THE VARIATION OF THE RESIDUAL IONIZATION IN AIR WITH PRESSURE, FOR A RANGE OF 57 ATMOSPHERES.[1]

BY K. MELVINA DOWNEY.

SYNOPSIS.

Residual Ionization in a Closed Spherical Steel Vessel One Foot in Diameter, for Pressures up to 58 Atmospheres.—The present work is an extension of previous experiments in which a linear relation was found between rate of ionization and pressure up to 22 atmospheres. Essentially the same method and apparatus was used as before. Results for air from 9 to 17 days old are given in curves. From 2 to 27 atmospheres, the rate of ionization increased linearly with the pressure at the rate of about 1.25 pairs of ions per c.c. per second per atmosphere change of pressure. Between 27 and 47 atmospheres the curves differ somewhat, the slope seeming to decrease with age, but above 47 atmospheres all curves are approximately horizontal, that is, the ionization was found to be practically independent of the pressure from 47 atmospheres up to the highest pressure tried. In view of the theoretical conclusions already established by Professor Swann this result clearly proves that the ionization due directly or indirectly to the action on the air of a penetrating cosmical or other radiation is extremely small, less than 0.1 pair of ions per c.c. per second at any pressure. Of the ionization produced at atmospheric pressure, about 1.25 pairs per c.c. per second must be due to radiations, either primary or secondary, coming from the walls of the vessel and having penetrations of from 28 to 47 ft. in air at atmospheric pressure; the rest must be due chiefly to much softer radiation, also from the walls. In the previous experiments performed outdoors over water instead of in the laboratory, the change of the rate of ionization with pressure was 1.56 instead of 1.25. The difference may be due to screening action by the laboratory building.

Ionization Due to the γ Rays of Radium in Air in a Closed Spherical Steel Vessel One Foot in Diameter, for Pressures Ranging up to 57 Atmospheres.—A curve obtained with 2 mg. of lead-shielded RaBr placed 8 feet from the vessel, shows a slope which constantly decreases as the pressure increases, the slope at 50 atmospheres being about one eighth of the slope at one atmosphere. Evidently most of the ionization is due to secondary radiation from the walls.

INTRODUCTION.

THE present investigation is a continuation to higher pressures of a previous experiment,[2] in which the residual ionization in air in a sphere having an internal diameter of one foot was found to be a linear function of the pressure up to twenty-two atmospheres. The experiments were undertaken for the purpose of gaining information as to the type of radiation responsible for the residual ionization. The linear relation obtained would indicate that the ionization was due either to a

[1] Presented at the annual meeting of the American Physical Society in Chicago, December 28–30, 1920.

[2] PHYS. REV., Vol. 16, pp. 420–437, 1920.

direct action of an external radiation, or to a secondary corpuscular radiation emitted from the walls of the vessel and having a penetration of at least twenty-two feet at one atmosphere. The results obtained by other observers on "Residual Ionization" were discussed in the previous paper.

Apparatus and Method.

In the earlier work the central systems of two similar spherical ionization chambers were connected together and to a fiber electrometer, while the outer walls of the chambers were connected to opposite ends of a high potential battery. This battery was shunted with a resistance of ten megohms, and the midpoint of this resistance was connected to the case of the electrometer, in order to eliminate completely the effect of any fluctuations of the potential of the batteries. In the present experiments it was found advisable to replace the 10-megohm resistance by adjustable wire resistances immersed in oil as these remained more constant under rather trying conditions. Furthermore a sliding connection with the earth terminal was arranged so that, in case of any irregular changes in the various resistances, the earthing point[1] could easily be kept connected to the electrical midpoint of the resistances.

With a few exceptions, the details of the pressure arrangement were the same as in the earlier work. The pressure in one sphere was varied, while that in the other sphere was kept atmospheric. The pressures recorded in this paper refer to the excess over atmospheric just as in the previous paper. In the case of the high-pressure ionization sphere, it was necessary to replace the bolts holding the hemispheres together by bolts of larger cross-sectional area. During the course of the work, several imperfections appeared on the plane surfaces of the cross-sections of the hemispheres, so that considerable difficulty was experienced in finding suitable material for the gaskets. Copper was found unsatisfactory and rubber was finally resorted to.

The method of measurement differed in no essential way from that given in the previous paper. The capacity of the system was found to be 27.4 e.s. units.

Saturation Voltage.

Thorough tests for the saturation voltage were made. The potentials given to the ionization spheres and the corresponding values for q, the number of pairs of ions per c.c. per second, are shown in Table I.

[1] It is convenient to speak of the common point to which all the shields, etc., were connected as the earthing point, although actual connection of this point to earth is, of course, unnecessary.

TABLE I.

Potential in Volts.	*q*		
	Pressure 52 Atmospheres.	Pressure 53 Atmospheres.	Pressure 56.7 Atmospheres.
120	42.4	42.4	
200	45.5	49.8	
320	50.4	50.4	
400	51.3	51.2	
520	51.5		
600	51.5	51.5	54.9
760	51.5		
800	——	51.7	54.8

It is evident from this table that 500 volts was ample for saturation. The potential on the spheres in the actual experimental work was from 700 to 800 volts.

RESIDUAL IONIZATION CURVES.

The graphs given in Figs. 1, 2, 3, 4 represent the change in residual ionization when the pressure excess over atmospheric was varied from zero to a value of the order of 57 atmospheres. A linear relation having a constant slope from one atmosphere to a pressure of the order of 27 atmospheres is shown by all four curves in agreement with the writer's former results. The decided drop in ionization below one atmosphere was undoubtedly due to easily absorbable radiation.

TABLE II.

Figure.	Age of Air.	Δq for AB.	Pressure at B.	Δq for CD.	Pressure at D.
I..............	17 days	1.23	27.7	0.58	45.6
II..............	14 "	1.31	26.3	0.70	46.5
III..............	10 "	1.20	26.3	0.84	47.0
IV..............	9 "	1.22	27.5	1.06	43.8
Average..........		1.25	27.0	0.79	45.7

The values for the change in the number of pairs of ions produced per c.c. per second for a change of pressure of one atmosphere are given for each of the curves in Table II., where they are designated by Δq. The air was left in cylinders for some time before each set of observations so as to allow radioactive emanation to decay, but, as will be seen from Table II., Δq shows no variation for the region AB of the curves for an increase of the time of ageing from 9 to 17 days. This confirms the

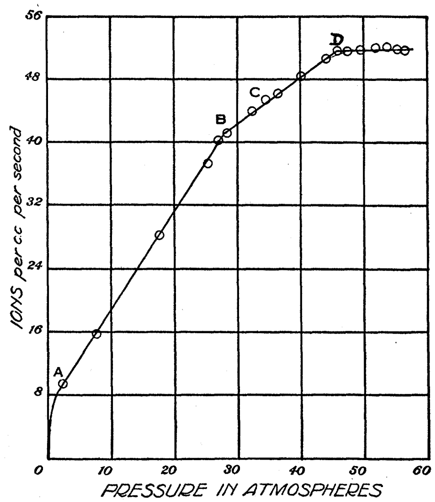

Fig. 1.

Residual ionization in air 17 days old.
1 P.M., Sept. 2, to 5:15 A.M., Sept. 3, 1920.

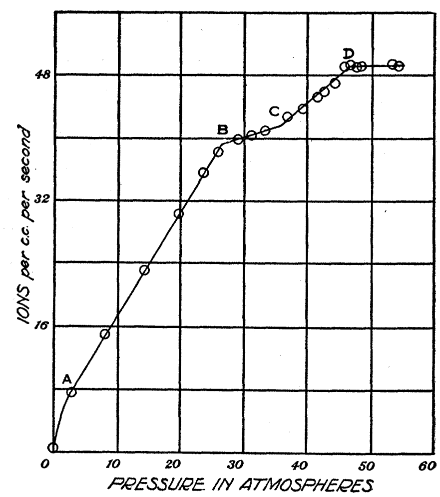

Fig. 2.

Residual ionization in air 14 days old.
4 P.M., Aug. 30, to 12 noon, Aug. 31, 1920.

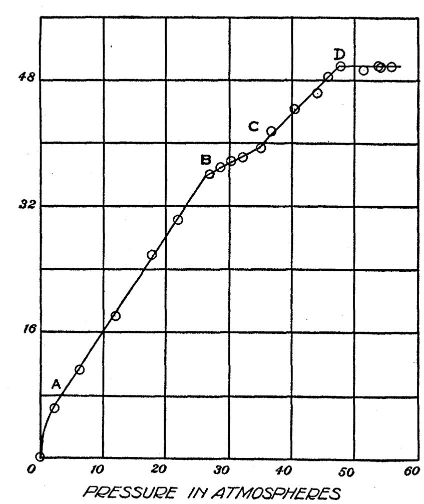

Fig. 3.

Residual ionization in air 10 days old.
5 P.M., Aug. 19, to 10 A.M., Aug. 20, 1920.

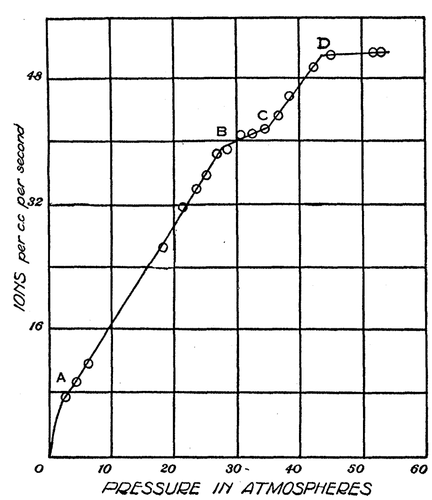

Fig. 4.

Residual ionization in air 9 days old.
10:50 A.M., Aug. 17, to 8 A.M., Aug. 18, 1920.

results of the preliminary experiments, for some of which the air was aged as long as 90 days. The effect of any small amount of emanation, which may be present, is masked then by the larger portion of soft radiation for the portion *AB* of the curve, but an examination of Δq for the portion *CD* gives a suggestion of an effect due to the emanation. (It may be noted that Curve IV., for which there was the shortest period of ageing, shows a greater deviation than any other curve from the average values in the last two columns of Table II.).

Emanation may also be in part responsible for the rather irregular changes in slope shown particularly by Curves 2, 3, and 4, which correspond to the smaller periods of ageing. This would seem probable because, before taking the readings at the higher pressures, it was not always possible to wait the required time for the old decay products of any emanation present to come into equilibrium with the new amount remaining after a part of the air was expelled. The result of this would be to cause the ionization after releasing the pressure to be greater than the normal value corresponding to the lower pressure. The difference would depend upon the interval elapsing between the change of pressure and the recording of the reading, and would consequently tend to cause more or less irregular changes in slope of the curve obtained. It is of interest to observe that these changes are conspicuously absent in the case of Curve 1, which corresponds to the longest period of ageing.

The curves agree in that they indicate an upper limit for the ionization, and this is attained at a pressure of the order of 46 or 47 atmospheres. The ionization was apparently constant for the remaining range of pressures tried (approximately 47 to 57 atmospheres). The *significance of the attainment of an upper limit* beyond which the ionization does not increase with further increase of pressure was pointed out by Professor W. F. G. Swann in a paper presented before the American Geophysical Union, Washington, D. C., April 18, 1921.[1] Professor Swann has shown that the minimum increase of ionization per c.c. per atmosphere, as measured for any pressure, is greater than any portion of the ionization per c.c. per second at one atmosphere, due to the direct action of a penetrating radiation and its accompanying secondary radiation produced in the gas. (In this proof the radiation was assumed to have a penetration comparable with that ordinarily assigned to a cosmical-penetrating radiation.) In view of the preceding conclusion, the fact that an upper limit is obtained for the ionization at the higher pressures indicates that no appreciable part of the ionization at atmospheric pressure is produced by the direct or indirect action on the gas itself of a radiation of a highly

[1] Bulletin of the National Research Council, No. 17, pp. 65–73, 1922.

penetrating type. Most if not all of the ionization then appears to be due to the direct action of a radiation of a penetration low compared with that usually attributed to the cosmical radiation. It is probable that this is radiation of the corpuscular type emitted from the walls of the vessel by impurities or by the primary radiation. The ionization pressure curves indicate that the radiation is completely absorbed at pressures above 47 atmospheres.

In the previous experiments performed over the Mississippi River in 1919 with a range of pressure from zero to 22 atmospheres, the values obtained for Δq on May 16 and May 17 were 1.55 and 1.58 ions per c.c. per second per atmosphere increase respectively. Since in these experiments the radiation from the soil was absorbed by the layer of water, it is apparent that in the present experiments (where lower values for Δq were obtained) the walls of the laboratory building served to screen away more of the shorter range radiation in the atmosphere.

Even the average value for Δq, 1.25 pairs of ions per c.c. per second, obtained from the portion AB of the curves of Figures I., II., III., and IV. (Table II.), is lower than the values at atmospheric pressure that have been given by other observers. McLennan and Murray found that 2.6 pairs of ions per c.c. per second were produced at atmospheric pressure in a vessel of ice.[1] Up to the present time this appears to be the lowest value obtained by direct measurement, but it may be noted here that Gockel estimated an approximate value as low as 1.66 for the number of pairs of ions produced per c.c. per second at atmospheric pressure.[2] McLennan and Murray seem to favor the view that this ionization is due to radioactive impurities in the material of the ionization chamber. In the light of present experiments it would be of interest to compare the penetration of the radiation given off by more common radioactive substances. Sodium and potassium are, of course, common impurities. While there have been experiments by N. R. Campbell indicating that potassium is radioactive, there seems to be no definite information as to any radiation which may be emitted.

"Radium" Curves and General Deductions.

In the writer's work for the sake of comparison it seemed best to repeat the ionization pressure experiments with radium-bromide placed 8 feet from the inoization spheres. The values thus obtained are given in Curves V. and VI. A two-milligram sample of radium-bromide enclosed in a lead box (walls of which were 1.5 cm. in thickness) was used for these

[1] Phil. Mag., 30, p. 428, 1915.
[2] Phys. Zeit., 16, pp. 345–352, 1915.

experiments, but when the values for Fig. 6 were obtained, the radium bromide was shielded by additional plates of lead. It is evident from the graphs that the ionization values for the curve of Fig. 5 are greater than

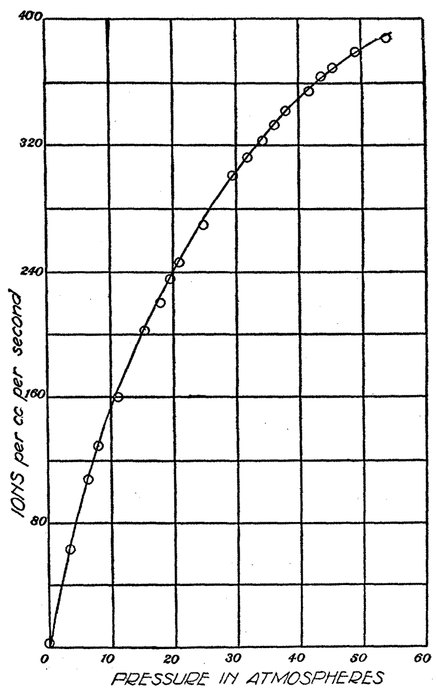

Fig. 5.

Ionization due to the gamma rays of radium.

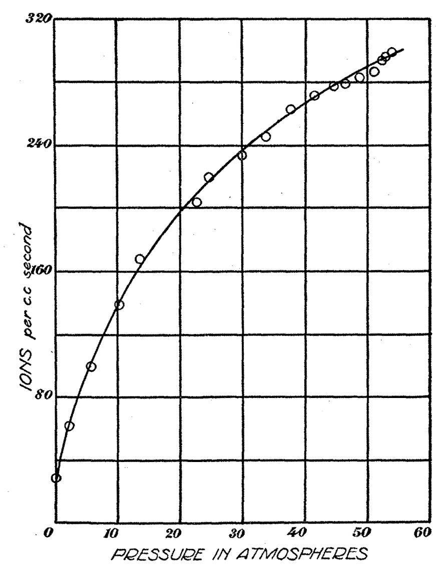

Fig. 6.

Ionization due to the gamma rays of radium. The shielding of the radium bromide used was greater for these observations than for those of Fig. 5.

those for the same pressures in the curve of Fig. 6, which of course represents ionization due to the harder type of radiation.

It is apparent that the upper limit of the ionization shown by the "residual ionization" curves is not to be found in the "radium" curves.

So far as the residual ionization at atmospheric pressure is concerned, it is obvious that the ionization due to the action of the penetrating radiation on the gas itself is practically immeasurable. It would seem than that the residual ionization must be attributed for the most part either to radiation emitted by impurities in the walls of the vessel or to secondary radiation from these walls.

This experimental work was carried on during the summer of 1920 in

the University of Minnesota. I am indebted to Professor F. B. Rowley, of the experimental engineering laboratories, for the calibration of the pressure gauge used in these experiments, and to the department of physics for the use of the laboratory facilities. I wish to express my most sincere thanks to Professor W. F. G. Swann, who has suggested this problem and given me much helpful advice throughout the course of this work.

Physical Laboratory,
University of Minnesota,
December, 1921.