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Gamma-Ray Ionization in Several Gases as a Function of Pressure and Collecting Field

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Ionization by low intensity γ-radiation in N_2, CO_2, A and He has been measured with pressures of from 0.98 to 93 atm. of N_2, 61 atm. of CO_2, 25 atm. of A, and 98 atm. of He and with uniform collecting fields from 1.57 to 1065 volts/cm, direct comparison being made with the results of Bowen for air. The marked increase in current with increased collecting gradient and independence of the shape of the current-field curves on intensity of radiation up to the intensity used demands rejection of the wall emission theory of Broxon and adaption of some recombination theory. Junction of Kaye and Laby's results to those of Bowen shows a gradient of 4×10^3 volts/cm as saturation value for air at 10 atm. pressure. A field of only 100 volts/cm is saturation value for argon up to 25 atm., and with this field the current from the inert gases examined is a linear function of the pressure up to 25 atm.

INTRODUCTION

DURING the last thirty years many observers[1, 2, 3, 4, 5, 6, 7, 8, 9] have studied γ-ray ionization in various gases as a function of pressure and collecting field; but excepting Bowen's[7] recent measurements on air and the present investigation of other gases, all observers have employed (1) either cylindrical or spherical ionization chambers, or (2) they have used a very high rate of ionization. In the first case the field is non-uniform and cannot be increased to large values because of the small central collecting electrode ordinarily used. Indeed the field amounts to only a few volts per cm in the regions of greatest volume even when several hundred volts are applied. Ordinary volume recombination complicates case (2) and makes theoretical interpretations very difficult. For example the very complete and careful study by Erikson[1] was made on ionization produced by 6 mg of Ra Br placed in the center of the ionization chamber, and hence the average ionization became thousands of times that now determined in cosmic-ray work.

APPARATUS AND PROCEDURE

To avoid objection (1) given above, the ions were collected between parallel plates 1 cm apart; to avoid objection (2) the ionization was always kept less than 20 times the residual ionization. The number of ions per cc per sec.

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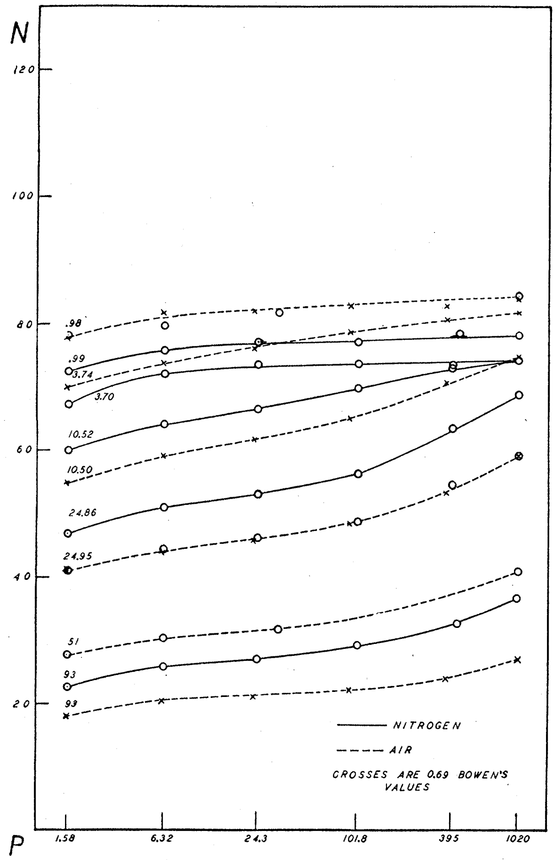

FIG. 1. Ionization observed in nitrogen.

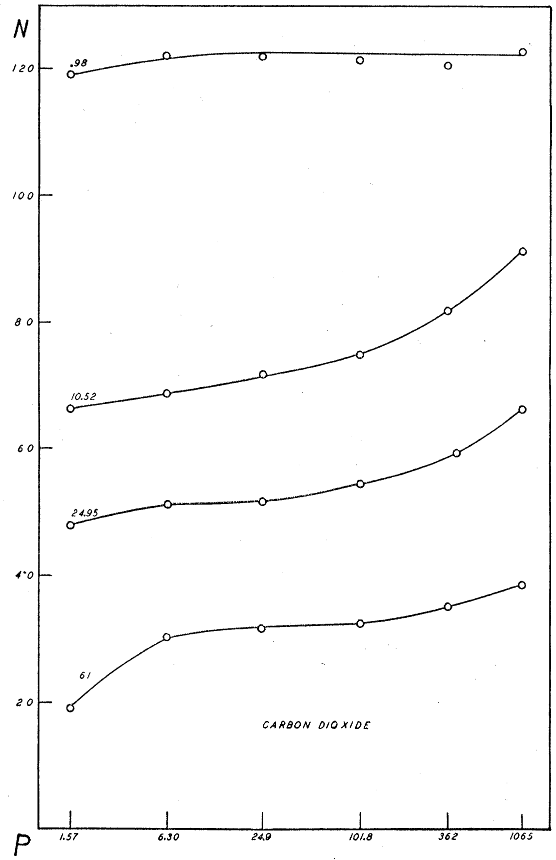

FIG. 2. Ionization observed in carbon dioxide.

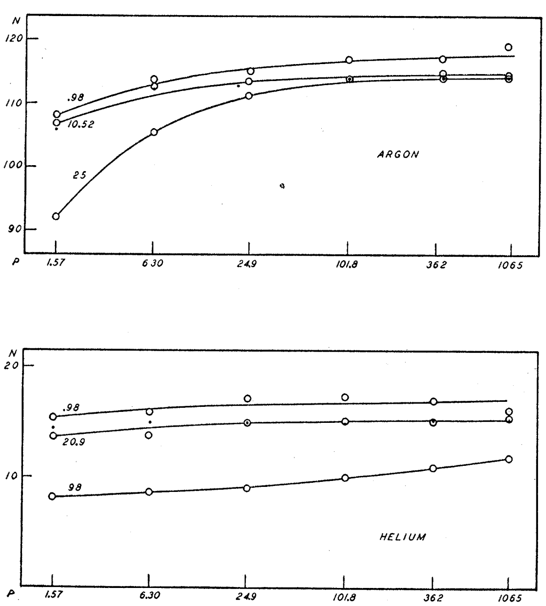

FIG. 3. Ionization observed in argon and helium.

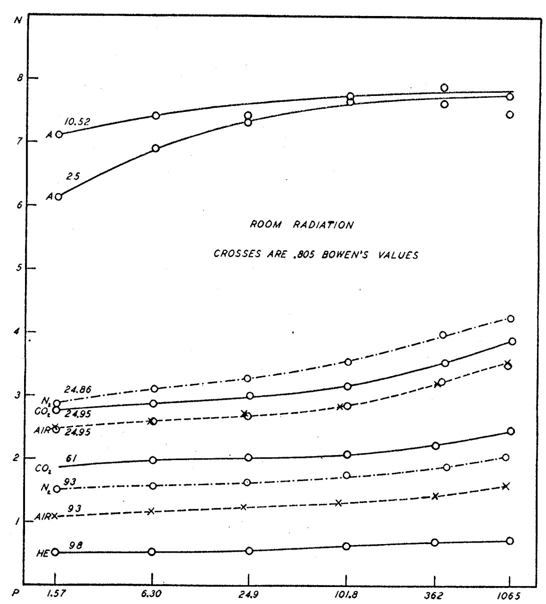

FIG. 4. Observed residual ionization in various gases.

per atm. was determined with the same apparatus and procedure described by Bowen[7] except that a small correction for the pressure change of dielectric constant of the gases, neglected by Bowen, was introduced.

Pressures near 1 atm. were read to about 2 percent with a manometer, while those from 2 to 50 atm. were registered by a periodically calibrated new 6-inch U. S. Test Gauge and should not be more than 0.1 atm. in error. For higher pressures it was necessary to use uncalibrated gauges whose errors may have been as large as 10 percent, probably too high if the new gauges of the California Institute cryogenic laboratory are assumed correct.

In order to fix the curves obtained by Bowen for air with those of the writer for other gases, data were taken for air at pressures of 0.98, 24.95, and 51 atm. Multiplication of Bowen's values by a factor of 0.69 gave nearly perfect agreement; and a factor 0.805 multiplying Bowen's values for room radiation did likewise. These transposed values with those of the writer for air appear in Figs. 1 and 4.

Similar measurements were next made in nitrogen, carbon dioxide, argon and helium. The nitrogen which was obtained from the Linde Air Products Co. was tested by Mr. W. M. Zaikowsky and found to contain no traces of CO_2 and 0.93 ± 0.025 percent of O_2. Commercial CO_2 was purchased from the Pure Carbonic Company but was not tested for purity. Dr. C. E. Hablutzel analyzed the argon obtained from the General Electric Co. and found it to contain 0.2 percent of O_2 but no trace of CO_2; an insensitive weight determination gave no evidence of nitrogen. The helium used was kindly furnished by Dr. A. Goetz from the supply of the cryogenic laboratory.

The general process of introducing the gases into the chamber was first to evacuate the chamber to less than 3 mm pressure. In the case of the cheaper gases the chamber was then filled with the gas to atmospheric pressure and re-evacuated several times before observations were begun. The chamber was flushed out with argon only once, but the evacuation was carried to a considerably lower pressure.

Results

The ionizations observed in N_2, CO_2, A and He at various pressures and collecting fields are displayed in Tables I–IV, and Figs. 1, 2, 3, respectively. Table V and Fig. 4 give the observed

TABLE I. *Number of ions/cc/sec./atm. from N_2.*

Field in volts/cm	Pressure in atm. 0.99	3.70	10.52	24.86	93
1.58	72.3	67.1	60.0	46.7	22.7
6.32	76.3	71.9	64.0	51.1	26.0
24.3	76.9	73.4	66.4	53.1	27.1
101.8	77.2	73.4	69.7	56.2	29.3
395	78.2	73.1	72.7	63.2	32.6
1020	78.0	74.0	73.9	68.6	36.7

TABLE II. *No. of ions/cc/sec./atm. from CO_2.*

Field in volts/cm	Pressure in atm. 0.98	10.52	24.95	61
1.57	118.8	66.2	47.8	18.8
6.30	121.7	68.5	51.1	30.2
24.9	121.4	71.5	51.5	31.5
101.8	120.9	74.6	54.3	32.4
362	120.1	81.6	59.1	35.1
1065	122.3	91.1	66.0	38.4

TABLE III. *No. of ions/cc/sec./atm. from argon.*

Field in volts/cm	Pressure in atm.			I_1	$4.55\ I_2$
	0.98	3.72	10.52	25	
1.57	108.2	105.9	106.9	92.1	95.1
6.30	113.8	112.3	112.7	105.5	105.5
24.9	115.1	112.8	113.5	111.2	111.2
101.8	117.0	114.0	114.0	114.0	112.6
362	117.2	114.1	114.9	114.1	113.8
1065	119.2	114.2	114.6	114.2	111.9

TABLE IV. *No. of ions/cc/sec./atm. from helium.*

Field in volts/cm	Pressure in atm. 0.98	10.52	20.9	98
1.57	15.4	14.4	13.7	8.20
6.30	15.9	14.9	13.8	8.77
24.9	17.2	14.9	15.0	9.12
101.8	17.3	14.9	15.1	10.0
362	17.0	15.2	15.1	11.0
1065	16.1	15.2	15.4	11.8

TABLE V. *No. of ions/cc/sec./atm. by room radiation.*

Gas	Pressure in atm.	Field in volts/cm 1.57	6.30	24.9	101.8	362	1065
Air	24.95	2.45	2.60	2.70	2.87	3.26	3.53
	93	1.08	1.17	1.25	1.32	1.42	1.60
N_2	24.86	2.86	3.10	3.28	3.56	4.00	4.26
	93	1.51	1.57	1.65	1.76	1.89	2.05
CO_2	24.95	2.76	2.88	3.01	3.19	3.56	3.92
	61	(2.76)	1.98	2.05	2.10	2.24	2.49
A	10.52	7.10	7.41	7.43	7.74	7.90	7.48
	25.0	6.12	6.91	7.32	7.66	7.64	7.77
He	98	.502	.530	.565	.635	.702	.742

residual ionization. In general each value listed represents the average of from 10 to 20 separate determinations. Due to the lower ionization and therefore longer observation time in helium only 7 observations were made for each point. N_2 and CO_2 evidently behave very similar to air, and the reader is again referred to Bowen's paper[7] for the interpretation. In the noble gases the ionization approaches much more nearly to proportionality with the pressure, indicating that *preferential* recombination with the parent ion plays a much smaller rôle in the case of these gases. This is in agreement with Hopfield's[8] observations on argon.

In the case of argon at its highest pressure the presence of volume recombination was further tested by measuring the ionization when the γ-ray intensity was cut to 1/4.55 of its normal value. The last column of Table III headed 4.55 I_2 gives the observed ionization times 4.55. A comparison of this column with the preceding one, giving the ionization with the normal intensity of γ-radiation, indicates that no volume recombination occurred except at the lowest collecting field.

The results here presented are useful in attempting a theory which will explain the decreasing ionization per atmosphere as the pressure is increased. Of the theories that have been advanced,[10, 11, 12, 13] only two allow quantitative comparison with the writer's results; and Gross[12] candidly concedes that his *initial* recombination theory cannot account for the high ionization in argon.

The writer wishes to thank Mr. W. M. Zaikowsky and Dr. C. E. Hablutzel for determining the purity of the gases used; Mr. B. E. Merkel for technical assistance with the high pressure gas system; Professor A. Goetz for the use of the helium gas from the supply of the cryogenic laboratory; and especially Professor I. S. Bowen for his patience, aid, and obliging advice throughout the course of experiment.

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