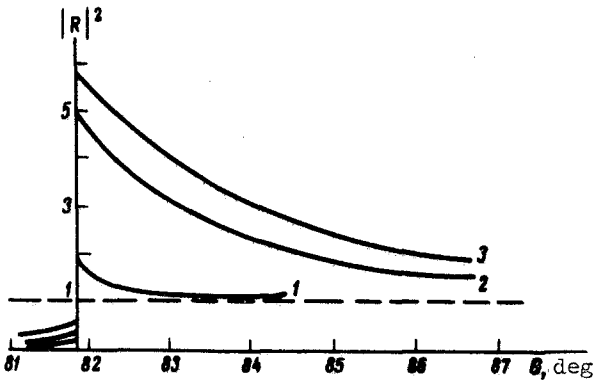

Fig. 1

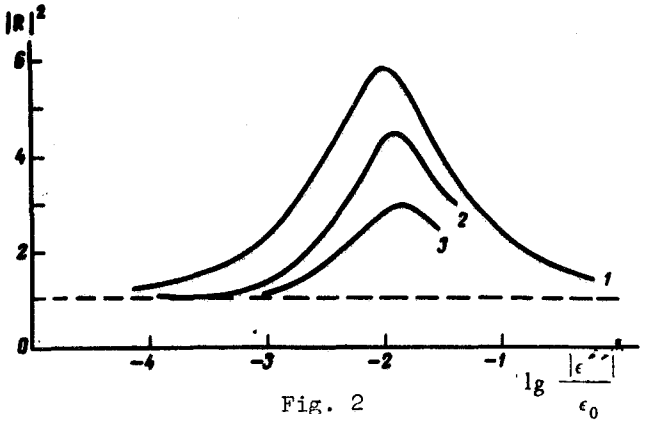

Fig. 2

Fig. 1. Square of the modulus of the reflection coefficient ($|R|^2$) vs. the incidence angle θ at a fixed value $\varepsilon'/\varepsilon_0 = 0.98$ and at various values of the ratio $\varepsilon''/\varepsilon_0$: 1) 10^{-3}, 2) 10^{-2}, 3) 2×10^{-2}.

Fig. 2. Square of the modulus of the reflection coefficient ($|R|^2$) vs. $\log(|\varepsilon''|/\varepsilon_0)$ at a fixed $\varepsilon'/\varepsilon_0 = 0.99$ and different incidence angles: 1) incidence at the angle of total internal reflection $\theta_0 \approx 84°17'$, 2) $\theta = 84°50'$, 3) $\theta = 85°57'$.

it follows that the condition $\nu' < 0$ (at which $|R| > 1$) means flow of energy from the second inverted medium into the first. A comparison of the expressions for $|R|^2$ and $\langle S_z \rangle$ allows us to conclude that the incident (one might say priming) flux, corresponding to unity in the expression for $|R|^2$, gives rise to stimulated transitions in the inverted medium, amplifying by the same token the reflected wave. The maximum value of the reflection coefficient for arbitrary $\varepsilon''/\varepsilon_0$ and $\varepsilon'/\varepsilon_0$ is attained near the total-internal-reflection angle $\theta = \theta_0 + 0$ (Fig. 1). But an unbounded increase of the inverted population does not mean an unbounded increase of the reflection coefficient, for when the so-called effective refractive index $n = (\varepsilon' + |\varepsilon''|)/\varepsilon_0$ is equal to unity, $|R|^2$ reaches an absolute maximum value approximately equal to e^2 near the angle $\theta = \theta_0 + 0$ (Fig. 2). This is explained by the fact that in the case of total internal reflection the depth d of penetration of the field into the inverted medium decreases with increasing inverted population. For example, $d \lesssim 30\lambda$ at $|\varepsilon''|/\varepsilon_0 = 10^{-4}$ and $d \lesssim 3\lambda$ at $|\varepsilon''|/\varepsilon_0 = 10^{-2}$. Similarly, in the geometrical-optics approximation, a large linear gain K of the inverted medium corresponds to a smaller path ℓ transversed in it by the incident beam, and the upper bound of the product $K\ell$ has the same value for all $\varepsilon'/\varepsilon_0$ and $\varepsilon''/\varepsilon_0$, so that $|R|^2 \lesssim e^{K\ell} \leq e^2$. These results are valid for both polarizations of the incident wave.

In conclusion, the authors are grateful to L.N. Kurbatov, V.I. Stafeev, and E.M. Kuznetsova for interest in the work and for a fruitful discussion.

POSSIBILITY OF GENERATING ULTRASHORT LASER PULSES ON COMBINATION VIBRATIONAL-ROTATIONAL TRANSITIONS OF MOLECULAR HYDROGEN

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Submitted 26 July 1972
ZhETF Pis. Red. 16, No. 5, 301 - 304 (5 September 1972)

1. We consider here the possibility of obtaining short laser-radiation pulses on vibrational-rotational transitions of the molecules of hydrogen and

its substitute isotopes. The molecules H_2 and D_2 have no dipole moment, and have therefore long vibrational-translational relaxation times. They can remain in an excited state for about 10^{-3} - 10^{-4} sec up to pressures of several atmospheres at T ~ 300°K. The rotational-translational equilibrium sets in within a time $\sim 10^{-8}$ sec, and it can be assumed that $T_{rot} = T_0$ (the gas temperature).

The ability of hydrogen to accumulate vibrational energy is used to obtain generation by resonant transfer of a vibrational quantum to the molecules of an impurity gas [1]. Owing to the absence of dipole transitions, and to the low probability of the quadrupole ones, it was impossible to use the hydrogen molecules directly to obtain generation on vibrational-rotational transitions.

We consider in this paper the possibility of obtaining generation on transitions that appear in the vibrational-rotational spectrum of hydrogen in the presence of a sufficiently strong electric field E, either constant or alternating. The probability of emitting or absorbing a quantum turns out to be proportional to E^2. The existence of these so-called electric-field-induced (EFI) transitions was predicted in [2]. The EFI transitions satisfy the selection rules $\Delta j = 0, \pm 2$. The case of application of an alternating induced field can be interpreted as a two-photon process.

It is assumed that the excitation of the vibrational levels of the molecules at high gas density is effected by the so-called electro-ionization method, i.e., by passing an electric current through a dense gas in which the conductivity is produced by an external ionization source [3, 4]. The electro-ionization method makes it possible to excite dense gases and hence to use high electric field intensities to induce a dipole moment on the transitions $\Delta j = 2$. The proposed system should have a high efficiency of conversion of electric energy into coherent-radiation energy.

2. The fraction of electric energy converted into molecule vibration energy in the electro-ionization excitation method, η_v, can be represented in the form

$$\eta_v = \frac{\langle \sigma_v V \rangle \Delta E_v}{\langle \sigma_v V \rangle \Delta E_v + \sum_{j,i} (N_j / N_0) \langle \sigma_{j,i'} V \rangle \Delta E_{j,i'} + \langle \sigma_m V \rangle (2m/M)\varepsilon},$$

where σ_v and $\sigma_{j,j'}$ are respectively the cross sections for the excitation of vibrations and rotations of the molecules, ΔE_v and $\Delta E_{j,j'}$ are the changes of the vibrational and rotational energy, ε is the average electron energy, σ_m is the cross section for momentum transfer, and m/M is the ratio of the electron mass to the hydrogen-molecule mass. Calculations at a temperature T ~ 100°K, based on cross-section data given in [5] and on an average electron energy ~1 eV (E/p ~ 10 V/cm-mm Hg) show that up to 90% of the electric energy can be converted into the energy of hydrogen-molecule vibration.

3. We define the vibrational temperature T_v by the relation

$$N_2 / N_1 = \exp(-\Delta E_v / kT_v), \tag{1}$$

where N_1 and N_2 are respectively the concentration of the molecules in the ground and first vibrational-excited states. The distribution of the molecules over the vibrational states is described by a Boltzmann factor with a temperature $T_{rot} = T_0$

$$n(j) \sim (2j+1) \exp\left(-\frac{Bj(j+1)}{kT_0}\right). \tag{2}$$

From (1) and (2) follows a condition for population inversion in the transition $j_2 \to j_1$ ($j_1 = j_2 + 2$)

$$T_v \geqslant T_0 \frac{\Delta E_v}{B(4j_2 + 6)} . \tag{3}$$

We chose hydrogen because of its large rotational constant B and the possibility of operating at temperatures $T \sim 30°K$.

4. The gain in the induced transitions can be represented in the form

$$K(\omega_1) = \left(\frac{\ln 2}{\pi}\right)^{1/2} \frac{A_{j_2 \to j_1}(E^2, \omega_0)\lambda_1^2}{4\pi\Delta\nu} \left[\frac{n(j_2)}{2j_2 + 1} - \frac{n(j_1)}{2j_1 + 1}\right], \tag{4}$$

where $A_{j2 \to j1}(E^2, \omega_0)$ is the transition probability and depends on the electric field intensity and on the frequency of the signal that induces the dipole moment. In the case

$$\omega_0 = 0, \quad \omega_1 = \frac{\Delta E_v + Bj_2(j_2 + 1) - Bj_1(j_1 + 1)}{\hbar};$$

$K(\omega)$ can be calculated on the basis of data on the emission line width and on the integral absorption coefficient β in H_2 on EFI transitions, given in [6, 7]

$$\frac{\beta}{E^2} \approx \frac{\pi^3 \nu \gamma_{01}^2}{hc} n(j_1): \quad \gamma_{01} = 0{,}72 \cdot 10^{-25} \text{ cm}^3, \tag{5}$$

$$\Delta\nu = 2\left[\frac{7{,}6N^2\sigma^4 kT}{4\pi m}\right]^{1/2}; \quad \sigma = 2{,}6 \cdot 10^{-9} \text{ cm}. \tag{6}$$

From (5) and (6) we obtain for $K(\omega_1)$ at $j_2 = 0$ and $T_0 \lesssim 77°K$

$$K(\text{cm}^{-1}) \approx \frac{4{,}5 \cdot 10^{-30}}{\Delta\nu(\text{см}^{-1})} E^2(\text{cgs esu}) N_2(\text{cm}^{-3}). \tag{7}$$

Expression (7) can be used to estimate the gain also at $\omega_0 \ll \omega_1$, for example if the strong induced electric field is that of ultrashort pulses of high-pressure CO_2 laser radiation. These estimates show that at a gas density $p \sim 25$ amagat, at which the line width $\Delta\nu$ amounts to $\sim 2 \times 10^{-2}$ cm^{-1}, and at a CO_2 laser pulse duration $\sim 10^{-11}$ sec and energy ~ 0.1 J/cm^2, the gain (in cm^{-1}) is $K = 0.1Q$, where Q is the accumulated vibrational energy in J/cm^3. Experiments show [3, 4] that it is not difficult, in principle, to store an energy on the order of 1 J/cm^3 in the vibrational reservoir of a symmetrical diatomic molecule. This makes it possible to obtain a gain $K = 0.1$ cm^{-1}. The quantum efficiency of conversion of the vibrational energy into coherent radiation is

$$\eta_k = \frac{\Delta E_v - \Delta E_{i,i'}}{\Delta E_v} \approx 85\%.$$

In conclusion we call attention to the fact that the forbiddenness of dipole transitions with $\Delta j = \pm 1$ is partly lifted in the molecules HD and HT,

owing to symmetry violation [8]. This makes it possible to obtain, in principle, generation without an external field to induce the transitions.

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INFLUENCE OF CARRIER DRIFT ON THE PROPAGATION OF ELECTROMAGNETIC WAVE IN A SOLID-STATE PLASMA

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Submitted 24 August 1972
ZhETF Pis. Red. 16, No. 5, 305 - 307 (5 September 1972)

Moss and co-workers [1], using a ring laser, succeeded in measuring with high accuracy the difference between the refractive indices of light propagating in a semiconductor parallel and antiparallel to the current lines. They associated the effect observed by them with the Fresnel dragging of light by the electrons of the semiconductor. By the same token, according to [1], this was the first observation of a relativistic effect caused by carriers moving relatively slowly in the direction of the field. A phenomenological theory of the Fresnel dragging, with the Doppler-effect contribution taken into account, was presented in [1] in accord with the assumed model.

It seems to us, however, that a more rigorous analysis should be based on the kinetic equation and Maxwell's equations, without using any model concepts for dragging. Indeed, if spatial disperson and drift of the electron gas are taken into account, the dielectric tensor $\varepsilon_{\mu\nu}(\omega, \vec{k})$ of the semiconductor does not satisfy the Onsager symmetry relation $\varepsilon_{\mu\nu}(\omega, \vec{k}) = \varepsilon_{\mu\nu}(\omega, -\vec{k})$. In the case of weak spatial dispersion, the expansion of $\varepsilon_{\mu\nu}(\omega, \vec{k})$ in powers of $\vec{k}$ in the presence of a constant electric field $\vec{F}$ contains linear terms (cf., e.g., [2]). The presence of these terms determines the difference between the conditions of electromagnetic wave propagation for $\vec{k} \uparrow\downarrow \vec{F}$ and $\vec{k} \uparrow\uparrow \vec{F}$.

To estimate this difference quantitatively, we consider the linear response of an electron gas with an isotropic energy dispersion law $\varepsilon(\vec{p})$ to a perturbation due to an electromagnetic wave $\vec{E}(\vec{r}, t)$, $\vec{H}(\vec{r}, t) \sim \exp[i\omega t - \vec{k}\cdot\vec{r})]$. The kinetic equation of the problem is

$$i(\omega - \mathbf{kv})\phi + \left(e\mathbf{F} + \frac{e}{c}[\mathbf{v} \times \mathbf{H}_0]\right)\frac{\partial \phi}{\partial \mathbf{p}} + \left(\frac{\partial \phi}{\partial t}\right)_c = -\left(e\mathbf{E} + \frac{e}{c}[\mathbf{v} \times \mathbf{H}]\right)\frac{\partial f}{\partial \mathbf{p}},$$

where $\phi(\vec{p}, \vec{k}, \omega)$ is the sought increment to the stationary distribution function $f(\vec{p})$; $\vec{F}$ and $\vec{H}_0$ are constant fields; $(\partial\phi/\partial t)_c$ is the collision integral, $\vec{v}(\vec{p}) = (\partial\varepsilon(\vec{p})/\partial\vec{p}) \equiv \vec{p}/m(\varepsilon)$ is the velocity of an electron with momentum $\vec{p}$.