Light-induced diffusion of sodium vapor[1]

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The results of experimental observation of a new effect—light induced diffusion of gases—are presented. It was established experimentally that sodium vapor, which undergoes resonance interaction with the radiation, can move in the direction of or opposite to the light flux as a result of collision with the buffer gas.

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A new effect was predicted in Ref. 1—the light-induced diffusion of gases, which can be explained as follows. Let us assume that the frequency of monochromatic radiation ω is close to the frequency ω_{mn} of the transition m-n between the ground state (n) and the excited state (m) of an atom. Because of the Doppler effect, the atoms whose velocities $\mathbf{v}$ satisfy the condition $\Omega \equiv \omega - \omega_{mn} = \mathbf{kv}$ interact most effectively with the field. For inhomogeneous broadening ($\Gamma \ll kv$, where Γ is the half-width of the luminescence line of a single atom and $\bar{v}$ is the average thermal velocity), the velocity distributions of the excited $[\rho_{mm}(\mathbf{v})]$ and unexcited $[\rho_{nn}(\mathbf{v})]$ atoms contain the so-called Bennett peaks and dips (Fig. 1a). For homogeneous broadening ($\Gamma > k\bar{v}$), each distribution can be represented as the sum of the equilibrium (Maxwellian) and anti-symmetric parts (Fig. 1b). It is characteristic that in both cases the velocity distributions $\rho_{mm}(\mathbf{v})$ and $\rho_{nn}(\mathbf{v})$ are asymmetric and the asymmetry sign is determined by the sign of Ω. Consequently, each state of the atom has an ordered motion or the flow: $\mathbf{j}_m = \int \mathbf{v} \rho_{mm}(\mathbf{v})\,d\mathbf{v}$ and $\mathbf{j}_n = \int \mathbf{v} \rho_{nn}(\mathbf{v})\,d\mathbf{v}$. It is clear that the $\mathbf{j}_m$ and $\mathbf{j}_n$ fluxes buck each other. If the gas of absorbing atoms is mixed with the buffer gas, then the indicated partial fluxes set in motion the absorbing gas as a whole. In fact, since the dimension of the atom in the ground state is different from that in the excited state, the partial fluxes encounter a different resistance from the buffer gas (Fig. 2). Since the atomic states change relatively rapidly in the radiation field (curved arrows in Fig. 2), the
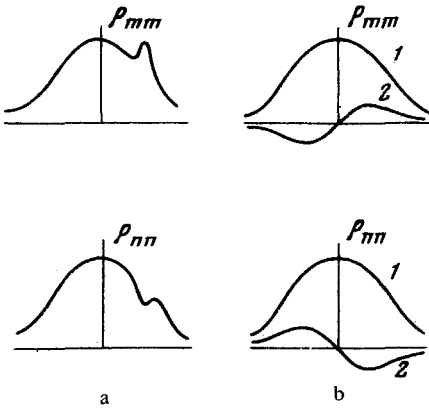
FIG. 1. Dependence of ρ_{mm} and ρ_{nn} on velocity (kv): a—$\Gamma \ll k\bar{v}$; b—$\Gamma > k\bar{v}$; 1-Maxwellian part; 2—antisymmetric corrections.

atoms as a whole experience a pressure from the buffer gas and, in the case of Fig. 2, they begin to move in the direction of $\mathbf{j}_n$ (the flux $\mathbf{j}_n$ is in the direction of or opposite to the wave vector $\mathbf{k}$, depending on the sign of Ω).

The estimates in Ref. 1 show that the velocity of the ordered motion of the absorbing gas can reach $0.1\bar{v}$. If, however, the absorbing cell has the shape of a capillary sealed at both ends, then the absorbing gas will move until it builds up a density gradient that compensates for the pressure force exerted by the buffer gas. Under actual conditions the absorbing gas may be collected in a layer ~ 0.1 mm thick.

We set up an experiment to observe the light-induced diffusion. We used sodium vapor as the absorbing gas and we selected nearly optimum conditions for the effect. The radiation source was a narrow-line dye laser (~ 300 MHz) tunable in the region of the sodium D lines. The laser output power was 20 mW. The absorbing cell was a glass capillary with 0.5-mm-i.d. diameter and 8 cm in length, with a hole in the middle through which the sodium vapor was injected. The light beam was partially cut off by the inlet hole, and the intensity at the outlet was ~ 10 mW. Thus, the radiation filled uniformly the cross section of the capillary. The cell was placed into a thermostat at a temperature of 100–150 °C. The geometry of the entire setup was symmetrical relative to the central hole of the capillary. The flow rate of sodium vapor through the capillary was regulated by a furnace with an independent heater. The vapor pressure varied from 10^{-5} to 10^{-6} mm Hg. We used helium and neon as the buffer gases at a pressure of 30 mm Hg.
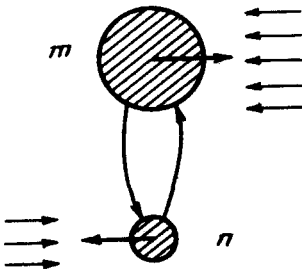

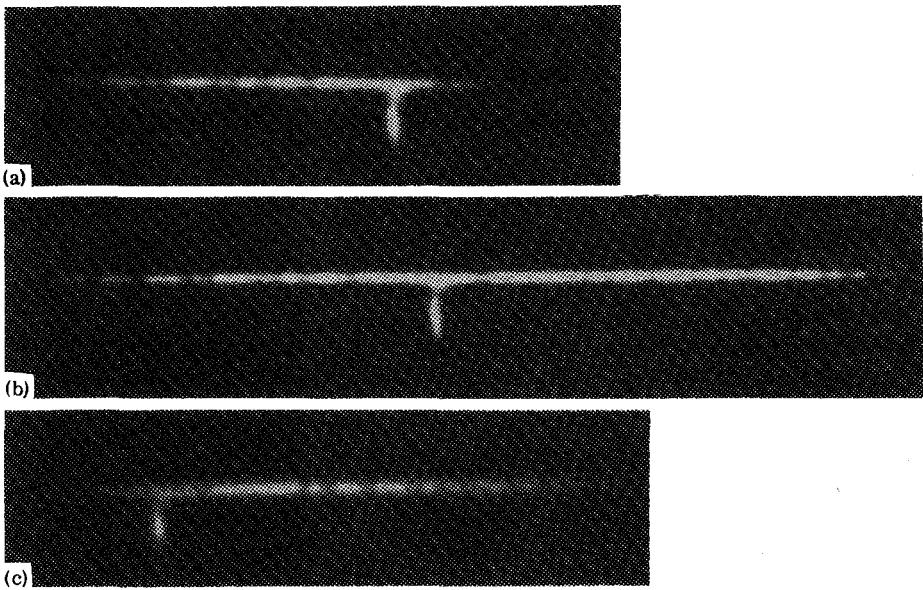FIG. 2. Illustration of the light-induced diffusion effect.

FIG. 3. Results of the experiment: a—$\Omega \approx -10^3$ MHz; b—$\Omega = 0$; c—$\Omega \approx 10^3$ MHz. The radiation is propagating from right to left.

The effect was observed visually from the fluorescence of the sodium vapor. In accordance with the effect, we expected that, after entering through the central hole, the sodium vapor would pass through only one of the arms of the capillary, depending on the sign of the difference $\omega - \omega_{mn} = \Omega$. It turned out, however, that because of the strong adsorption of sodium on the surface, the sodium vapor penetrated a distance of only ~ 3 cm from the hole, and the effect appeared in the form of variation of the ratio of the lengths of the luminous regions on the left- and right-hand side of the hole.

Figure 3 shows photographs of the characteristic luminescence when helium was used as the buffer gas and the radiation excited the sodium D_2 line. Analogous results were obtained for excitation of the D_1 line and also when neon was used as the buffer gas.

The qualitative results obtained by us for the first time show that the light-induced diffusion effect can be highly pronounced. A quantitative comparison with theory at this stage of investigation would not serve any purpose because of the strong masking effect of the adsorption of sodium at the capillary walls. In particular, the adsorption is attributable to the fact that a stationary distribution of the sodium vapor density takes a rather long time to be established (10–15 min).

[1]F.Kh. Gel'mukhanov and A.M. Shalagin, Pis'ma Zh. Eksp. Teor. Fiz. **29**, 773 (1979) [JETP Lett. **29**, 711 (1979).