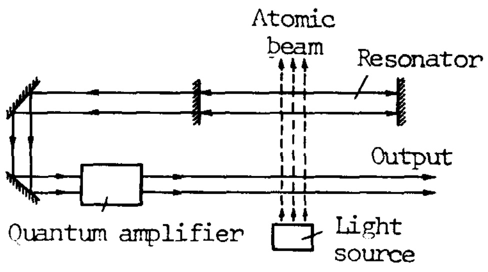
ATOMIC BEAM LASERS

N. G. Basov and V. S. Letokhov
P. N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 15 May 1965

1. By reducing the active-medium spectral line width, it is possible to increase the resolution of spectroscopes or to increase the frequency stability of lasers. The width of the narrowest spectral lines attainable in gas media is governed by the Doppler effect. To decrease the width, it is natural to use atomic beams passing parallel to the front of the resonator wave, when the Doppler broadening can be appreciably decreased [1]. For high-frequency stability it is desirable to have the spontaneous emission line width much smaller than the resonator bandwidth, for in this case the natural frequency of generation will be determined by the frequency of the optical transition. However, allowed optical transitions are not suitable for population inversion in a beam, since the atom can travel only 10^{-2} - 10^{-3} cm during its lifetime in the excited state (10^{-7} - 10^{-8} sec). Therefore only forbidden transitions with lifetimes 10^{-3} - 10^{-5} sec are suitable for atomic-beam lasers.

2. To obtain inversion of the optical transition level population in this case, it is convenient to use the "180-degree momentum" method [2], which can be used for an atomic beam in the following fashion: a beam of atoms in the ground state passes through an exciting light ray, the frequency ω of which coincides with the frequency ω_0 of the transition of the atom to the excited long-lived state, and the average transit time τ_0 of the atoms through the ray coincides with the inversion time $\tau_i = \pi\hbar/2\mu_{12}E_0$, where E_0 is the field intensity in the ray and μ_{12} is the radiative-transition matrix element.

The Doppler width of the spontaneous emission line of the beam is in practice much larger than the reciprocal of the transit time $1/\tau_0$, and therefore only the inverted atoms are those in the frequency interval $(\omega - 1/\tau_0, \omega + 1/\tau_0)$, whose center is at the light-ray frequency ω. Consequently, the generation frequency is determined by the frequency ω and may not coincide with the central transition frequency ω_0. To get around this difficulty and to effect generation at ω_0, it is possible to excite the beam with a light ray from the laser operating with the same beam (see the Figure).



To compensate for the energy loss it is necessary to pass the light ray first through an optical quantum amplifier, which amplifies the band containing ω_0. Such a circuit can be tuned to the center ω_0 of the transition and can be a very stable frequency.

3. The transitions that are suitable for excitation in the beam satisfy the following conditions: the lower state of the transition must be at the ground or near-ground level, and the spontaneous lifetime of the excited state must be 10^{-3} - 10^{-5} sec. These conditions are satis-

fied by the intercombination transitions n^1S_1 - n^3P_1 of several alkali-earth elements (Sr, Co, Mg) and of Zn, and also by the magnetic-dipole optical transitions between the levels of the deep terms of the atoms with electron configuration p^n (for example, $^3P^o_{3/2}$ - $^3P^o_{1/2}$ in Tl; $^3P_1$ - $^3P_0$ in Pb; $^2P^o_{3/2;5/2}$ - $^4S^o_{1/2}$ in N, P, As, Sb, and Bi; $^1P_2$ - $^3P_2$ in S, Se, and Te; and $^2P^o_{1/2}$ - $^2P^o_{3/2}$ in I) [3].

The numerical estimates listed in the table for the coefficient of negative absorption α for intercombination transitions of Mg, Ca, Sr, Zn in an atomic beam of density 10^{11} atoms/cm^3 show that the large value of α makes it possible to use a short broadband cavity only several centimeters long. The symbols in the table are: λ - wavelength, f - transition oscillator strength, T_1 - spontaneous lifetime of the excited level, P_0 - excitation power, I_0 - spectral density of the excitation

Excitation of intercombination transitions n^1S_0 - n^3P_1

	λ, Å	f [4]	T_1, sec	P_0, $\frac{W}{cm^2 cps}$	I_0, $\frac{W}{cm^2 cps}$	α, cm^{-1}
Mg	4571.15	2.6×10^{-6}	1.1×10^{-3}	6×10^{-6}	3.3×10^{-10}	0.013
Ca	6572.78	4.2×10^{-5}	1.4×10^{-4}	7×10^{-6}	4.9×10^{-11}	0.66
Sr	6892.59	8.6×10^{-4}	0.8×10^{-5}	1.1×10^{-4}	2.8×10^{-11}	19.0
Zn	3075.90	1.7×10^{-4}	0.8×10^{-5}	1.2×10^{-3}	4.4×10^{-11}	2.6

4. To realize a beam laser with "its own" exciting ray (see the Figure) it is necessary to construct a quantum amplifier for the transition frequency ω_0. For Ca, Sr, and several other elements one can apparently use a simiconductor quantum amplifier based on ternary compounds [5], whose frequency can be varied over a wide range. For a laser with an Se beam one can use an amplifier with a crystal doped with Nd^{3+} [6], whose wavelength can be changed near 1.05 μ by changing the crystal.

5. We note that an atomic beam can also be excited by an intense spectral line of an incoherent source. Inasmuch as such a spectral line is also broader than the beam radiation line, the center of the line of amplification of the inverted beam, meaning also the generation frequency, is determined by the transition frequency ω_0. Furthermore, spectral lamps which radiate just the intense intercombination lines of Ca, Sr, and others have recently been constructed [7].

[1] N. G. Basov and A. M. Prokhorov, JETP 27, 431 (1954).

[2] N. Ramsay, Molecular Beams (Russ. transl.), IIL, 1960.

[3] I. I. Sobel'man, Vvedenie v teoriyu atomnykh spektrov (Introduction to the Theory of Atomic Spectra) Fizmatgiz, 1963.

[4] S. E. Frish, Opticheskie spektry atomov (Optical Spectra of Atoms), Fizmatgiz, 1963.

[5] N. Holonyak and A. F. Bevacqua, Appl. Phys. Lett. 1, 82 (1963).

[6] E. Snitzer, Phys. Rev. Lett. 7, 444 (1961); L. F. Johnson, J. Appl. Phys. 33, 756 (1962).
[7] Budick, Novick, and Lurio, Appl. Optics 4, 229 (1965).

PARITY CONSERVING AMPLITUDES OF HADRON DECAYS OF BARYONS IN THE $\tilde{U}(12)$ SYMMETRY SCHEME

E. V. Gedalin, O. V. Kancheli, and S. G. Matinyan
Physics Institute, Georgian Academy of Sciences
Submitted 17 May 1965

In a preceding letter [1] we reported the results of application of the $\tilde{U}(12)$ symmetry [2-4] to hadron decays of hyperons 1).

In the case of parity nonconserving amplitudes, the transformation properties of the weak spurion were fixed in this case in a perfectly natural and unique manner. It belonged to the representation 143 of $\tilde{U}(12)$, being a pseudoscalar and the sixth component of an SU(3) vector. As to the parity-conserving amplitudes, one can conceive with respect to the weak (scalar) spurion of at least two possibilities. If no condictions such as the Bargmann-Wigner equations are imposed on the spurion, the latter can belong to the representation 143. Such a possibility was considered by us in [1] (see also [5]), and we found that the relations obtained in this case for the parity-conserving amplitudes of hadron decays of baryons disagree with the experimental data.

We consider here the other possibility: the spurion enters on an equal basis as real particles with respect to the transformation properties of $\tilde{U}(12)$ symmetry. The lowest representations of $\tilde{U}(12)$ symmetry, containing a CP-even scalar, are 4212 and 5940 [6,7], and we shall use them to describe the weak spurion H. With respect to SU(3) symmetry, this spurion should be a sixth component of a vector.

In other words, the weak spurion belonging to the representation 4212 is of the form

$$H^{[A,B]}_{[C,D]} = (\gamma_5 C)_{\gamma\delta}(C^{-1}\gamma_5)^{\alpha\beta}\left[T^i_k\delta^j_\ell + T^j_\ell\delta^i_k + T^i_\ell\delta^j_k + T^j_k\delta^i_\ell\right] - \text{trace}$$

while the weak spurion transforming in accordance with the representation 5940 is given by

$$H^{\{A,B\}}_{\{C,D\}} = (\gamma_5 C)_{\gamma\delta}(C^{-1}\gamma_5)^{\alpha\beta}\left[T^i_k\delta^j_\ell + T^j_\ell\delta^i_k - T^i_\ell\delta^j_k - T^j_k\delta^i_\ell\right] - \text{trace}$$

Here T is the sixth component of the SU(3) vector (all symbols are the same as in [1]).

For the CP-invariant parity-conserving matrix element of hadron decays we can write

$$\begin{aligned} M_{p.c.} = {} & b_1\bar{\Psi}^{\{ABC\}}(p_2)\Phi^E_M(q)H^{\{MD\}}_{\{EA\}}\Psi_{\{BCD\}}(p_1) + \\ & + b_2\bar{\Psi}^{\{ABC\}}(p_2)\left[\Phi^D_M(q)H^{\{ME\}}_{\{AB\}} + \Phi^M_A(q)H^{\{DE\}}_{\{MB\}}\right]\Psi_{\{CED\}}(p_1) + \\ & + b_3\bar{\Psi}^{\{ABC\}}(p_2)\Phi^D_A(q)H^{\{EM\}}_{\{BC\}}\Psi_{\{DEM\}}(p_1) + \\ & + b_4\,\bar{\Psi}^{\{ABC\}}(p_2)\Phi^E_M(q)H^{\{MD\}}_{\{EA\}}\Psi_{\{DBC\}}(p_1), \qquad (p_1 = p_2 + q) \end{aligned} \tag{1}$$