Production of Photons in a Townsend Gap in Air, Nitrogen, and Argon

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RECENTLY, Geballe[1] reported measurements in a Townsend gap of the photon-ion ratio in hydrogen. This study has been extended, with the same equipment, to air, nitrogen, and argon. No photoelectric currents could be measured below breakdown in any of the three gases studied, regardless of values of pressure and voltage. The electrometer used was capable of detecting 10^{-15} ampere.

In order to detect photoelectrons at the brass surface, photons of adequate energy must be produced in the gas, and these high energy photons must not be absorbed too strongly in the gas. High energy photons may be expected especially in gases having metastable states, and photon absorption will be high in mixed gases and in gases having metastable states. Streamers (which depend on photoionization in the gas) may be expected in mixed gases, and in gases containing metastables. Weissler[2] has shown that no pre-onset streamers appear in the positive point-to-plane discharge in pure hydrogen and in pure nitrogen. In argon, the first streamer is so intense that the gap breaks down immediately.

In pure hydrogen, high energy photons reach the photoelectric surface. Therefore streamers are not formed because of the transparency of the gas to photons. Photoelectrons in the gas are produced too far from the positive ion space charge to be effective in producing streamers. In air, high energy photons are produced very close to the space charge, hence one observes streamers but no photoelectric action at the surface. In argon, as in air, the photon absorption is so high that one observes no photoelectric effect at the surface. In nitrogen, no streamers are formed, and no photoelectric currents were measured. This can be understood if one assumes that photons in nitrogen are not very energetic.

[1] R. Geballe, Phys. Rev. 66, 316 (1944).
[2] G. L. Weissler, Phys. Rev. 63, 96 (1943).

Evidence of Increased Radioactivity of the Atmosphere after the Atomic Bomb Test in New Mexico

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FROM July 12 through July 19, 1945 a G-M counter and circuit similar to that previously described in *The Review of Scientific Instruments*[1] was being tested for background count in my home near Annapolis. The following data were obtained (Table I). Observations on August 16 and from October 31 through November 3 confirm the normal background of 5.5 counts per minute.

Rain fell from the 15th through the 18th of July, the weather clearing during the latter part of the counting period on the 18th and remaining clear through the counting period on the 19th. No change of background count had been observed during rainy periods previous to the above dates. During the past three weeks a series of more than twenty observations under different conditions of temperature and humidity produced by weather changes have been made. The background count has been normal during these recent observations.

TABLE I.

Day	Time of count	Counts per minute	Hours after bomb test to middle of counting period
12	1500 to 2200	5.5	
14	1600 to 2400	5.5	
15	1500 to 1900	5.5	
16	1900 to 2300	6.3	12.5
17	2000 to 2300	7.7	37.5
18	1600 to 2300	10.9	59
19	1300 to 1500	5.5	78

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[1] A. W. Coven, Rev. Sci. Inst. 13, 188 (1942).

Nuclear Spectroscopy and Inelastic Scattering of Particles by Nuclei

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THE purpose of this and of the following note is to discuss the excitation[1] of stable nuclei by inelastic scattering of particles and, in particular, to discuss the detection of this excitation by study of the energy distribution of inelastically scattered deuterons and electrons.

Excitation of nuclei by inelastic scattering may be detected through: (*a*) γ-rays from the excited states, (*b*) decay of a metastable state with which the excited states intercombine (the lowest of these excited states is the threshold for this process), (*c*) energy distribution of inelastically scattered particles, and (*d*) recoil of the nucleus.

Method (*a*) may be applied by using protons, deuterons, alphas, and fast neutrons. Detection of γ-rays is hardly possible in the presence of strong x-rays accompanying an electron beam. Method (*b*) applies only to nuclei possessing a metastable state only; in addition, it yields only a certain part of the nuclear spectrum. Method (*c*) seems to be the most universal method. Method (*d*) may be applied by using p, d, α, n, but it will be quite laborious; apparently, it has not as yet been used.

(*a*) *Fast neutrons* striking medium and heavy nuclei yielded γ-rays according to Kikuchi, *et al.*[2] No quantitative study of the γ-ray energies was made, however. *Protons* were used by Herb, *et al.*[3] (Li^6, Li^7). Schnetzler[4] and Savel[5] used alphas to excite Li^6. The excited level found at about 0.6 Mev by Schnetzler[4] and that at 0.45 Mev found by Herb, *et al.*[3] may be identical; further study is needed.

(*b*) *Fast neutrons* excite In^{115} as discovered by Goldhaber, Hill, and Szilard.[6] For some elements the γ-rays observed by Kikuchi, *et al.*[2] may have originated by this process. *Protons* were used by Barnes and Aradine[7] and *alphas* by Lark-Horovitz, Risser, and Smith[8] to excite In^{115}. *Electrons* were used by the Notre Dame group[9] to excite In^{115} and Cd. X-rays were employed more extensively by the Notre Dame group[10] to excite a whole series of nuclei. The theoretical basis for this method was given by the author.[11]

(*c*) The general idea of this method is that charged particles are scattered elastically (Rutherford) mainly in the forward direction; *inelastically* scattered particles will tend to a spherically symmetrical angular distribution, however. This difference may enable the detection of *inelastically* scattered (through 90° and backward) particles, although for medium and heavy nuclei the cross section for inelastic scattering may be by orders of magnitude smaller than that of the elastic scattering. *Protons* scattered by a few *light* nuclei were used by Wilkins and Kuerti[12] (Mg, Al) and by Powell, May, Chadwick, and Pickavance[13] (Ne^{20}, Al) employing a photographic method. A counter method was employed by R. H. Dicke and J. Marshall, Jr.[13] (Al^{27}, Cr^{52}, Mg, S^{32}). The protons penetrate the Coulomb barrier and are captured by the nuclei. The resulting compound nucleus re-emits the protons with spherically symmetrical angular distribution. Their number is (for such light nuclei) of the same order (about $\frac{1}{2}$) as that of the elastically scattered protons. Powell, *et al.*[14] point out that the probability of this (p,p) process decreases rapidly with increasing nuclear charge. The same holds for excitation by (d,d) and—*a fortiori*—by an (α,α) nuclear reaction. Cl and A gave too few inelastically scattered particles to observe.

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[1] M. S. Livingston and H. A. Bethe summarized the evidence up to 1937. Rev. Mod. Phys. **9**, 245 (1937). Recently, P. Comparat (cf. F. C. Champion, Nature **153**, 720 (1944)) obtained a large number of levels of N^{15} employing the interesting though laborious method of recoil.

[2] S. Kikuchi, I. Acki, and Y. Husimi, Nature **132**, 186 (1936).

[3] C. M. Hudson, R. G. Herb, and G. J. Plain, Phys. Rev. **57**, 587 (1940).

[4] P. Schnetzler, Zeits. f. Physik **95**, 302 (1935).

[5] X. Savel, Comptes rendus **198** (1934).

[6] M. Goldhaber, R. D. Hill, and L. Szilard, Phys. Rev. **55**, 47 (1939).

[7] S. W. Barnes and P. W. Aradine, Phys. Rev. **55**, 50 (1939).

[8] K. Lark-Horovitz, J. R. Risser, and R. N. Smith, Phys. Rev. **55**, 878 (1939).

[9] B. Waldman and M. L. Wiedenbeck, Phys. Rev. **63**, 60 (1943); M. L. Wiedenbeck, Phys. Rev. **67**, 92 (1945). The work at Notre Dame was initiated by G. B. Collins and B. Waldman and further developed by M. L. Wiedenbeck.

[10] M. L. Wiedenbeck, Phys. Rev. **68**, 1 (1945); M. L. Wiedenbeck, Phys. Rev. **67**, 267 (1945).

[11] E. Guth, Phys. Rev. **59**, 325 (1941).

[12] T. R. Wilkins and G. Kuerti, Phys. Rev. **57**, 1082; **58**, 758 (1940).

[13] R. H. Dicke and J. Marshall, Jr., Phys. Rev. **63**, 86 (1943).

[14] C. G. Powell, A. N. May, J. Chadwick, and T. G. Pickavance, Nature **145**, 893 (1940).

Nuclear Spectroscopy and Energy Distribution of Charged Particles Inelastically Scattered by Nuclei

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IN the foregoing note various methods of detecting nuclear excitation caused by inelastic scattering of charged particles were discussed. Method (*c*), *viz.* measurement of the energy distribution of the inelastically scattered particles will now be discussed for the cases in which the scattered particles are (1) protons or alphas, (2) deuterons, and (3) electrons.

1. *Protons or alphas.* Besides the (p,p), (α,α) and (d,d) nuclear reactions, excitation of a nucleus may be brought about by the Coulomb field of the approaching charged particle. In the excitation of In^{115} by protons this process may play some role, and in the excitation of this nucleus by alphas it may make the main contribution. The cross section for the excitation of a nucleus of charge Ze by the Coulomb field of a charge ze has the form,

$$\sigma = f(v) \exp\left[\frac{-2\pi e^2 zZ}{\hbar}\left(\frac{1}{v'}-\frac{1}{v}\right)\right],$$

where v and v' are the velocities of the particle before and after the collision. The form of $f(v)$ depends upon the multipole-character of the transition involved, while the exponential factor (which varies much faster than $f(v)$), probably does not.[1] Because of this exponential factor, transfer of energy from a charged particle to the nucleus can happen with appreciable probability only if $v \gg v'$. Even then methods (e.g., using counters) more sensitive than the photographic method will be necessary for the detection of inelastically scattered particles.

2. *Deuterons.* The use of deuterons yields a somewhat different picture. Because of its low binding energy the deuteron may be polarized by the nuclear field. In this way the neutron may come close enough to the nucleus to enable an energy transfer from the deuteron to the nucleus without the necessity of a (d,d) reaction or even excitation by the Coulomb field of the deuteron. The new process ("polarization scattering") is somewhat similar to the well-known Oppenheimer-Phillips process, but differs from it essentially in that the outgoing particle is not a proton but a deuteron. This difference makes it possible to distinguish between the two processes,[2] even when the conditions for the O-P process are fulfilled (kinetic energy of the deuteron larger than its binding energy, medium, and heavy nuclei). In^{115} for instance should be excitable by deuteron with an energy less than its binding energy. The threshold for the process is just slightly higher than that for excitation by x-rays, because of the recoil of the nucleus.[3] Observation of the inelastically scattered deuterons seems to be a promising method for studying nuclear spectroscopy. Polarization scattering may be used, among other things, to liberate neutrons from Be^9 and D, etc.

3. *Electrons.* Inelastically scattered electrons will not be easy to detect, even in the case in which the scattering angle approaches 180°, because of the background of the elastic scattering. Still a suitable β-ray spectrograph employing sensitive counters should make detection possible. Once established, the use of electrons for nuclear spectroscopy may very well be preferable even to the use of deuterons. For in contrast to the case with deuterons only electrons with comparatively high energies (namely, energies greater than the threshold for photo-disintegration) can disintegrate nuclei.

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[1] A rigorous derivation of this formula (including the exact form of $f(v)$) was given by V. F. Weisskopf and the author (unpublished). An earlier derivation of the exponential factor by L. Landau, Physik. Zeits. U.S.S.R. **1**, 88 (1932) is not very clear and does not give the value of $f(v)$. The author is indebted to Dr. S. N. Dancoff for pointing out that in the formula giving the cross section for nuclear excitation, followed by re-emission, the same exponential factor enters while the factor $f(v)$ is replaced by another $g(v)$ which in general is much smaller than $f(v)$.

[2] The same holds for excitation of the nucleus by the deuterons disintegrated by the Coulomb field of the nucleus, and for the ordinary (d,d) reaction, mentioned before.

[3] This process has actually been observed for In^{115} by M. L. Wiedenbeck (private communication).