If the excitation of the nucleus depends on the nature of the particle passing through it, then ΔN_h will be determined not only by the cross section of the interaction of the particles in the nucleus, but also by its excitation energy.

[1] A.Kh. Vinitskii, I.G. Golyak, N.P. Pavlova, V.I. Rus'kin, and Zh.S. Takibaev, Trudy IYaF AN KazSSR (Proceedings, Nuclear Physics Institute, Kazakh Academy of Sciences) 6, 144 (1963).
[2] Z.V. Anzon, A.Kh. Vinitskii, M. Izbasarov, I.S. Strel'tsov, Zh.S. Takibaev, I.Ya. Chasnikov, and Ts.I. Shakhova, ibid. 7, 100 (1967).
[3] Z.V. Anzon, A.Kh. Vinitskii, V.G. Voinov, I.S. Strel'tsov, Zh.S. Takibaev, I.Ya. Chasnikov, and Ts.I. Shakhova, Yad. Fiz. 10, 991 (1969) [Sov. J. Nucl. Phys. 10, 570 (1970)].
[4] S. Ciurlo, E. Picasso, G. Tomasini, Nuovo Cim. 27, 791 (1963).
[5] P.L. Jain, H.C. Clahe, J.D. Rinaldo, and P.D. Bharadwaj, Nucl. Phys. 67, 641 (1965).
[6] J.M. Kohli, Nucl. Phys. B14, 500 (1969).
[7] J. Gerula, E.R. Loza, R. Holynski, G. Nowak, K. Rybicki, and W. Wolter, Krakow, Poland, HB-21, 441 (1970).
[8] B. Edwards, J. Losty, D.H. Perkins, K. Pinkau, J. Reynolds, and H.H. Wills, Phil. Mag. 3, 237 (1958).
[9] M. Koshiba, Proc. Int. Conf. on Cos. Rays, Jaipur, 20, 1011 (1961).
[10] F. Brisbout, C. Gauld, J. Lehane, C.B. McCusker, J. Malos, K. Nishikawa, and L.G. Van Loon, Nucl. Phys. 26, 634 (1961).
[11] H. Winzeler, Nucl. Phys. 69, 661 (1965).
[12] N.P. Bogachev, Wang Shu-fen, I.M. Gramenitskii, et al., Atomnaya energia 4, 281 (1958).
[13] V.S. Barashenkov, V.M. Mal'tsev, and E.K. Mikhul, Nucl. Phys. 24, 642 (1961).
[14] C. Bricman, M. Csejthey-Barth, J.P. Lagnaux, and J. Sacton, Nuovo Cim. 20, 1017 (1961).
[15] E.G. Boos, N.P. Pavlova, Zh.S. Takibaev, T. Temiraliev, and R.A. Tursunov, Zh. Eksp. Teor. Fiz. 47, 2041 (1964) [Sov. Phys.-JETP 20, 1371 (1965)].
[16] G. Cvijanovich, B. Dayton, P. Egli, B. Klaiber, W. Koch, M. Nikolic, R. Schneeberger, H. Winzeler, J.C. Combe, W.M. Gibson, W.O. Lock, M. Schneeberger, and G. Vanderhaeghe, Nuovo Cim. 20, 1011 (1961).
[17] H. Meyer, M.W. Teucher, and E. Lohrmann, Nuovo Cim. 28, 1399 (1963).
[18] E. Lohrmann, M.W. Teucher, and M. Schein, Phys. Rev. 122, 672 (1961).
[19] F. Brisbout, C. Gould, C.B. McCusker, J. Malos, K. Nishikawa, L.S. Peak, and L.G. Van Loon, Nucl, Phys. 26, 217 (1961).
[20] A. Barkow, B. Chamany, D.M. Haskin, P.L. Jain, E. Lohrmann, M.W. Teucher, and M. Schein, Phys. Rev. 122, 617 (1961).
[21] H.H. Aly, J.G.M. Duthie, C.M. Fisher, and H.H. Wills, Phil. Mag. 4, 993 (1959).
[22] I.Z. Artykov and V.S. Barashenkov, Dubna, R2-4510, 1969.
[23] O. Czyzewski and K. Rybicki, Poland, INR, No. 703/PH, 1970.
[24] P. Rotelli, Letters al Nuovo Cim., 1, 117 (1971).

MAKING A MEDIUM TRANSLUCENT TO RADIATION EXCITED BY A DIRECTED STREAM OF ATOMIC PARTICLES

V.V. Afrosimov, Yu.S. Gordeev, V.M. Lavrov, and G.N. Ogurtsov
A.F. Ioffe Physico-technical Institute, USSR Academy of Sciences

Submitted 23 August 1971
ZhETF Pis. Red. 14, No. 7, 408 - 411 (5 October 1971)

Excitation by atomic collision, unlike excitation by electron impact or photoexcitation, is frequently accompanied by transfer of considerable momentum from the impinging particle to the target particle. Therefore the kinematics of the atomic collisions may exert a definite influence on the emission-spectrum lines as a result of Doppler shift and broadening of the lines.

The influence of the kinematics of collisions on the Auger-electron and optical line shapes was considered earlier in [1, 2]. Using reasoning analogous to that given in [1], it can be shown that if in a reference system connected with the radiating atomic particle the radiation is monochromatic (λ_0) and isotropic, but during the excitation the particle is scattered through an angle θ and acquires a velocity v, then the distribution function of the radiation observed at angle α in the laboratory coordinate system, with respect to the wavelength λ, takes the form

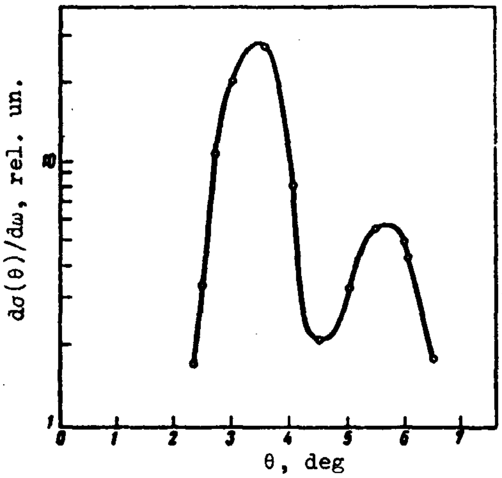

Fig. 1. Differential cross section for the scattering of K^+ ions in argon as a function of the scattering angle θ upon excitation of an Ar atom, accompanied by emission of the 1066.7-Å Ar I line. Energy of impinging ions 2 keV.

$$\Phi(\lambda) = \frac{N_0}{\sqrt{\lambda_0^2 \frac{v^2}{c^2} \sin^2\alpha \sin^2\theta - (\lambda - \lambda_0 + \lambda_0 \frac{v}{c} \cos\alpha \cos\theta)^2}}, \qquad (1)$$

where N_0 is a normalization factor and c is the speed of light. Recognizing that excitation of a definite level can be accompanied by transfer of different momenta to the atomic particles (different θ and v), the shape of the line actually observed in the laboratory system can be described by a convolution of four functions:

$$f(\lambda) = \iiiint f_0(\lambda_0)\, a(\lambda' - \lambda_0)\, \Phi(\lambda - \lambda', v, \theta)\, \Psi(v, \theta)\, d\lambda_0\, d\lambda'\, dv \sin\theta\, d\theta, \qquad (2)$$

where $f_0(\lambda_0)$ is the line contour in the coordinate system connected with the radiating particle, $a(\lambda' - \lambda_0)$ is the apparatus function of the spectrometer, Ψ(v, θ) is the distribution function of the emitting particles with respect to velocity and the scattering angle. The contour f(λ) can be calculated only in the presence of information concerning the kinematics of the collision, i.e., concerning the distribution function Ψ(v, θ).

We investigated the kinematics of K^+-Ar collisions with the aid of the method described in [3]. We studied separately the collisions connected with different inelastic transitions. The energy of the impinging K^+ pions was 2 keV. Figure 1 shows the differential scattering cross section dσ(θ)/dω following excitation of the levels accompanied by emission of the 1066.7-Å Ar I resonance line. The obtained data show that excitation of the levels in question has a threshold behavior and proceeds with noticeable probability only when the impinging K^+ ions are scattered through angles $\theta > 2.5°$. The scattering of the fast particles is accompanied by transfer of considerable kinetic energy to the recoil particles. In the investigated case of K^+-Ar collisions, the kinetic energy of the excited Ar atoms lies in the interval 3.5 - 25 eV.

On the basis of the obtained data on the scattering, with allowance for the thermal motion of the atoms prior to the collision, we obtained the distribution function Ψ(v, θ), which subsequently was used to calculate the shape of the 1066.7-Å Ar I resonance line, observed at different angles α. The calculations were performed for an ideal spectrometer, i.e., the apparatus function $a(\lambda' - \lambda_0)$ was assumed to be a δ-function. The line contour in the system of the radiating particle $f_0(\lambda_0)$ was taken to be a Gaussian contour corresponding to a lifetime $\tau = 21 \times 10^{-9}$ sec [4]. The results of the calculation are shown in Fig. 2. For comparison, the figure shows also the absorption line contour at room temperature. We see that in this case the shape and width of the line are determined practically completely by the kinematics of the collision. The strong redistribution of the radiation over the wavelength causes only a small fraction of the radiation intensity to lie in the spectral region corresponding to the absorption line.

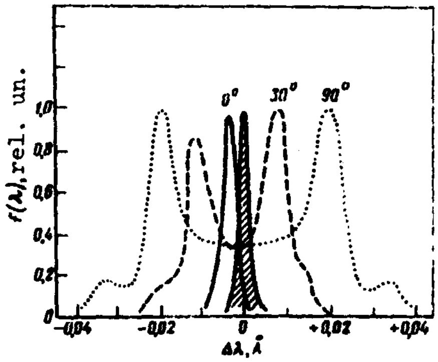

Fig. 2. Line shape of resonance radiation of 1066.7-Å Ar I line, excited by K^+-Ar collisions, as a function of the observation angle. The shaded contour represents the absorption of the resonant radiation in argon at room temperature.

Thus, appreciable transfer of kinetic energy in atomic collisions leads to a sharp decrease of the absorption of the resonant radiation in the medium. A quantitative estimate of the magnitude of this effect can be obtained by comparing the fraction of the absorbed radiation $A = \int f(\lambda)[1 - \exp(-\kappa_\lambda \ell)]d\lambda / \int f(\lambda)d\lambda$ (κ_λ is the absorption coefficient at the wavelength λ) for cases of excitation of Ar atoms by K^+-Ar collisions and by electron impact.

A	e − Ar	K⁺ − Ar		
$\kappa_0 \ell$ \ α	0 − 180°	0°	30°	90°
1	0.430	0.12	0.03	0.02
10	0.950	0.39	0.07	0.04
100	0.997	0.79	0.10	0.06

The table lists the results of a calculation of the ratio A at different observation angles α and different values of the parameter $\kappa_0 \ell$ (ℓ - distance from the radiation source to the receiver, κ_0 - absorption coefficient at the line center [5]). We see that in the case of atomic collision the value of A is characterized by strong anisotropy with respect to the observation angle. If the angle α is not very small, then the light absorption in atomic collision amounts to only several per cent even at $\ell \sim 10$ cm and a gas pressure $p \sim 10^{-3}$ mm Hg ($\kappa_0 \ell = 100$), whereas in the case of excitation by electron impact more than 99% of the radiation is absorbed in this way.

Thus, the obvious result of the influence of the kinematics of the atomic collisions on the shape of the spectral lines is the appreciable increase of the transparency of the absorbing medium and the strong dependence of the absorption on the observation angle. Similar phenomena can be observed in many cases when a gaseous medium is excited, under laboratory or natural conditions, by directed corpuscular radiation.

The authors are grateful to S.V. Bobashev, who called their attention to the important role that the effect under consideration cay play in optical research.

[1] Yu.S. Gordeev and G.N. Ogurtsov, Zh. Eksp. Teor. Fiz. 60, 2051 (1971) [Sov. Phys.-JETP 33, No. 6 (1971)].
[2] E.S. Parilis, Fiz. Tverd. Tela 11, 1569 (1969) [Sov. Phys.-Solid State 11, 1270 (1969)].
[3] V.V. Afrosimov, Yu.S. Gordeev, V.M. Lavrov, and S.G. Shchemelinin, ZhETF Pis. Red. 12, 455 (1970) [JETP Lett. 12, 317 (1970)].
[4] J.L. Morack and C.E. Fairchild, Phys. Rev. 163, 125 (1967).
[5] A. Mitchell and M. Zemansky, Resonant Radiation and Excited Atoms, McMillan, 1934.

INVESTIGATION OF THE $K_1^0K_1^0$ SYSTEM IN π^-p INTERACTIONS AT 4.0 AND 5.0 GeV/c

V. Boldea1), Yu.A. Budagov, V.B. Vinogradov, A.G. Volod'ko, N.G. Grigoryan2), V.P. Dzhelepov, Zh.K. Karamyan3), V.S. Kladnitskii, A.A. Kuznetsov, Yu.F. Lomakin, G. Martinska, N.N. Mel'nikova, A. Mikhul, T. Ponta1), S. Felea1), V.B. Flyagin, B. Chadraa3), L. Sandor, and P.V. Shlyapnikov4)
Joint Institute for Nuclear Research
Submitted 23 August 1971
ZhETF Pis. Red. 14, No. 7, 412 - 415 (5 October 1971)

The first investigations of the $K_1^0K_1^0$ system in λ^-p interactions [1 - 3] pointed to the existence of a near-threshold anomaly in the $K_1^0K_1^0$ effective-mass spectrum, with mass $M \simeq 1070$ MeV/c^2. In K^-p interactions at 3.6 - 5 GeV/c [4] and in pp interactions at 1.18 GeV/c [5] and 0.7 and 1.2 GeV [6], a noticeable excess of events over the background was observed in the $K_1^0K_1^0$ effective-mass spectrum at $M = 1030$ MeV/c^2 and $M = 1045$ MeV/c^2, respectively. In [3 - 5, 8, 12], the near-threshold anomaly was regarded as a manifestation of isoscalar S-wave, KK interaction, which can be described with the aid of a complex scattering length. On the other hand, the data of [7, 9, 10, 11] are in better agreement with production of the resonance $S^*(1068) \to K_1^0 + K_1^0$, with $I^GJ^P = 0^+0^+$.

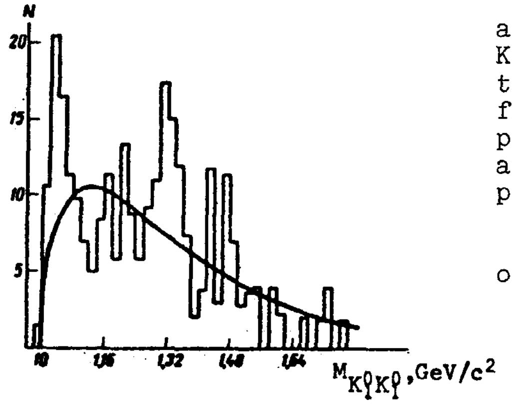

Fig. 1. Distribution of effective masses of the $K_1^0K_1^0$ system produced in π^-p interactions at 4.0 and 5.0 GeV/c.

In the present paper we present results of a study of the effective-mass spectrum of the $K_1^0K_1^0$ system. The experimental data were obtained by processing 230,000 photographs each from a 55-cm [13, 15] and a 1-m [14, 16] propane bubble chamber bombarded with beams of 4 and 5.0 GeV/c pions, respectively from the JINR proton synchrotron.

Figure 1 shows the effective-mass spectrum of the $K_1^0K_1^0$ combinations for events of the type

$$\begin{aligned}\pi^-p &\to K_1^0K_1^0n\,(m\pi^0)\\ &\to K_1^0K_1^0\pi^-p\,(m\pi^0)\\ &\to K_1^0K_1^0\pi^+\pi^-n\,(m\pi^0),\end{aligned}$$

where $m = 0, 1, 2, \ldots$ is the number of π^0 mesons. The phase-volume curve was drawn with allowance for the relations between the cross sections of the reactions indicated above, and

---

1) Atomic Physics Institute in Bucharest.

2) Erevan Physics Institute, Armenian Academy of Sciences.

3) Institute of Physics and Mathematics, Mongolian People's Republic, Ulan-Bator.

4) High Energy Physics Institute in Serpukhov.