fundamental character, it is necessary to organize experiments in which the structure and properties of the hydrogen-atom levels would become manifest in different aspects and modifications. One of the experimental methods of interest from the point of view indicated above is the observation of interference of different states of the hydrogen atom, since the interference picture can be exceedingly sensitive to the characteristic of its components.

In this paper we describe a number of preliminary experiments performed principally for the purpose of observing interference of certain excited states of the H atom.

When a beam of unstable $2s_{1/2}$ hydrogen atoms passes through the boundaries of a region in which an electric field is localized, their transitions to a state $2p_{1/2}$ become possible. The amplitude of the $2p_{1/2}$ state after emergence from the field is determined by the amplitudes of the transitions and by the phase difference, which depends on the time of flight of the atom through the region of the field and on the frequency of the transition between the terms that are split by the electric field. Since such a splitting is determined entirely by the field intensity $\mathcal{E}$, it follows that at a certain fixed point on the trajectory of the beam passing through the field, in the case of monotonic variation of $\mathcal{E}$, there will be observed a periodic (in antiphase) oscillation of the intensity of the fluxes of $2s_{1/2}$ and $2p_{1/2}$ atoms, due to the interference of the waves produced on the boundaries of the electric field. The yield of atoms in the states $2p_{1/2}$, corresponding to a definite value of $\mathcal{E}$, depends on the character of the variation of the field within the limits of the boundary regions. If the field increases and decreases adiabatically, the amplitude of the transition will be exponentially small; in the case of non-adiabatic ("instantaneous") change of the field, at sufficiently large intensity $\mathcal{E}$, the intensities of the $2s_{1/2}$ and $2p_{1/2}$ components of the beam become identical. The criterion of the non-adiabaticity is the condition that the flight frequency $\Omega = v/d$ should be larger than or of the order of the Lamb frequency $\omega_L$ (here v is the velocity of the atom and d is the width of the boundary region).

In a series of experiments performed by us, a beam of metastable $2s_{1/2}$ atoms of hydrogen with energy $E \sim 20$ keV (obtained by charge exchange of protons in hydrogen) was passed through a special capacitor with a sufficiently abrupt change of the field on the edges. The flux of the produced $2p_{1/2}$ atoms was measured by registering the $L_\alpha$ quanta ($\lambda = 1216$ Å) corresponding to the transition $2p \rightarrow 1s$ of the hydrogen atom.

Two systems of capacitors were used, with transverse and with longitudinal field (relative to the direction of motion of the atoms). The "dual" capacitor with transverse field (Fig. 1) was used to study the dependence of the effect on the field intensity of the boundaries ("adiabatic" and "nonadiabatic" connection of the plates), and also on the distance from the boundary to the field.

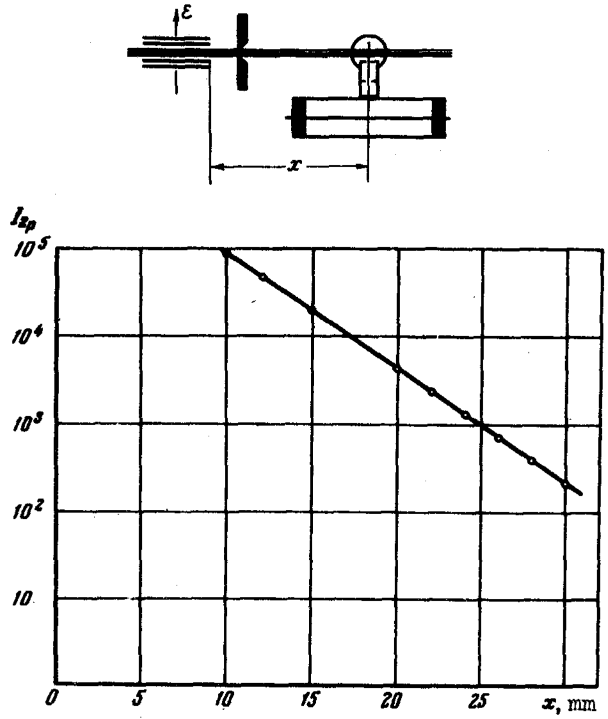


Fig. 1. Plot of $I_{2p}(x)$ at $v = 2.083 \times 10^8$ cm/sec and $\mathscr{E}$ = const.

The capacitor with longitudinal field was used to determine the dependence of the effect on the field intensity and time of flight through it ($\tau$ ranged from $1 \times 10^{-9}$ to $5 \times 10^{-9}$ sec).

Figure 1 shows, in semilogarithmic coordinates, the dependence of the number of the $L_\alpha$ quanta emitted from a unit length of the beam on the distance x between the collimator axis of the counter and the edge of the dual capacitor in the case of non-adiabatic connection of its plates. The experimental points fit a straight line, the slope of which corresponds to the lifetime of $1.60 \times 10^{-9}$ sec for the excited H atom. This value was obtained for a proton velocity $v = 2.083 \times 10^8$ cm/sec, determined by passing the beam through an analyzer with crossed fields. The obtained time coincides exactly with the lifetime of the $H_{2p}$ atom, from which it follows that in this particular case we actually observed the emission of the 2p-component of the beam, produced in the capacitor with non-adiabatic field variation on the edges.

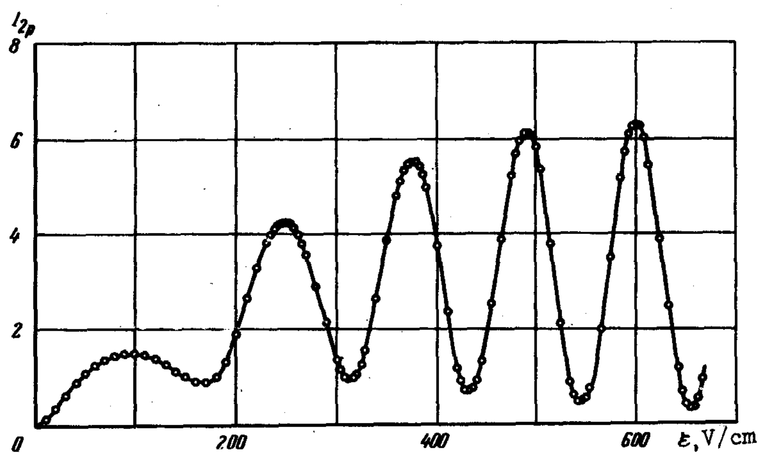


Fig. 2. Plot of $I_{2p}(\mathscr{E})$ at $\tau = 2.4 \times 10^{-9}$ sec and x = 1.5 cm. The curve was plotted with the aid of a counting system.

Figures 2 and 3 show the yield of the 2p component as a function of the field intensity in a longitudinal capacitor for two values of the time of flight $\tau$. The $I_{2p}(\mathscr{E})$ plot shows a sufficiently distinct interference picture, which is the optical analog of the effect predicted by Pais and Piccioni for the system of $K^0$ and $\overline{K}^0$ mesons [2].

The influence of the Lamb shift $\delta_H$ is clearly pronounced, for example, in the initial sections of the $I_{2p}(\mathscr{E})$ curves in the energy region $\mathscr{E}$ from zero to ∿600 V/cm, and consists, first, of a gradual increase of the amplitudes, and second, of a change in the period $\Delta\mathscr{E}$, which decreases gradually with increasing $\mathscr{E}$, approaching a constant value $\Delta\mathscr{E}_\tau$. The product $\tau\Delta\mathscr{E}_\tau$ remains subsequently constant in a wide interval of values of $\mathcal{E}$. The described phenomena become all the more pronounced the larger the time of flight $\tau$. In addition to the foregoing, a gradual rise and subsequent lowering of the points corresponding to the minima of the curve is observed in the same region; this is due to emission of the excited atoms in the field $\mathcal{E}$.

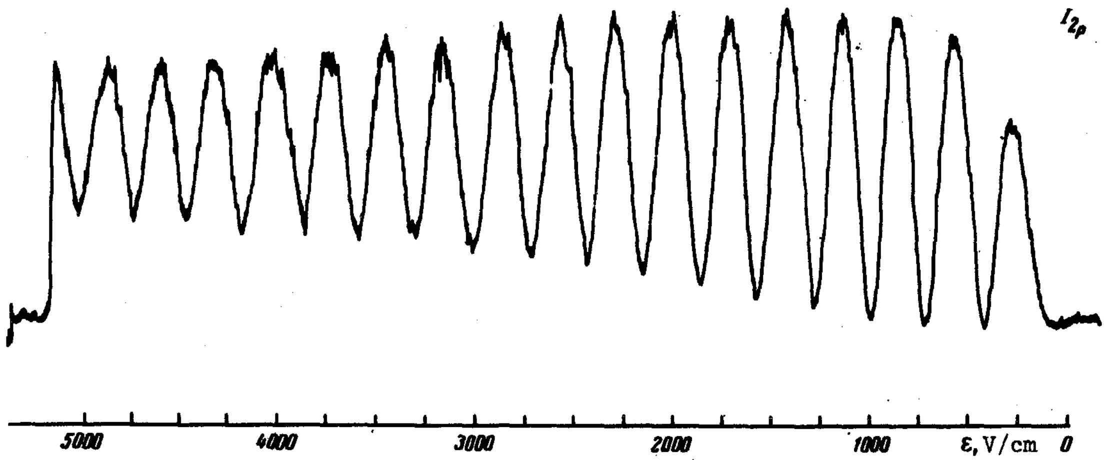


Fig. 3. Plot of $I_{2p}(\mathcal{E})$ at $\tau = 1 \times 10^{-9}$ sec and x = 1.5 cm. Automatic plotting at an integrator time constant of 1 sec.

In stronger fields, a rise of the points corresponding to the minima of the curve is again observed, and is accompanied by a decrease of the amplitudes. This effect also depends on the time of flight $\tau$. With further increase of the field, a certain increase of the amplitude takes place (e.g., for $\tau \sim 2.4 \times 10^{-9}$ sec, the increase begins approximately with the 42nd "loop" of the curve, corresponding to a field intensity on the order of 4600 V/cm). It should be noted that certain essential features of the observed phenomena (especially at large x, $\tau$, and $\mathcal{E}$), call for further study.

The described experiments revealed an obvious dependence of the interference picture on the Lamb shift. However, at the initial stage of the investigation it is difficult to obtain a reliable estimate of the practically attainable accuracy of determining $\delta_H$, inasmuch as in precision measurements it is necessary to use a procedure that makes it possible to separate the contributions of individual components of the hyperfine structure. In addition, it is also necessary to establish optimal methods for reducing the experimental data. At the present time the theoretical part of the paper, namely an exact solution of the problem of the flight of an $H_{2s}$ atom through a field $\mathcal{E}$ is not fully completed. A preliminary analysis by V.M. Galitskii has shown that if the field is turned off not too abruptly, the calculation of the transition amplitude, with accuracy on the order of $10^{-5}$, entails a number of considerable difficulties. Nonetheless, fromthe analysis of the performed experiments it follows that there is apparently a definite possibility of decreasing the error in the value of $\delta_H$ in comparison with its existing value. Therefore, in subsequent experiments, provision is made for an exact determination of the initial data for the calculation of $\delta_H$.

The author is grateful to V.M. Galitskii for constant help and a number of valuable hints, to I.N. Golovin for support, to E.K. Zavoiskii, O.B. Firsov, A.I. Baz', and D.P. Grechukhin for discussion of the results, and to V.V. Chashchin for preparing the electronic apparatus and taking part in the measurements.

[1] B.N. Taylor, W.H. Parker, and D.N. Langenberg, Revs. Mod. Phys. 41, 375 (1969).
[2] A. Pais and O. Piccioni, Phys. Rev. 100, 1487 (1955).

## GAUSS-AMPERE CHARACTERISTICS IN p-Ge IN STRONG ELECTRIC FIELDS

N.G. Kalitenko, D.A. Kichigin, and V.P. Lobachev
Institute of Radiophysics and Electronics, Ukrainian Academy of Sciences
Submitted 10 April 1970; resubmitted 25 April 1970
ZhETF Pis. Red. 11, No. 11, 528 - 531 (5 June 1970)

There has been much recent interest in different effects connected with inelastic scattering of carriers in semiconductors [1 - 5]. It was shown in particular in [1 - 2] that in the case of inelastic scattering by optical phonons $\omega_0$ at temperatures $T \ll \omega_0$ and at a magnetic field $H_c$, in a definite interval of electric fields $E^- \ll E \ll E^+$, singularities appear in the gauss-ampere characteristics, namely a sharp decrease of the dissipative current and a maximum of the Hall current.

The experiments described in the present communication were performed for the purpose of observing the indicated effect.

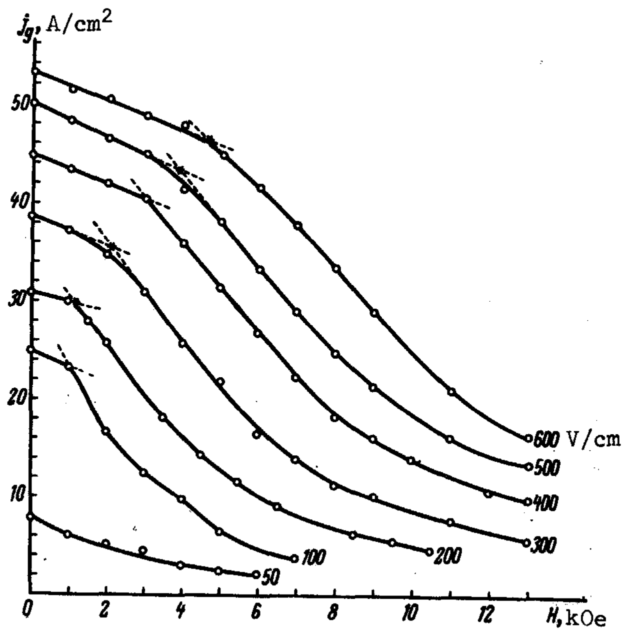


Fig. 1. Density of dissipative current vs. magnetic field.

The measurements were performed at 20°K on a p-Ge sample with resistivity 48 ohm-cm (carrier density $N_a - N_d = 3 \times 10^{13}$), in the form of a rectangular plate measuring 9 × 1.8 × 0.5 mm.

To eliminate the Hall potential [6], an alloy of tin with indium (80% Sn + 20% In) was melted into the long side faces of the sample by diffusion, and current electrodes were attached to this alloy. The pulsed electric field was always perpendicular to the magnetic field, which ranged from zero to 13 kOe. The maximum electric field intensity was ~800 V/cm.

Figure 1 shows the gauss-ampere characteristics obtained at different values of the electric field. It is seen from the figure that in the region of electric fields from zero to 50 V/cm there are no noticeable singularities in the plot of the dissipative current against the magnetic field, and the current varies monotonically as the result of the magnetoresistance. In stronger electric fields it is possible to observe on the plot sections that have different slopes, and the point of inflection moves towards larger values of the magnetic field with increasing applied electric field. The dependence of E on the values of $H_c$ corresponding to these inflection points is a straight line (Fig. 2).

In analogous experiments performed for the case of open Hall contacts, no characteristic singularities were observed in the gauss-ampere curves.