served.) The resultant discrepancy can be attributed in our case to the fact that the matrix element $M^A_{\mu\nu}$ (8) is not a finite quantity. If we renormalize $M^A_{\mu\nu}$, then the infinite renormalization constants will enter in the right side of a relation of the type (2), and the system becomes similar to that of the preceding example.

As a result, we arrive at the conclusion that in our approximation the Bjorken relation holds true whenever its right and left sides are finite quantities. In the case of weak vector and axial currents it is assumed in the theory of universal V-A interaction that the bare constant of this interaction is finite.** Since the axial-current renormalization constant is finite in V-A theory, the example considered by us offers evidence in favor of the applicability of Bjorken's relation to vector and axial currents in V-A theory. However, the application of these relations to any other field operator (say, the pion field operator φ), the renormalization of which can be infinite, is in general not valid.

The authors are grateful to V. V. Sokolov, I. B. Khriplovich, and E. P. Shabalin for discussions.

[1] J. D. Bjorken, Phys. Rev. 148, 1467 (1966).

* Relation (2) for $M_{0\nu}$ is of the form $\lim k_0 M_{0\nu} = 2\Gamma^{(3)}_\nu(p', p)$, where $\Gamma^{(3)}_\nu$ is the vertex function; this relation follows directly from the relation $k_\mu M_{\mu\nu} = 2\Gamma^{(3)}_\nu$, in which vector-current conservation is used.

** We are dealing at all times with normalization due to strong interactions only.

MECHANISM OF GENERATION EXCITATION IN A CONTINUOUSLY OPERATING ARGON ION LASER

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Submitted 14 July 1967; resubmitted 19 September 1967
ZhETF Pis'ma 6, No. 10, 919-921 (15 November 1967)

The main processes that ensure population of the upper levels of a continuous argon ion laser are: (1) excitation by electron impact from the Ar^+ ground state [1,2], (2) from the 3rd configuration states of Ar^+, (3) radiative cascade population [2], and (4) direct electronic excitation from the ground state of the neutral Ar atom (Bennet's process) [3]. The lack of data on the ion excitation cross sections has not made it possible to compare the intensities of these processes directly, and there are only indirect experimental data [1-3].

We have calculated the rates of excitation $\langle v\sigma \rangle$ of the ions by electron impact, from the ground and the excited states (the angle brackets denote averaging over a Maxwellian velocity distribution). The cross sections were obtained numerically in a Born-Coulomb approximation, in which the external electron is described by continuous-spectrum Coulomb wave functions with $z = 1$. In this approximation, the effective cross section for the excitation of the configuration as a whole is practically independent of the coupling scheme of the atomic electrons. We did not calculate the cross sections for transitions between individual levels, since such a calculation calls for the use of an intermediate coupling scheme and is a rather laborious problem. We used in the calculations semi-empirical radial wave functions [4]. The obtained values of $\langle v\sigma \rangle$ are listed in the table.

T a b l e

Values of ⟨vσ⟩ (10^{-10} cm^3/sec) for Ar^+ configurations

Transition \ T°K·10^{-4}	3	5	8	10
3p - 4p	0,18	3,0	14	23
3p - 3d	3,0	44	190	300
3p - 4d	0,078	2,4	16	28
3p - 5d	0,0047	0,22	1,8	3,4
3p - 4s	0,23	2,7	11	17
3p - 5s	0,003	0,10	0,62	11
3d - 4p	1900	2000	2000	1900
4s - 4p	4800	6600	7700	8000

To estimate the pumping rate, we assume, in accord with the experimental data, that under conditions close to optimal (from the point of view of the generation power) the electron concentration is 5×10^{13} cm^{-3} and the electron temperature is 80 000°K [5]. Estimates show that under these conditions the main contribution to the pumping is made by process (1). The number of acts of configuration-level excitation is 3.5×10^{18} $cm^{-3}sec^{-1}$, which agrees with the value obtained from the maximum attainable generation power (~1 W/cm^3). The same pumping rate is obtained at $n_e = 10^{14}$ cm^{-3} and T_e = 50 000°K.

If we assume that the radiation rate of decay of the $3p^4 3d$ configuration is ~10^9 sec^{-1}, then the pumping rate of the configuration 4p, resulting from process (2) at $n_e = 5 \times 10^{13}$ cm^{-3} and T_e = 80 000°K amounts to ~40% of the rate given by process (1).

Cascade transitions from the 4d configuration can also introduce a noticeable contribution to the population of the upper laser levels. Taking into account the probabilities of the radiative transitions from 4d to 4p and 3p [6], we find that this contribution is 30% of the indirect pumping from the ground state of Ar^+. Thus, processes (1), (2), and (3) make approximately equal contributions to the pumping. On the other hand, cascade transitions from 5s and 5d can be neglected, since the excitation rates of these levels are lower by one order of magnitude than that of 4p.

It can be shown that the process (4) begins to play a noticeable role in the population of the upper laser levels at high electron temperatures (80 000°K and higher) [3].

To estimate the role of impacts of the second kind in the deactivation of the upper laser levels, the table lists the cross sections of the transitions 4s - 4p. At an electron concentration 10^{14} cm^{-3} the rate of deactivation as a result of electron impacts is 4×10^7

sec^{-1}, which is comparable with the radiative-transition probabilities ($\sim 10^8$ sec^{-1}).

[1] E. F. Labuda, E. I. Gordon, and R. C. Miller, IEEE J. Quant. Elect. QE-1, 273 (1965).
[2] R. J. Rudko and C. L. Tang, Appl. Phys. Lett. 9, 41 (1966).
[3] W. R. Bennett, Appl. Optics, Suppl. 2, Chemical Lasers, 1965, p. 3; W. R. Bennett et al., Phys. Rev. Lett. 17, 987 (1966); G. N. Mercer, V. P. Chebotayev, and W. R. Bennett, Jr., Appl. Phys. Lett. 10, 177 (1967).
[4] L. A. Vainshtein, Opt. Spektrosk. 11, 301 (1961); L. A. Vainshtein and I. I. Sobel'man, Effective Born Cross Sections for the Excitation of Atoms by Electrons, FIAN Preprint No. 66, 1967.
[5] V. F. Kitaeva, Yu. I. Osipov, and N. N. Sobolev, Dokl. Akad. Nauk SSSR 172, 317 (1967) [Sov. Phys.-Dokl. 12, 55 (1967)]; V. F. Kitaeva, Yu. I. Osipov, and N. N. Sobolev, IEEE J. Quant. Elect. QE-2, 635 (1966).
[6] H. Statz et al.; J. Appl. Phys. 36, 2278 (1965); H. Statz et al., Physics of Quantum Electronics, McGraw Hill, 1965, p. 3.

INTERPRETATION OF ELECTRODYNAMICS AS A CONSEQUENCE OF QUANTUM THEORY

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Submitted 26 September 1967
ZhETF Pis'ma 6, No. 10, 922-925 (15 November 1967)

In classical theory, action is the sum of three parts pertaining to the particles (S_p), to their interaction with the field (S_i), and to the field itself (S_f)

$$S = S_p + S_i + S_f = -mc \int dS - \frac{e}{c}\int A_i dx^i - \frac{1}{8\pi c}\int (E^2 - H^2)\, d^4x. \quad (1)$$

In quantum theory of fermions we have

$$S_p = -\int \bar{\psi}\hat{p}\psi\, d^4x, \quad S_i = -\frac{e}{c}\int \bar{\psi}\hat{A}\psi\, d^4x. \quad (2)$$

Expressing E and H in terms of A, we write $S_f = L(A_{\mu,\nu})$, where L is a quadratic expression.

In quantum theory, the interaction between the field and the vacuum leads to renormalization of the charge; this means that a new term appears in the action, of the form [1]

$$S_v = ne^2 L(A_{\mu,\nu}), \quad n = \frac{2\nu}{3\pi\hbar c} \ln \Lambda/mc. \quad (3)$$

Combining S_v with S_p and denoting the renormalized quantities by primes, we have

$$S_f' = S_f + S_v = (1 + ne^2)L(A_{\mu,\nu}) = L(A_{\mu,\nu}\sqrt{1+ne^2}) = L(A'_{\mu,\nu}),$$
$$A'_{\mu,\nu} = A_{\mu,\nu}\sqrt{1+ne^2}, \ eA_\mu = e'A'_\mu, \ e' = e\, A_\mu/A'_\mu = e/\sqrt{1+ne^2}. \quad (4)$$

Landau and Pomeranchuk [1] note that when $ne^2 \gg 1$, as $e'^2 \to n^{-1}$, "it becomes possible to neglect the effect of the free electromagnetic field in the Lagrangian." See also Fradkin [4].

Following this remark, let us consider a theory in which we start out from the expression

$$S = S_p + S_i \quad (5)$$