atmospheres pressure. With this source the counting rates observed were as follows:

Counters coplanar	11.85 ± 0.43 counts/min
Counters not coplanar	1.33 ± 0.15 counts/min
Difference	10.52 ± 0.46 counts/min

The tenfold increase of the effect confirms the stability of positronium in freon.

Finally, Fig. 2 shows the results of the study of pulse-height distribution. Curve 1 shows the distribution of pulses from a single counter exposed to the γ-radiation from a source of Na^{22}. The photopeaks of the 1.3-Mev nuclear γ-ray and of the 0.510-Mev annihilation line are used to calibrate the *DPHS* scale; another calibration point is provided by the position of the photopeak of the 0.367-Mev γ-rays from I^{131}.

Curve 2 was obtained with a double coincidence arrangement responding to two-quantum annihilation; it shows the pulse-height distribution of the coincident pulses from one of the two counters. It is evident that only the effect of the mc^2 γ-rays is present here. Curve 3 was obtained with the triple coincidence setup of Fig. 1 responding to the triplet annihilation of the source in freon, and shows the distribution of the coincident pulses in any one of the three counters. The single peak at $\frac{2}{3}\,mc^2$ is further evidence for the three-quantum effect. Curve 4 is the corresponding background measured as described above.

Further studies of the effect in solids and gases are in progress.

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† AEC Predoctoral Fellow.

1 A. Ore and J. L. Powell, Phys. Rev. 75, 1696 (1949).
2 J. A. Rich, Phys. Rev. 81, 140 (1951).
3 M. Deutsch, Phys. Rev. 82, 455 (1951); Phys. Rev. 83, 866 (1951); M. Deutsch and E. Dulit, Phys. Rev. 84, 601 (1951).

Negative Ion Formation in Oxygen*

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We have made measurements of ionization currents in O_2 which clarify certain points in connection with the Townsend coefficient and the attachment cross section in this gas. These measurements used plane-parallel electrodes separated as far as 40 mm and pressures from 11 to 40 mm of Hg in a range of E/p from 27.5 to 75 volts/cm/mm. Plotting, in the conventional way, log i against electrode separation, we find at each pressure a family of curves markedly different from the ordinary. Although the initial slope of such graphs has been reported as strictly linear for all gases investigated previously[1,2] we find O_2 exhibits an initial curvature followed by a more or less linear portion. The initial curvature becomes less prominent as E/p increases and is imperceptible for $E/p > 65$ at these pressures. We have observed similar curves in another gas, CF_3SF_5,[3] but will confine this discussion to the case of O_2. To check our apparatus we made careful measurements in H_2 but found no trace of a departure from linearity.

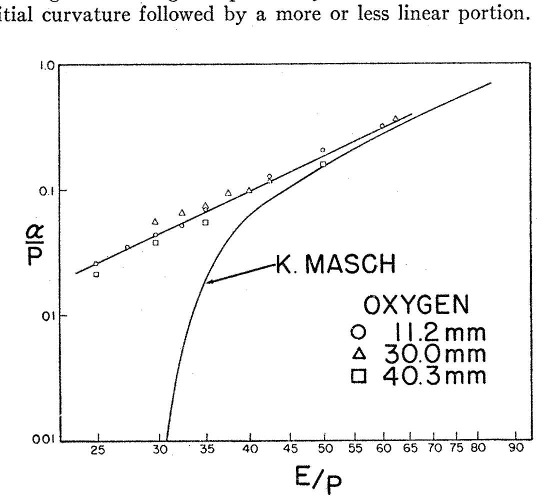

Fig. 1. Values of ionization coefficient α/p vs E/p in O_2 given by Masch (see reference 4) compared with those of the present experiment.

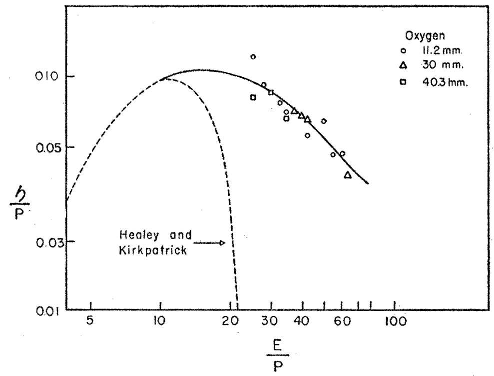

Fig. 2. Values of attachment probability η/p in O_2 given by Healey and Kirkpatrick (see reference 6) compared with those of the present experiment.

If ionization occurs in the gas at the mean rate α per cm and attachment forms negative ions (O_2^- and/or O^-) at the mean rate η per cm, the steady-state current is given by

$$i = i_0[\alpha \exp(\alpha-\eta)\delta - \eta]/[\alpha-\eta],$$

where δ is the plate separation and i_0 is the photoelectric current liberated at the cathode by an external source. This equation can be fitted closely to our experimental points. The process of curve-fitting on a basis of the foregoing assumptions yields values of both α/p and η/p.

The only published data with which to compare the present values of α/p are those of Masch[4] reproduced in Fig. 1. Masch attributed the rapid drop below $E/p \sim 40$ to attachment but did not attempt to analyze its effect. It can be seen from Fig. 1 that if due allowance is made for attachment in computing α/p, this drop, which does not appear in other gases, is not found in O_2.

Attachment probabilities in O_2 have been measured by Bradbury[5] and Healey and Kirkpatrick.[6] The curves submitted by these authors are similar in shape but differ by a factor of about 2 in magnitude. It is likely that this discrepancy arises only from differences in the values of drift velocity used to compute probabilities from the directly measured values of η/p. Figure 2 shows the values of η/p quoted by Healey and Kirkpatrick, which therefore are probably close to those (not quoted directly) found

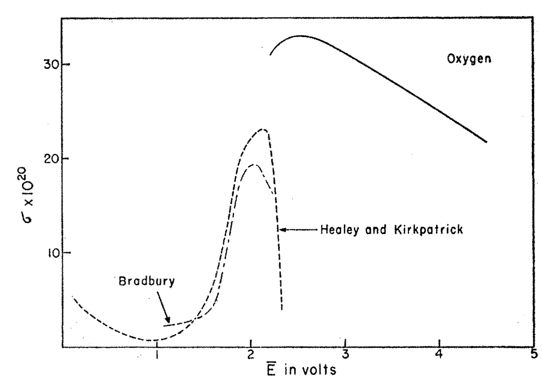

Fig. 3. Attachment cross section *vs* mean electron energy. Dashed curve—Healey and Kirkpatrick; dot-dashed curve—Bradbury; solid curve—present results computed from our η/p using thermal and drift velocities of Healey and Kirkpatrick.

by the former. It can be seen that instead of the steeply falling curve of the aforementioned authors, present data indicate a coefficient of appreciable magnitude at relatively large E/p. This circumstance can be explained by reference to our data on α/p; it is apparent that some multiplication is taking place. If proper allowance for this process is not made, the apparent attachment will be less than the true rate. It thus appears that the quantities α and η cannot be treated independently in regions where they are of comparable magnitude.

Figure 3 shows the attachment cross section plotted against mean electron energy computed from our measurements with the aid of the data of Healey and Kirkpatrick.[6] Previous explanations[5,7] of the maximum at 2 volts have been influenced by its apparent sharpness and have led to the conclusion that the negative ions were molecular. It now seems plausible that the reaction

$$O_2+e\rightarrow O^-+O$$

found by Lozier[8] and Hagstrum[9] with an appearance potential of 3.0 volts and a maximum at 7 volts is responsible for much of the high energy negative ion production. It is still possible that the process postulated by Bradbury[2,5] contributes to the steep rise that occurs at about 1.6 volts.

Further investigations of attachment processes in O_2 and other gases are in progress.

* This work was presented at the Conference on Gaseous Electronics, Schenectady, October 4–6, 1951.
[1] J. S. Townsend, *Electricity in Gases* (Oxford University Press, London, 1914).
[2] L. B. Loeb, *Fundamental Processes of Electrical Discharge in Gases* (John Wiley and Sons, Inc., New York, 1939).
[3] M. A. Harrison and R. Geballe, Phys. Rev. **83**, 884 (1951).
[4] K. Masch, Arch. Electrotech. **26**, 587 (1932).
[5] N. Bradbury, Phys. Rev. **44**, 883 (1933).
[6] R. H. Healey and J. W. Reed, *The Behavior of Slow Electrons in Gases* (Amalgamated Wireless, Sydney, 1941), p. 94.
[7] D. R. Bates and H. S. W. Massey, Phil. Trans. **A239**, 269 (1943).
[8] W. W. Lozier, Phys. Rev. **46**, 268 (1934).
[9] H. D. Hagstrum, Revs. Modern Phys. **23**, 185 (1951).

The Yield of Neutral Mesons from Proton Bombardment of Light Nuclei*

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THIS experiment was planned in order to study the relative cross sections of various light nuclei for the production of neutral pions by 340-Mev protons.

In particular we wished to measure the yield of π^0's in $p-p$ collisions in order to obtain information about the symmetry properties of the π^0-meson.

If the π^0 is a pseudoscalar meson it cannot be emitted in a P angular momentum state from a $p-p$ collision in an even orbital state, since parity and angular momentum cannot be conserved simultaneously in this case. If the π^0 is emitted in an S state, then, in analogy with π^+-production for which the S state yield is about one-eighth of the P state yield, we should expect the numbers of π^0's from $p-p$ collisions to be about one-eighth of that from $p-n$ collisions. If the π^0 is a scalar meson no such large ratio would be expected.

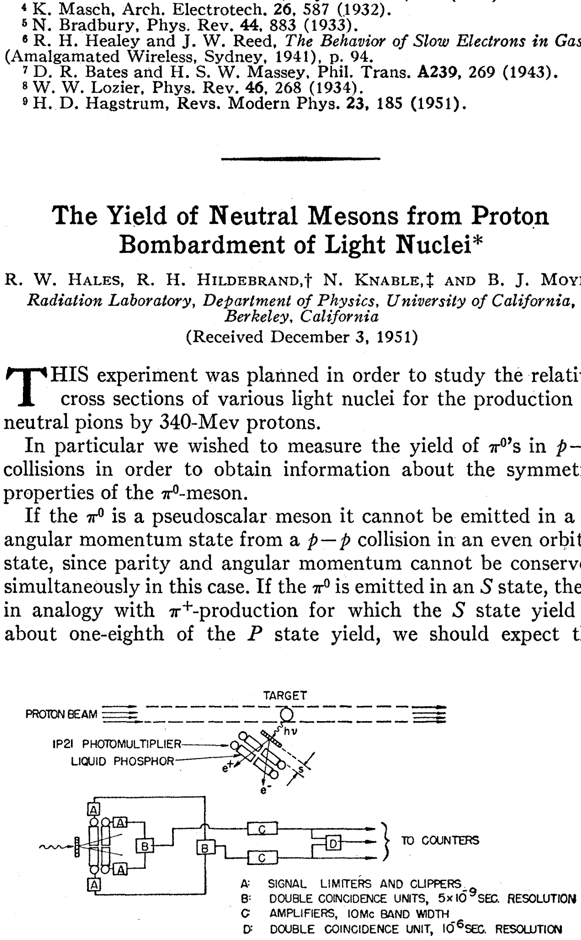

FIG. 1. Apparatus and circuit for detection of high energy photons.

TABLE I. Relative cross sections for neutral meson production by 341-Mev protons. The carbon yield has arbitrarily been given the value 6.00.

Nucleus	Relative cross section
H^1	0.07 ± 0.06
H^2	0.85 ± 0.20
Be^9	5.01 ± 0.12
B^{10}	4.99 ± 0.11
B^{11}	5.95 ± 0.13
C^{12}	6.00 ± 0.16
O^{16}	7.46 ± 0.28

No direct comparison of the $p-p$ and $p-n$ π^0-yields could be made using a proton beam, but relative $p-p$ and $p-d$ yields were obtained by subtractions utilizing targets of carbon, polyethylene, heavy water, ordinary water and liquid oxygen. The series Be^9, B^{10}, B^{11}, C^{12} was also studied.

A unique method of identifying a neutral pion would be to detect both of the decay γ-rays in coincidence in the manner used for detection of neutral photomesons,[1] but the unfavorable neutron background conditions associated with proton bombarded targets makes the method infeasible for this experiment. Hence it was necessary to depend on single γ-detection. This is probably a valid measure of the neutral meson yield since the photon spectrum from proton-bombarded targets, which has been measured by Bjorklund, Crandall, Moyer, and York[2] and by Crandall and Panofsky,[3] is nearly consistent with a pure π^0-decay spectrum. The possible reabsorption of a charged or neutral meson within the nucleus in which it is created seems to be not more than a few percent.

The pair spectrometer method of Bjorklund *et al.*[2] was not suitable for comparing yields from different targets because of the uncertainties involved in multiple traversals when viewing internal cyclotron targets.

The photon detector used for this experiment was of the type developed by Hildebrand, Knable, and Leith,[4] in which multiple scattering in a thick converter is used to separate the electron pairs. In this device two scintillation counter telescopes are

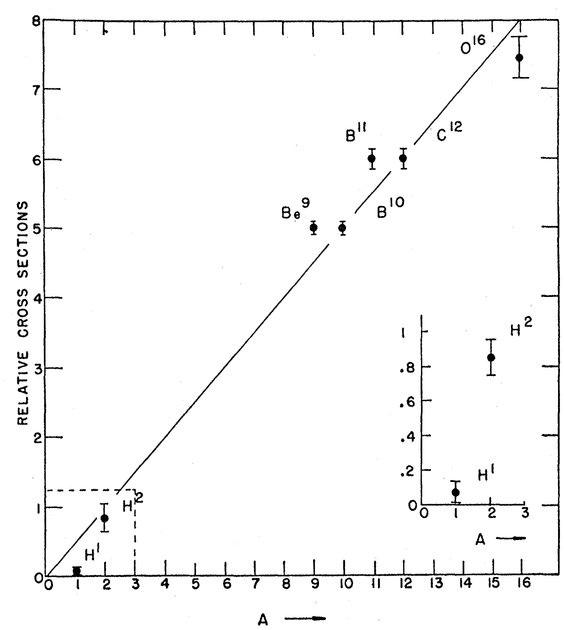

FIG. 2. Relative neutral meson yields.