The differential cross section passes through a minimum in the region ω = 20 - 30 GeV, and increases further like $\ln^2\omega$. To observe a significant difference in the behavior of the differential cross section it is therefore desirable to measure the cross section at energies $\omega \geq 40$ GeV.

The ratio of the real part of the amplitude to its imaginary part, which is larger than zero at ω = 10 - 20 GeV, passes through zero in the region ω = 10 - 20 GeV and approaches the limit $-2/\pi \ln \omega$ at larger ω.

The influence of the constancy of $\Delta\sigma$ on the behavior of the forward elastic KN scattering is much weaker than in the case of charge exchange. The changes are particularly small in the case of β_{el}. However, this influence could be observed in the differential elastic-scattering cross section if the measurement errors at $\omega > 50$ GeV were not to exceed 5 - 10%.

In conclusion, it is my pleasant duty to thank L.D. Solov'ev for suggesting the problem and for a discussion of the results.

[1] J.V. Allaby, Yu.B. Bushnin, Yu.P. Gorin, et al. Preprint IFVE SEF 69-87, Serpukhov (1969).
[2] I.G. Aznauryan and L.D. Solov'ev, Preprint IFVE STF 70 - 3, Serpukhov (1970).
[3] R.J. Glauber, Phys. Rev. 100, 242 (1955); V. France and R.J. Glauber, Phys. Rev. 142, 1195 (1966).
[4] M. Froissart, Phys. Rev. 123, 1053 (1961); A. Martin, Nuovo Cimento 42A, 930 (1966); 44A, 1219 (1966). G.G. Volkov, A.A. Logunov, and M.A. Mestvirishvili, Preprint IFVE STF 69-110, Serpukhov (1969).
[5] A.A. Logunov, Nguen Van Hieu, and I.T. Todorov, Usp. Fiz. Nauk 88, 51 (1966) [Sov. Phys.-Usp. 9, 31 (1966)].
[6] P. Astbury et al. Phys. Lett. 16, 328 (1965); 23, 396 (1966).
[7] M.L. Goldberger, H. Miyuzawa, R. Oehme. Phys. Rev. 99, 686 (1955); M.L. Goldberger, Phys. Rev. 99, 979 (1955).
[8] A.A. Logunov, L.D. Soloviev, and A.N. Tavkhelidze, Phys. Lett. 24B, 181 (1967); P.D. Vecchia, F. Drago, and M.L. Pacielle, Phys. Lett. 26B, 530 (1968).
[9] R.J. Phillips and W. Rarita, Phys. Rev. 139B, 1336 (1965).
[10] M. Lusigneli, M. Restigneli, C.A. Snow, and G. Vipolini, Nuovo Cim. 49A, 705 (1967).
[11] W. Galbraith et al. Phys. Rev. 138B, 913 (1965).

MULTIPHOTON PROCESSES INDUCED BY POWERFUL INTENSE LIGHT IN THE PRESENCE OF EXTERNAL ELECTRIC FIELDS. DETECTION OF IONS IN MEDIA

I.N. Arutyunyan and G.A. Askar'yan
P.N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 14 August 1970
ZhETF Pis. Red. 12, No. 7, 378 - 380 (5 October 1970)

We consider in this article the influence of external fields on multiphoton processes, and estimate the conditions under which external fields can greatly influence their probability, decreasing the necessary number of quanta. Practical applications of the processes under consideration are indicated.

It is known that the ionization of an atom in an intense light field $E_1 \sin\omega t$, with a quantum energy much lower than the ionization potential ($\hbar\omega << I$), proceeds in different manners in two characteristic cases:

1. If $\omega\tau \ll 1$, where $\tau \sim I/eE_1v_a$ is the time that an electron with atomic velocity $v_a \simeq \sqrt{I/m}$ takes to "fly through the barrier," then the process is quasistatic and is analogous to the ordinary tunnel effect, for which the probability is $w \sim \exp(-E_a/E)$, where E_a is close in value to the field inside the atom. In the presence of an external constant field E_0, the effective field causing the tunneling is $E = |\vec{E}_1 \sin\omega t + \vec{E}_0|$, which yields for the ratio of the probabilities with and without the field $\vec{E}_0$, under the optimal conditions ($\vec{E}_1 \parallel \vec{E}_0$),

$$w_0/w \approx \exp\left\{-E_a\left(\frac{1}{E_1+E_0} - \frac{1}{E_1}\right)\right\} \approx \exp(E_aE_0/E_1^2)$$

when $E_1 \gg E_0$. Thus, the condition for a noticeable change of the probability of the process is $E_0 > E_1^2/E_a$. For $E_1 \simeq 10^5$ cgs esu (focused laser beam of $\sim$300 MW power) and for $E_a \sim 10^7$ cgs esu, we obtain $E_0 > 10^3$ cgs esu $\sim 3 \times 10^5$ V/cm.

2. In the case $\omega\tau \gg 1$, when the field has time to change during the time of flight through the barrier, we have a pure multiquantum effect, for which [1] $w \sim (e^2E_1^2/8m\omega^2I)^k$, where $k = \langle I/\hbar\omega + 1\rangle$ is the number of quanta needed for ionization. In this case application of a constant field can reduce the number of quanta.

A calculation performed in the quasiclassical approximation yields, for $\vec{E}_1 \parallel \vec{E}_0$ (for the plane case of a localized well),

$$w \sim (e^2E_1^2/8m\omega^2I)^{I(1-3eE_0/\omega\sqrt{2mI})/h\omega}$$

at $E_0 < E_1$, i.e., the presence of an electric field leads, as it were, to a decrease of the ionization potential by an amount $\Delta I \simeq 3eE_0(I/h\omega)(h/\sqrt{2mI}) \simeq 3eE_0ka \sim 3eE_0v_a/\omega$, where $a \simeq h/\sqrt{2mI}$ is the dimension of the principal region of electron localization, $v_a \simeq \sqrt{I/2m}$, and ka is the path traversed by the electron prior to its "release," and is of the order of the path traversed by the electron during one period of the field: $ka \simeq v_a/\omega$).

Let us estimate the value of the external field that reduces the number of the required quanta by one, $\Delta I \simeq h\omega$, i.e., $E_0 \simeq h\omega^2/3ev_a \simeq 3 \times 10^4$ cgs esu $\simeq$ 10MV/cm if $v_a \simeq 2 \times 10^8$ cm/sec. Frequently, however, $I/h\omega$ is an integer with a small increment ($I/h - \langle I/h\omega\rangle \ll 1$), and therefore a reduction of the number of quanta by one can be expected also in weaker external fields, on the order of one MV/cm. It is possible to facilitate tuning to resonance in the case of multiquantum excitation.

We note that a reduction of the number of needed quanta usually greatly increases the probability of the process, since the quantity raised to the power is $x = e^2E_1^2/8m\omega^2I \ll 1$ for most cases of practical interest (for example, when $E_1 \simeq 10^5$ cgs esu and $\omega \simeq 10^{15}$ rad/sec we get $x \simeq 10^{-2}$).

The foregoing effects are of practical interest also for photoionization of excited atoms, atoms on surfaces of media, and in the case of dissociation, for in these cases the work function is several times smaller than the ionization energy of the atoms.

Let us note other possibilities of lowering the potential of the atom [2] ($\Delta I \approx 2(e^3E_0)^{1/2}$) and of shifting the absorption edge [3] under the influence of a field; these possibilities can supplement the action of the effects considered above.

The external fields employed can be the beams of lasers of longer wavelength or radio-emission pulses.

3. Let us consider the influence of charged particles on the process of multiquantum ionization and the practical use of this influence.

The presence or appearance of charged particles can greatly increase the probability of multiquantum ionization of atoms situated in a sphere of radius

$$r_{cr} \approx \sqrt{e/E_{cr}} \approx 10^{-7} - 10^{-6}\text{cm}.$$

The ions can therefore serve as catalysts for the formation of islets of photoionization of the medium in an intense optical field, a fact that can be used, for example, to detect ions and to develop track chambers. Indeed, in many cases, to reveal the presence of ions in dense media (e.g., by bubble production), it is necessary that the ions be produced at a large initial concentration, or that heat be released (in the case of photoionization of an islet, the energy released is approximately $4\pi n r_E^3 \varepsilon_1/3 \approx 10$ keV at a concentration n $\approx 3 \times 10^{22}$ cm^{-3} and a photoelectron energy ε_1 eV; such an increase of the energy-release density makes it possible to lower the metastability greatly and to increase the sensitivity time of the medium. The photoionization islets can also be revealed by their glow. It is possible to intensify the glow by applying an electric field.

The presence of excited atoms produced by a particle near the track can increase the number of ions when the track is illuminated with powerful light, in view of the very large probability of single-quantum, multiquantum, or tunnel photoionization of the excited atoms.

For electrons, the condition under which the action on the atom is quasistatic is satisfied up to velocities $v < r_E\omega \sim 10^8$ cm/sec, and in this case the formulas given above can be used.

It is important that in the presence of an intense optical field the atom can become ionized even at lower electron energies. At high energies this process can be regarded also as an increase of the cross section for the ionization of the atom by an electron in the presence of an intense field (the condition for the equality of the rates of ionization is $\pi(e/E_{cr})w(E_1E_{cr})/\omega \sim \sigma_s f$, where $\pi(e/E_{cr})$ is the "cross section of sufficiently close approach," w/ω is the probability of photoionization during the time of flight, σ_s is the cross section for collision with the atom, and f is the probability of impact ionization). Such processes are particularly important for picosecond laser flashes, which produce large field intensities but whose durations are too short for cascade development.

Large cross sections of sufficiently close approach, $\sigma_E \sim \pi r_E^2 \sim 10^{-14} - 10^{-12}$ cm^2, make the repetition frequency ν of the action sufficiently large even in a plasma that is not very dense. The summary fraction of the action time is $\alpha \approx t\nu \sim n_e r^3 \approx 0.3$ at concentrations $n_e \sim 0.1/r^3 \sim 10^{17}$ cm^{-3} such that the Debye radius $\delta_D \sim v_e/\omega_p \sim 10^{-5}$ cm is large enough and no screening of the field takes place. The role of the external field may also be assumed by the plasma field $E_p \approx ne\delta_D$ or by the collective fields in the plasma. Such a plasma may be formed in small volumes (the volume of a delta-electron track, mode-focusing volumes, and hot points in the focus of a laser, etc.), and must be taken into account when the effects are estimated. Cascade multiphoton ionization and the propagation of the front of multiphoton ionization are also possible.

An intense light field can also change the specific ionization of fast particles, adding its own quanta to the momentum of the field of a particle moving past the atoms, and producing bursts of multiphoton ionization at the instant when the particle crosses the maxima of the light-wave field; this marks the specific ionization of the track, with a spatial period $L = \pi v/(\omega - \vec{k}\cdot\vec{v})$, from which it is possible to estimate the particle velocity; since the velocity of an ultrarelativistic particle is close to the velocity of light in the gas, the period $L_{max} = \lambda/2(1 - \beta')$ may greatly exceed the wavelength of the light and can be readily observed. This method differs from marking the track by bursts of microwave breakdown [4] not only because we are using in our case multiphoton ionization for the marking, rather than breakdown, but also because the changeover to light with a short wavelength makes it possible to measure the velocities of ultrarelativistic particles in small regions of the medium.

The authors are grateful to Corresponding Member L.V. Keldysh for interest in the work and useful discussions.

[1] L.V. Keldysh, Zh. Eksp. Teor. Fiz. 47, 1945 (1964) [Sov. Phys.-JETP 20, 1307 (1965)2.
[2] Ya.I. Frenkel', ibid. 8, 1292 (1938).
[3] L.V. Keldysh, ibid. 34, 1138 (1958) [Sov. Phys.-JETP 7, 788 (1958)].
[4] D. Gabor and B. Hampton, Nature 180, 746 (1957).

STATIONARY RELATIVISTIC GAS IN COSMIC OBJECTS AND γ BACKGROUND IN THE 1 - 20 MeV REGION

R.A. Syunyaev
Applied Mathematics Institute, USSR Academy of Sciences
Submitted 18 August 1970
ZhETF Pis. Red. 12, No. 7, 381 - 383 (5 October 1970)

As is well known [1], the spectrum of the x-ray and γ-ray background at 40 keV < hν < 1 MeV and the points at hν ∿ 30 MeV [2] and 100 MeV [3] are in good agreement with the power law $I_\nu \sim \nu^{-1.2}$. Recent measurements have revealed an increase of the background radiation in the region 1 < hν < 6 MeV [4]. In this paper this fact is interpreted as a superposition of the summary radiation from discrete sources of bremsstrahlung γ rays on the general power-law spectrum of the background.

Attempts were made earlier to explain the observed effect as the result of the γ activity of the nuclei Ni^{56} and Co^{56}, which are possibly synthesized in supernova explosions in galaxies [5], or else as the γ quanta produced in π^0-meson decays during the expansion period of the universe, corresponding to a red shift z ∿ 70 - 100 [6]. In the second variant it is assumed that the π^0 mesons are produced in collisions between the cosmic-ray protons and the intergalactic gas. Both interpretations contradict the latest experimental data. The first predicts a cutoff of the spectrum at 3.26 MeV, which is not observed [7], and the background intensity expected according to the latter at hν ∿ 30 and 100 MeV exceeds the observed value [2, 3].