# LETTERS TO THE EDITOR

*Prompt publication of brief reports of important discoveries in physics may be secured by addressing them to this department. Closing dates for this department are, for the first issue of the month, the twenty-eighth of the preceding month; for the second issue, the thirteenth of the month. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents.*

## Ionization as a Function of Pressure and Temperature

Attention has been called by Swann,[1] Broxon[2] and others[3] to the fact that the residual ionization in an ionization chamber (due chiefly to cosmic rays) is not proportional to the pressure, but reaches a maximum value in the neighborhood of a hundred atmospheres. The proposed explanation has been that the ions are formed by high speed beta-particles ejected from the walls of the ionization chamber, and that these beta-rays are completely absorbed by the air if the pressure is sufficiently high.

An alternative explanation of the phenomenon is that a form of recombination may occur at high pressures, due to the fact that the electron ejected from a molecule by the ionizing beta-ray may lose its initial energy through molecular collisions before it has moved far enough from the parent positive ion to escape from the effect of its electrostatic attraction. In accord with the ideas underlying Thomson's theory of recombination,[4] we may suppose that if the initial energy of the electron carries it beyond a critical distance, molecular diffusion will probably carry it away, and a permanent ion will be formed. If $i$ is the ionization per unit pressure when all ions remain permanent, $p$ the pressure, and $P$ is the probability that an ion will remain permanent, the ionization may be written as

$$i = i_1 pP. \quad (1)$$

The probability $P$ will approach unity for low pressures and zero for high pressures, and will have a greater value at high temperatures than at low temperatures, since diffusion will be more rapid. Kinetic theory calculations lead to rather complicated expressions for $P$, which will be presented in a later paper. They show, however, that the ionization $i$ should reach a maximum as the pressure increases, and then fall gradually to zero for very high pressures. For the range of pressures studied by Broxon, the theoretical curve is similar to that observed, though the agreement is not exact.

A consequence of this recombination theory is that the variation of ionization with pressure should be nearly the same with gamma-rays as with cosmic rays, since neither are much absorbed by the air in the ionization chamber. On the beta-ray absorption theory, since the beta-rays excited by gamma-rays are presumably of much shorter range than those due to cosmic rays, the ionization should either reach its limit at a lower pressure, if the ionizing beta-rays come from the walls, or should increase without limit if the gamma-rays produce beta-rays within the gas. Experiments at Chicago with a spherical steel ionization chamber, 4 inches in diameter, and on Mt. Evans with a cylindrical steel chamber, gave pressure ionization curves with gamma-rays and cosmic rays which were closely similar to each other and to Broxon's pressure curve using a 10 (?) inch chamber

The 4 inch ionization chamber was also surrounded by a water bath so that its temperature could be varied from about 0°C to 35°C. With air at 100 atmospheres pressure the ionization was about 8 percent greater at the higher temperature, while at 20 atmospheres we were unable to detect any effect of temperature change. These results are in approximate quantitative agreement with the predictions

[1] W. F. G. Swann, J. Frank. Inst. **209,** 151 (1930).

[2] J. W. Broxon, Phys. Rev. **37,** 1321 (1931).

[3] K. M. Downey, Phys. Rev. **16,** 420 (1922). H. H. Fruth, Phys. Rev. **22,** 109 (1923).

[4] Thomson, Phil. Mag. **47,** 337 (1924); Conduction of Electricity Through Gases, 3 ed. pp. 44–57.

of the recombination theory, whereas the beta-ray range theory would predict no effect at either pressure.

Further support of the recombination theory of the limited ionization at high pressures comes from the observation that when nitrogen is used, the ionization remains proportional to the pressure up to pressures much higher than is the case with air. We have observed this to be the case using gamma-rays, and Broxon informs us that he finds the same difference with cosmic rays. The interpretation of this difference between nitrogen and air is apparently the fact that the energy lost by an electron per collision is much less in nitrogen than in air. Thus an electron ejected by a passing beta-particle should move farther from its parent positive ion in nitrogen than in air before losing its initial energy. This would make recombination less likely in nitrogen.

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## The Constancy of Cosmic Rays

In the preceding letter to the Physical Review we have called attention to the fact that the ionization of air traversed by gamma-rays from radium is a function of the pressure, and that this dependence upon the pressure is greater when the pressure is high. There have been from time to time important and careful experiments which have indicated a variation in the intensity of cosmic rays with the time of day. Those of Millikan have, for example, shown a maximum intensity in the afternoon and a minimum at night. This is the type of apparent variation that one should expect if the apparatus is not kept at a uniform temperature. Other observers have noted that the apparent variation in cosmic ray intensity is greater for the softer component of the cosmic rays. These softer components, however, can only be studied in very high altitudes where the temperature variation between day and night becomes relatively large. We, therefore, determined to study the variations in the intensity of cosmic rays in a high altitude in such a way that possible temperature variations would not influence our results.

The ionization chamber used in these experiments was a hollow steel sphere, 4 inches in diameter, filled with dry air at thirty atmospheres pressure. (The ionization was measured by means of a Lindemann electrometer. Hourly readings were taken of the ratio of the intensity of the cosmic ray entering this chamber when shielded with two inches of lead to the intensity of the gamma-rays from a milligram of radium placed in a fixed position about 30 centimeters from the chamber.) Any temperature variations should, under these conditions, affect equally the ionization produced by the cosmic rays and the gamma-rays.

This apparatus was taken to Summit Lake, near the top of Mount Evans, Colorado, at an altitude of 12,680 feet. A series of hourly readings taken for 240 consecutive hours showed no variations in the intensity greater than the variations to be expected from purely statistical considerations. (The probable error of the intensity for a four hour period was about 0.15 percent.) This series of readings appears to be as thorough a test of the diurnal variations of cosmic ray intensity as has yet been made, and since it shows no intensity changes, it would appear that probably some of the previous changes that have been recorded may be due merely to variations in the temperature of the apparatus employed.

The long, continuous series of readings necessary to make this test of diurnal variations could not have been completed without the cooperation of Messrs. V. J. Andrew, F. P. Longman, V. L. Ridenour, and A. A. Compton of Chicago; and W. J. Overbeck, P. M. Barth, and J. A. Headberg of Denver.

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## Thermionic Emission from a Plane Electrode

Being convinced of the importance of space charge in any theory of the thermionic work function, as Waterman and I have pointed out, I have sought explanations of the differences between experimental results and theoretical calculations along this line. In addi-