From (4) we get in second order of perturbation theory:

$$I_0 = 9\hbar\omega_0^3\omega_D^4\Delta\omega_0 Q^2G_1^2G_2^2[2^2(2\pi)^7 v^{14} q^4 V^2]^{-1}, \tag{5}$$

where G_1 and G_2 are the averaged values of $G_{\alpha\beta\gamma\xi}$ and $G_{\alpha\beta\gamma}$, $G_1 = 2\pi 10^{-18}$ erg, $G_2 = R2a^3N/3!(2\sqrt{2})^3$ [7], $R \sim 10^{13}$ erg/cm^3, $a = 6.45$ Å, ω_D is the Debye frequency of InSb, $\Delta\omega_0 = 5\pi 10^4$ rad/sec - width of absorption line of In^{115}, $v = 4.25 \times 10^5$ cm/sec - speed of sound, and $q = 5.8$ g/cm^3 - density of sample. Calculations by means of (5) and (1) with allowance for the coefficient α yield $I \sim 10^{-15}$ W at the maximum, coinciding with the experimental value of this quantity. We note also that in the described phenomenon we registered for the first time spontaneous two-quantum transitions of a quantum system. When $T_1 \to T_2$ and when impurities with strong spin-phonon interaction are used (such as paraelectrics), the SPI phenomenon can be used for effective generation of sound.

In our experiment the InSb sample acted as a phonon quantum generator [8] (PQG) at the coherent spontaneous transitions of the crystal lattice, and the pumping of the population was "automatically realized" as a result of the nuclear spin-lattice relaxation, while the emission intensity was set by the amplitude of the applied alternating magnetic field. Unlike the usual PQG [7], the present generator operates at any spin temperature $\infty > T_S \gtrless 0$, this being connected with the use of zero-point oscillations in the generation process. This example points to the promising nature of using zero-point oscillations in quantum and nuclear electronics. It is obvious that the principle of phonon generation realized by us can be used to excite other quasiparticles with the aid of various zero-point oscillations in any frequency range.

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CHARGE EXCHANGE OF PROTONS ON ALKALI-ELEMENT ATOMS

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The effective cross sections for charge exchange of protons on atoms (the reaction $H^+ + A \to H(n, \ell) + A^+$, where n and ℓ are the principal and orbital quantum numbers) were measured recently in states with different values of n and ℓ. A characteristic feature of charge exchange in an excited state at low energies (1 - 10 keV) is the presence of several maxima on the plot of the cross section against the energy [1]. The appearance of additional maxima can be qualitatively attributed to a transition through an intermediate level [2]. With increasing collision energy, this effect ceases to play an important role, and the cross section is satisfactorily described as a rule by the first approximation of perturbation theory, which yields a decrease rate $\sigma \sim E^{-6} - E^{-7}$ (E - proton energy). However, recently measured [3] cross sections for the charge exchange of protons on alkali-element atoms with production of excited hydrogen atoms revealed an exceedingly weak dependence on the energy in the 20 - 40 keV region. It is shown in the present paper that such a dependence is connected with the possibility of electron capture from the internal shells.

For an analysis of the available experimental material it is necessary to take into account the dependence of the cross section on the orbital quantum number ℓ of the produced atom. However, even in the simplest modification of first-order perturbation theory (the Brinkman-Kramers (BK) approximation), reasonable analytic results can be obtained only for the cross sections summed over all values of the orbital angular momentum ℓ (at a given n) [4]. The solution of this problem therefore calls for a numerical calculation.

The effective cross section for proton-atom charge exchange with production of a hydrogen atom in a state $n\ell$ has in the BK approximation the form (we use atomic units):

$$\sigma = \pi a_0^2 \frac{8N}{v^2}(2\ell+1) \int_{\frac{\omega}{v}+\frac{v}{2}}^{\infty} y\,dy \Big[\int_0^{\infty} R_{n\ell}(r)\, i_\ell(yr)\, r^2 dr \int_0^{\infty} R_{n_0\ell_0}(r)\, i_{\ell_0}(\sqrt{y^2-2\omega}\, r)$$

$$\times \zeta(r)\, r^2 dr \Big]^2 .$$

Here N - number of equivalent electrons of the atom shell from which the capture takes place, ω - resonance defect, v - relative velocity, $n_0\ell_0$ - quantum numbers of the target-atom electron, $R_{n\ell}$ - radial wave function [5], $i_\ell(r)$ - spherical Bessel function, and $\zeta(r)$ - effective field of atomic residue [5].

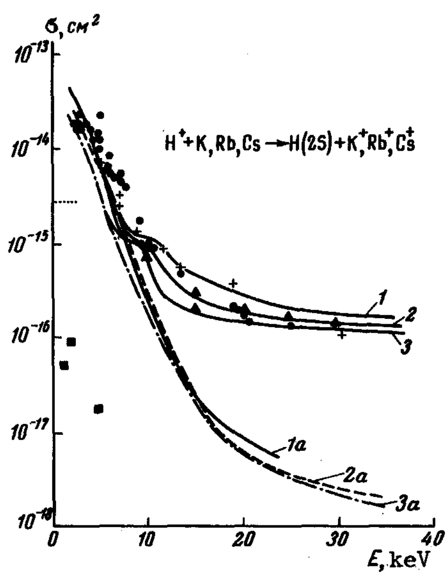
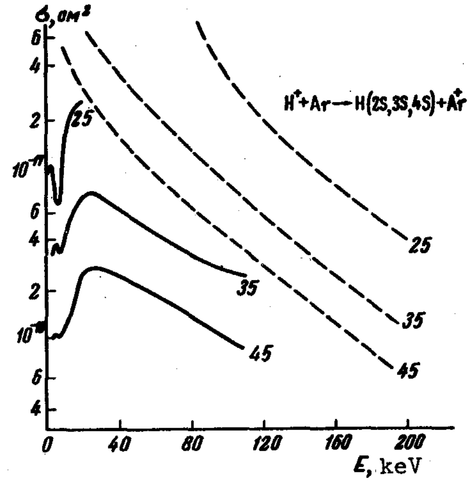


Fig. 1. Curves 1, 2, 3 - cross sections for the capture of an electron in state 2s in charge exchange of protons on Cs, Rb, and K atoms respectively; 1a, 2a, 3a - the same quantities calculated with allowance for the outer shell only; experimental data: ● - Cs, + - Rb, ▲ - K [3], ■ - Cs [6], ●●● - Cs [7].

Fig. 2. Cross sections of the reactions $H^+ + Ar \rightarrow H(2s, 3s, 4s) + Ar^+$. Solid curves - experiment [8], dashed - calculation according to (1).



The calculation was performed with an M-20 electronic computer using a universal program that made it possible to calculate the charge-exchange cross sections of protons with arbitrary atoms, with allowance for the contributions of all the electron shells of the target atom. The latter is important, since the main regularities of charge exchange at high energies are presently being investigated with capture of the optical electron as an example. However, capture of an electron from an internal shell is also a first-order process, and should in general be taken into account simultaneously with the capture of an optical electron.

The foregoing is illustrated in Fig. 1, where the results of the calculations are compared with the experimental data [3,6,7]. In charge exchange of protons with atoms of alkali elements, the cross section for the capture of the optical electron is smaller than the experimental one by two orders of magnitude. The large values of the experimental cross sections and their anomalously slow decrease at energies higher than 20 keV are attributed to the fact that the main role is played in this region by charge exchange from the internal shells. Thus, in the case of the Cs atom the contribution of the $5p^6$ shell amounts to 70% and that of the $5s^2$ shell to 30% at energies 20 - 40 keV. Analogously, it is necessary to take into account the shells $4p^6$ (90%) and $5s^2$ (10%) for the Rb atom, and the shells $3p^6$ (90%) and $3s^2$ (10%) for the K atom.

The results can be explained in terms of the specific features of the structure of the electron shells of the alkali-element atoms and the small resonance defect of the reaction. It should be noted that an appreciable contribution from the internal shells is possible also in other reactions accompanied by a redistribution of particles, for example in the ionization of the atoms of alkali elements by electrons and ions.

In the charge exchange of protons with inert-gas atoms, owing to the large resonance defect, the internal-shell electrons do not play any role, up to collision energies $E \sim 200 - 300$ keV. Figure 2 shows by way of an example the charge-exchange cross sections with the Ar atom. Capture of the optical electron describes the experimental data [8] with an error that is standard for the BK approximation.

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QUANTUM EFFECTS IN A SINGLY-CONNECTED SUPERCONDUCTING CYLINDER

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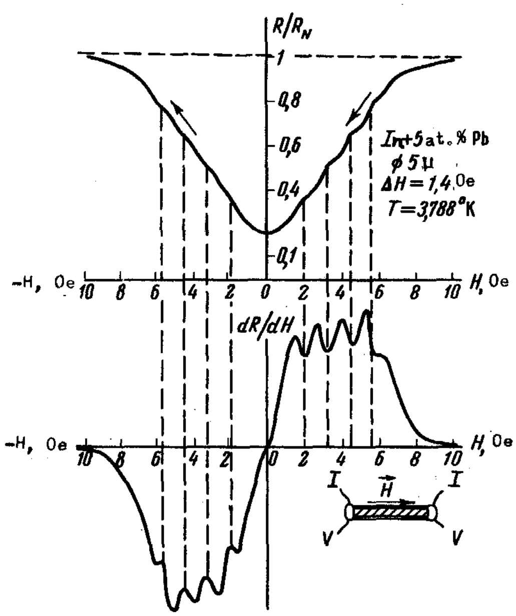
As is well known [1], a superconducting surface-current layer is produced in superconductors with $\kappa \gtrsim 0.4$ in fields $H \leq H_{c3} = 1.69H_c$ parallel to the superconductor surface. Such a superconducting surface layer is analogous to a doubly-connected superconductor that quantizes the magnetic flux. The possibility of quantization by means of surface-superconductivy currents was considered theoretically in a paper by Saint-James [2]. On the basis of his paper, one could expect the existence of an oscillatory dependence of the critical temperature of solid small-diameter cylinders, in analogy with the behavior of hollow thin-wall superconducting cylinders in the experiments of Parks and Little [3].

We investigated the resistance of a wire of indium alloyed with 5 at.% lead [4], with diameters from 1 to 5 μ, as a function of the magnetic field parallel to the wire axis at temperatures near critical. The samples were prepared by drawing a glass capillary with the molten metal. The glass was not removed from the sample. The figure shows a typical R(H) plot obtained for a sample of approximately 5 μ diameter and 4 mm length. The same figure shows a plot of the derivative dR/dH. The amplitude of the field modulation was 0.1 G.



A theoretical calculation of δT_c [5], based on a calculation of the field $H_{c3}(T)$ for bounded samples by a variational method leads to a formula analogous to the case of the Parks-Little effect:

$$\delta T_c = 0{,}14\, T_c \left(\frac{\zeta_0}{a}\right)^2,$$

where a - radius of cylinder. The amplitude of the