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Role of Metastable States in the Production of Scintillations in the Rare Gases by Alpha Particles

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The lifetimes of alpha-ray induced scintillations in the rare gases (Xe, Kr, A, and Ne) were measured as a function of pressure. The lifetimes were found to be inversely proportional to the pressure. It is shown that the major part of the scintillations are in the far ultraviolet—below 1250 A. It is suggested that these scintillations result from the destruction of metastable excited states of the rare gas ions.

IT has recently been reported that xenon and krypton can be used as fairly efficient scintillators for heavy ionized particles.[1] In this work it has been shown that large numbers of metastable states are produced by the passage of alpha particles through the rare gases and that the destruction of these metastable states is accompanied by light emission in the far ultraviolet (less than 1250 A). With an appropriate light converter, it was shown that the major part of the resulting light scintillations is produced by this process.

The average pulse height and the rise time of the integrated light pulses obtained by the passage of Po^{210} alpha particles through the rare gases (pure xenon, krypton, argon, and neon) were measured as a function of pressure in the range between 40 and 700 mm Hg. An E.M.I. multiplier with a quartz envelope was used. The walls of the counting cell as well as the quartz window facing the multiplier were covered with a thin layer of sodium salicylate, which is known to be a converter for the far ultraviolet radiation. With xenon at a pressure of 600 mm Hg, a resolution of 14% was obtained for 5.3-Mev alpha particles.

Relatively long fluorescent decay times were observed, between 2×10^{-7} and 4×10^{-6} sec. The lifetimes were found to be inversely proportional to the pressure, throughout the range investigated, for all the gases (Fig. 1). Experiments carried out with a lithium fluoride window, instead of quartz, showed that most of the quanta in gas scintillations lay below 1250 A. The long decay times point to the production of metastable states, which may yield light upon destruction. The linear dependence of $1/\tau$ on pressure shows that the destruction of the metastable state takes place mainly by two-body collisions, for the pressures examined. Colli[2] observed the light associated with the production of metastable states in the Townsend discharge taking place in a proportional counter, containing argon, and it is very likely that these phenomena are closely connected with those described here, although her lifetimes are considerably different than those found in the present work.

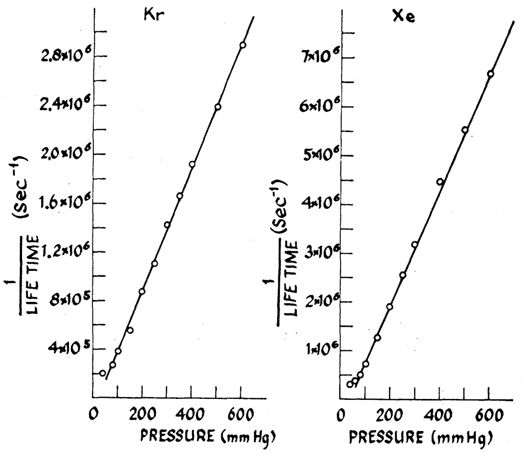

Fig. 1. Variation of inverse mean life ($1/\tau$) with rare gas pressure (accuracy of τ: ±10%).

The excitation of a metastable state to a near-lying resonance level in two-body collisions provides an efficient mechanism for destruction of the metastable states, and will be accompanied by emission of the resonance radiation. However, if the metastable states are those of neutral atoms, the resonance radiation will be imprisoned at the pressures used and cannot account for the scintillations. Moreover, in xenon, the expected resonance radiation of the neutral atoms of xenon would have a wavelength of 1490 A, much longer than that observed. We are therefore led to the hypothesis that resonance levels of *rare gas ions* may be excited in the destruction of ionic metastable states by two-body collisions, and that the resultant resonance radiations give rise to the observed scintillations. In such a process, the resonance radiation will not be imprisoned

Table I. Effect of light converter on pulse height. The figures in column 2 are relative values as compared to the normalized pulse height with converter for each particular gas and they represent the fraction of light quanta between 2200 and 5500 A.

Rare gas	No light conversion	Sodium salicylate as light converter
A	35	100
Ne	80	100
Xe	12	100
Kr	18	100

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[1] R. Nobles, Rev. Sci. Instr. 27, 280 (1956).

[2] L. Colli, Phys. Rev. 95, 892 (1954).

because of the relatively low concentration of ions; also, the strong resonance lines of the rare gas ions are well below 1250 A (e.g., 1100 A for xenon).

From the observed amplitude of the light pulses and assuming that the quantum yield of sodium salicylate is near unity, we obtain that the ratio between the number of metastable states formed to the total number of ions produced in the passage of the alpha particle is about 0.03. This does not appear to be inconsistent with the experiments of Hagstrum[3] who showed that one can detect metastable ions by the secondary electrons emitted on impact with metal surfaces. He has shown that the ratio of cross sections for the formation of metastable ions and normal ions by slow electrons is about 0.02. As a further support for this explanation of the scintillations, we may mention that in Ne^+ there are no metastable states similar to those occurring in Xe and Kr ions[3,4] and indeed, in the present experiments, neon was the only rare gas for which the presence of sodium salicylate did not produce a large increase in the total light output. (See Table I.)

It would seem that in addition to the importance of these phenomena for the understanding of gas scintillations, they indicate new methods of studying the properties and fate of metastable atoms.

A detailed description of these experiments is in preparation.

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[3] H. D. Hagstrum, Phys. Rev. **104**, 309 (1956).

[4] C. E. Moore, *Atomic Energy Levels*, National Bureau of Standards Circular No. 467 (U. S. Government Printing Office, Washington, D. C., 1949), Vol. 1.

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Medium-Energy Deuteron Photodisintegration*

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It is shown that the distinctive features of the photoeffect angular distribution in the energy range 20–100 Mev probably result from a strong modification of the $^3P_0$ outgoing wave amplitude, to be understood as a result of the excitation of virtual mesons in a fashion which violates the Siegert theorem. Some evidence also is found which suggests the need for a repulsive-core modification of the ground-state wave function. The contributions from the transition $^3D_1 \to {}^3F_2$ are analyzed, and are found to be rather large.

I. INTRODUCTION

PHENOMENOLOGICAL analysis of the photodisintegration data can give one or another of two kinds of information about the deuteron system. If both the initial and final state wave functions are known, it might give information about the nature of the radiative interaction; if the interaction mechanism is known, it might give information about the wave functions. In the past it has seemed that the second of these two possibilities would apply in the medium-energy range, 20–100 Mev, and would provide useful information about the nuclear force in the $^3P_{0,1,2}$ states, the important final states of the process. In this paper it will be demonstrated to be unlikely that such information can be obtained, even though the energies are rather far below the meson threshold, for in the medium-energy region an unexpectedly strong modification seems to appear in the radiative-interaction mechanism.

Good data regarding the medium-energy photoeffect have been available for some time.[1] Nevertheless, the analysis only recently has become interesting, since nucleon scattering experiments with polarized beams have given information about the ^3P_J wave phase shifts.[2] Several authors[3] already have tested their nuclear-force ideas against the photoeffect data. The attitude which will be taken in this paper will be to attempt to extract the outgoing wave amplitudes from the data, and only after getting the amplitudes to attempt their interpretation. This approach is feasible because of the quite striking nature of the data.

The photodisintegration is well known to be reliably

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† On leave of absence during the 1957–58 academic year at the University of Sydney, Sydney, Australia.

[1] Lew Allen, Jr., Phys. Rev. **98**, 705 (1955); Whalin, Schriever, and Hanson, Phys. Rev. **101**, 377 (1956).

[2] For several analyses of the experiments, see H. Feshbach and E. A. Lomon, Phys. Rev. **102**, 891 (1956); A. M. Saperstein and L. Durand, III, Phys. Rev. **104**, 1102 (1956); J. L. Gammel and R. M. Thaler, Phys. Rev. **107**, 290 (1957). I am grateful to Gammel and Thaler for a prepublication copy of their paper, and to G. Breit for a prepublication copy of the Saperstein, Durand paper. Moreover, I am especially grateful to L. Wolfenstein for many discussions about the high-energy phase shifts. The present paper is a direct outgrowth of those discussions.

[3] S. H. Hsieh and M. Nakagawa, Progr. Theoret. Phys. (Kyoto) **15**, 79 (1956); S. H. Hsieh, Nuovo cimento 4, 138 (1956); S. H. Hsieh, Progr. Theoret. Phys. (Kyoto) **16**, 68 (1956). Some work along related lines also was done by J. Bernstein and H. Feshbach (private communication).