THE RESIDUAL IONIZATION IN NITROGEN AT HIGH PRESSURES

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Abstract

The residual ionization in nitrogen at high pressures was measured under conditions existing during a recent investigation of the residual ionization in air, with lead and water shields. As in earlier investigations, the residual ionization in nitrogen was found to be greater than that in air at all pressures. However, at the new high pressures the ionization-pressure curve becomes parallel to the pressure axis, as do the air curves. The explanation in terms of subsidiary radiations excited by the cosmic penetrating radiation in the walls of the ionization chamber serves as well for nitrogen as for air. The new work is discussed in relation to earlier investigations of the residual ionization in air, oxygen, nitrogen and carbon dioxide.

RECENTLY the writer[1] investigated the ionization produced by the cosmic penetrating radiation in aged, dry air contained in a large spherical ionization chamber at pressures up to 170 atmospheres. Earlier investigations[2] of the residual ionization in four gases, air, oxygen, nitrogen and carbon dioxide, over a pressure range extending from 1 to 70 or 80 atmospheres, had shown that within this range the ionization in the former two gases was very nearly the same under corresponding conditions. The latter two gases also yielded nearly identical ionization values, but in these gases the absolute values of the ionization and also the final slopes of the ionization-pressure curves were decidedly greater than in the cases of air and oxygen. Further, the forms of the ionization-pressure curves obtained with nitrogen and carbon dioxide were such as to arouse a suspicion that constant slopes of appreciable magnitude might have been attained. In view of these observations and the essentially constant values of the residual ionization in air measured at the higher pressures in the more recent work, it appeared that a special investigation of the residual ionization in nitrogen at the new high pressures would be of value.

Equipment and Procedure

The nitrogen used was obtained from a commercial concern. It would seem that in the process of purification of the nitrogen by evaporation from liquid air, any radium emanation would be retained in the oxygen and the nitrogen would be particularly free from radioactive contamination. However, in view of the high ionization values formerly observed, the nitrogen was kept stored in cylinders for a period of six months before being admitted into the chamber in which the ionization was measured.

[1] J. W. Broxon, Phys. Rev. **37,** 1320 (1931).
[2] H. F. Fruth, Phys. Rev. **22,** 109 (1923); J. W. Broxon, Phys. Rev. **27,** 542 (1926).

According to a statement by the company manufacturing it, the nitrogen was 99.8 percent pure, with 0.2 percent argon and oxygen. The gas was passed through a long tube containing phosphorus pentoxide and also plugs of glass wool and cotton to remove moisture and dust, precisely as in the case of the high pressure measurements in air. The chamber was washed by admitting and then releasing the gas until, as calculated on the basis of fractional removal, less than 10^{-6} percent of the gas finally investigated should have consisted of air originally in the ionization chamber. However, the gas as it was released from the ionization chamber was analyzed by Mr. K. A. Gagos of the University Department of Chemistry, and was found to contain 0.72 percent oxygen, with no observable carbon dioxide or water vapor. No test was made for argon. Mr. Gagos used a Bureau of Mines[3] apparatus, and estimated his accuracy at 0.02 percent. Subsequent analysis of gas obtained directly from the commercial cylinders, incidentally, showed that some of these had an even greater oxygen content.

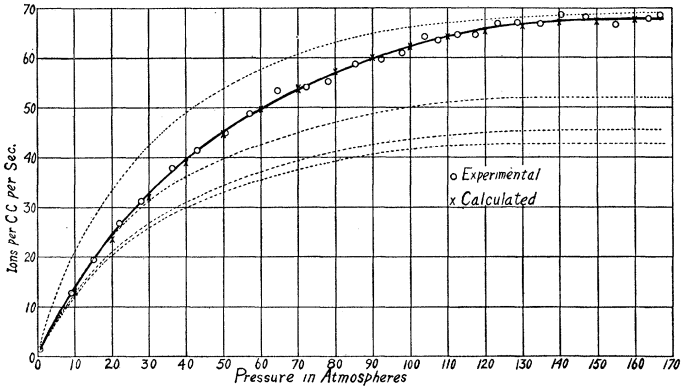

Fig. 1. Residual ionization in nitrogen.

The ionization was measured with precisely the same equipment used in the investigation of air,[1] the location of the apparatus and the method of measurement remaining unchanged. Because of the expense involved, only one series of pressure observations could be made. These were made[4] with the ionization chamber surrounded both by the two-inch lead shield and by the water shield formed by filling the fourteen-foot water tank in the center of which the ionization chamber was located. The series of readings extended over a five-day interval, June 15–19, 1931.

Observations

The observed ionization values are shown plotted against the pressures in Fig. 1. The actual temperatures during the observations varied between 15.35°C and 17.5°C. In order to facilitate comparison with the ionization-pressure curves previously found for air, the pressures were changed to cor-

[3] Bull. Bur. of Mines **42**, 17 (1913)

[4] Measurements of the dielectric constant of the nitrogen at the high pressures were made, also, and will be presented in a later paper.

responding pressures at 18°C, and these are the pressures designated in the diagram. In order further to facilitate comparison, the four curves formerly[1] obtained with air with various conditions as to shielding are represented in the diagram by dotted lines.

Discussion

Notwithstanding the long aging of the nitrogen, the ionization in this gas was again observed to be very considerably higher than that in air under the same conditions. The lowest of the dotted curves represents the ionization in the air under corresponding conditions, with both shields about the ionization chamber. At all pressures at which observations were made, extending from 0.82 to 167 atmospheres, the ionization in the nitrogen was greater than that in the air at corresponding pressures. In fact, the relation between the new high pressure nitrogen and air curves is nearly the same, in the region of the earlier investigation, as the relation between the nitrogen and air curves obtained by the writer[2] at sea level in 1925, these measurements having been made with entirely separate equipment, but with ionization chambers of about the same size and shape. If the ionization in excess of that at atmospheric pressure as observed with the present equipment with both lead and water shields is divided by the corresponding values obtained in the 1925 work with the unlined twelve-inch sphere, the ratio obtained in the case of air increases from 0.29 at 20 atmospheres to 0.30+ at 70 atmospheres, while the corresponding ratio in the case of nitrogen increases from 0.32 to 0.35 in the same region. The ionization in the nitrogen does not appear to have been decreased quite as much as that in air by the heavy shielding, but perhaps this may be accounted for by the fact that the nitrogen used in the earlier investigation was also commercial nitrogen, and no test of its purity was made.

A very significant characteristic of the new nitrogen curve is the very small slope at the high pressure end. Although the ionization at first increases with increase of pressure more rapidly than does that in air, so that the curve approaches that obtained with air with no special shielding, yet the slope continues to decrease with pressure and appears to be quite definitely zero (not exceeding 0.02 or 0.03 ion/cc·sec·atm.) at the high pressure end, precisely as in the case of the curves obtained with air. The region of constant ionization values does not begin at quite as low pressures as do those obtained with air, but it is sufficiently extended to establish definitely the very small value of the final slope. Therefore, on the basis of the explanation of the ionization-pressure relation previously suggested, in terms of secondary radiations excited by the cosmic penetrating radiation in the walls of the container, the ionization measurements made with the two gases now agree in showing an exceedingly small primary ionization due directly to the penetrating radiation. On this basis, however, it would appear that the secondary radiations with nitrogen in the chamber must be somewhat more penetrating and ionize more copiously than in the case of air. The form of the nitrogen curve is better represented by the simple relation derived by the writer[1] in explanation of the observations made in air, than is the case with the air curves. The calculated

values designated in the diagram were obtained by the use of this relation and the assumption that 90 percent of the final maximum ionization was due to radiations of range corresponding to 180 atmospheres in the bomb (roughly 180 diameters of the bomb in nitrogen at atmospheric pressure) and 10 percent to radiations of range corresponding to 50 atmospheres. The final slope of the curve found by differentiating the theoretical expression thus obtained and evaluating the derivative at 170 atmospheres is $dI/dP = 0.003$ ion per cc per sec. per atmosphere.

In the opinion of the writer, the chief discrepancy between the residual ionization measurements in the different gases investigated has been removed by the discovery that at the very high pressures practically no increase of ionization with pressure is observed in either air or nitrogen. The greater absolute values[5] of the ionization in nitrogen are quite striking, however, and deserve consideration. This difference between the magnitudes of the ionization in these gases appears to be well established. As mentioned before, the difference was observed both by Fruth[2] and by the writer in the earlier experiments. Moreover, Fruth separated nitrogen from air and found that the ionization-pressure relation was practically the same as in commercial nitrogen, although the nitrogen he prepared contained 4 percent of oxygen. However, when he mixed nitrogen and oxygen in the proper proportions to form air, he observed the same ionization-pressure relation as in air (and oxygen), with the exception of the sharp breaks and the horizontal portions of the curves which he observed at about 53 atmospheres and which have not been verified by the later experiments. Very recently, Professor A. H. Compton discussed with the writer some unpublished work which he has been carrying on. He, also, has observed the constancy of the residual ionization at high pressures, and that the ionization in nitrogen is greater than that in air.

That the difference in absolute values might be due to a radioactive gas in the nitrogen seems very unlikely in view of the precautions taken. Moreover, that it might be due either to this cause or to a spontaneous disintegration of the nitrogen seems unlikely in view of the forms of the ionization-pressure curves. In such a case the ionization would be expected to increase with the density of the gas. Not only does the ionization in each gas fail to increase beyond a certain amount, but the pressure-rate of divergence between the corresponding curves for nitrogen and air, although nearly constant up to about 70 atmospheres, gradually decreases at higher pressures, and the two curves become practically parallel and horizontal at pressures above 140 atmospheres. If the explanation of observations in terms of subsidiary radia-

[5] An observation contributing to the establishment of the fact that the differences among the curves obtained with different conditions as to shielding in the recent investigation of the residual ionization in air at high pressures were due solely to the differences in shielding, was unintentionally omitted from the report (reference 1) of that investigation. The air remaining in the chamber at atmospheric pressure after a series of observations with a particular shield was kept enclosed until the succeeding shielding had been arranged. In each instance the ionization measured under these circumstances was the same as that measured in the new supply of air at atmospheric pressure at the end of the succeeding series of observations.

tions from the walls of the chamber is accepted, the differences among the residual ionization values in the four gases investigated suggest the possibility of the production, whenever sufficient free oxygen is present, of some surface condition causing an appreciable absorption of the subsidiary radiations.

Although the difference between the final values of the ionization in air and nitrogen is very considerable in comparison with either of these, being 59 percent of the maximum ionization in air, it is perhaps worth remarking that the difference is after all a rather small quantity in view of the high pressures; a little more than 25 ions per cc per sec. at 167 atmospheres, the difference amounts only to about 0.15 ion per cc per sec. per atmosphere. At the local atmospheric pressure, the difference between the ionization values is of the order of 0.1 ion per cc per sec.

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