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The Effect of Cathode Material on the Second Townsend Coefficient for Ionization by Collision in Pure and Contaminated N_2 Gas

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Experiments for the measurement of the Townsend coefficients for ionization by collision were performed on pure N_2 and N_2 contaminated with Na vapor and Hg vapor. Cathodes of Pt, Na, and Hg were used. Values of α/p in N_2 contaminated with Hg vapor agree with the values found by previous investigators using N_2 of similar purity. With pure N_2 at the lower pressures and higher X/p, the values were seventeen percent lower than the corresponding values in the Hg contaminated N_2. At high pressure and low X/p, the curves differed by relatively little. With Na contamination which may have been accompanied by H_2 contamination, a larger increase in α/p was observed, which amounted at low pressure and high X/p to as much as twenty-four percent higher than the value for the pure N_2. The high value of α/p for Hg contaminated N_2 is explained as being partly due to the direct ionization of Hg vapor atoms by electrons and partly being due to the action of metastable N_2 molecules on Hg. Imprisoned radiation is probably not an important factor. Because of the low vapor pressure of the Na, the direct electron ionization and the ionization by metastable molecules can hardly be invoked to explain the increase in α/p. One must conclude either that the vapor pressure of the Na at room temperature is far above the extrapolated values taken from tables, which is unlikely, or that H_2 introduced in the distillation of Na or N_2 make a volatile compound with Na under excitation or action of ultraviolet light. The shapes of the β/p curves plotted as $f(X/p)$ show abrupt rises at certain values of X/p, definite plateaus, and subsequent gradual increases. These effects have not been observed in previous investigations where Hg contamination predominates, those curves rising asymptotically. Greater significance attaches to the $\beta/\alpha=\gamma=\eta\theta g/\alpha$ curves, which in the case of Pt and Na rise abruptly from zero at a given X/p to a high peak, then fall abruptly and rise again gradually at higher X/p. The rise for the Pt electrode at $X/p=60$ is sharp and occurs at a much lower X/p than any previously observed when low electron current densities are used. The curve with the Na cathode rises at a *higher* X/p than that for Pt to a lower maximum and then, after a fall, rises again. This is surprising, in view of the fact that the Na surface has a far lower work function and far greater photoelectric efficiency than Pt. The sharp peak in pure N_2 is ascribed to the action of radiation either via metastable molecules or by some other mechanism in liberating electrons from the cathode. In the presence of either Hg or Na vapor (possibly contaminated with H_2), the metastable or radiative action is completely destroyed, the energy going to the ionization of the Hg or of the Na and H_2 atoms, if present. In the case of Na, it is possible that only the lower energy states are destroyed so that some of the higher energy states are able to reach the Na cathode. Hence, the small peak at higher X/p with Na. Deducting the peaks leads to curves for Na and Pt and to a lesser extent Hg which intercept the axis at an X/p between 200 and 300. In this region, positive ions have an energy of the order of between two and five volts. Such ions can liberate secondary electrons from the cathode, and we have the effect of a true γ.

INTRODUCTION

DESPITE the many studies made on the Townsend coefficients α and β for ionization by collision in gases, practically none of the work except that done by Penning[1-3] and his associates has been carried out in such a fashion as certainly to avoid contamination of the gases by Hg vapor. Owing to the use of mercury gauges in measurements of pressure and the evacuation techniques in filling the chambers with otherwise pure gases, this contamination was unavoidably present to about 10^{-3} mm pressure in all previous work. The effect of mercury vapor on the coefficient α in inert gases has been amply shown by Penning.[4] Furthermore, all electrode surfaces in such gases are coated with monomolecular or thicker layers of Hg as a result of evacuation of the chamber. Hence any value obtained in earlier work for the second coefficient β, which recent work has indicated to be a cathode mechanism, has been that due to a Hg contaminated surface.[5] It is the purpose of this investigation by careful elimination of Hg vapor to determine the second Townsend coefficient β, or better its more significant correlate[5] $\gamma=\beta/\alpha$ for surfaces of Pt and Pt coated with Na in a molecular gas, N_2. The choice of N_2 was in a

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[1] Kruithof and Penning, Physica **3**, 515 (1936).

[2] Kruithof and Penning, Physica **4**, 430 (1937).

[3] Kruithof and Druyvesteyn, Physica **4**, 450 (1937).

[4] F. M. Penning, Phil. Mag. **11**, 979 (1931).

[5] L. B. Loeb, Rev. Mod. Phys. **8**, 267 (1936).

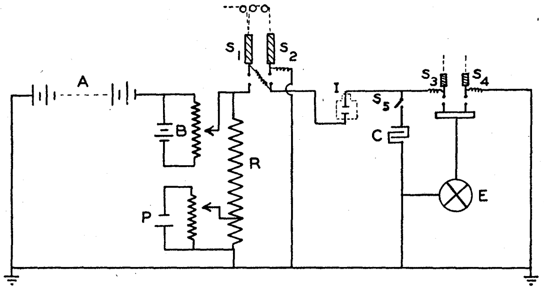

FIG. 1. Diagram of apparatus.

sense unfortunate since N_2 has metastable and active states which complicate the results. Had the importance of these states been recognized at the start the gas used would have been H_2 which is now under investigation in this laboratory instead of N_2.

APPARATUS AND EXPERIMENTAL PROCEDURE

The experimental arrangement is shown in Fig. 1. The potential was supplied by a bank of batteries, A. The positive side was connected to ground and the negative side to one fixed terminal of a slide wire rheostat, B. A few cells were connected across the rheostat and the sliding contact was connected to the illuminated plate of the ionization chamber through the switch, S_1. The potential was measured by means of a standard cell, the resistance R and the potentiometer P. The resistances of the plug box, ratio box, and potentiometer and the e.m.f. of the standard cell were accurate to within a few one-hundredths of one percent. Switches S_1 and S_2 were used to connect the cathode of the ionization chamber I either to the potential source or to ground. Both were fitted with platinum contacts and mechanically connected so that when one opened the other closed. Switch S_3 connected the anode of the ionization chamber to the electrometer. Under the system of measurement used by the writer S_3 was kept closed but was used in testing for electrical leaks. Switch S_4 was connected to ground and was used during the application of potential to the chamber and was also used to remove charge from the electrometer. Switch S_5 was used to connect the sulphur-insulated cylindrical condenser C in parallel with the electrometer when the ionization currents became large. The ionization currents were measured by the rate of deflection method using the quadrant electrometer E. As a result of varying the capacity and the interval of making measurements, currents ranging from 3×10^{-14} to 2×10^{-11} amperes were capable of being measured.

The ionization chamber is shown in detail in Fig. 2. The internal parts of the chamber were electrically shielded from the glass walls by the monel metal screen A, which was connected to ground. The cathode B was 3.8 centimeters in diameter. The cathode consisted of a 0.007″ platinum surface mounted on a quartz plate. The anode D was made of nickel and was of the same diameter as the cathode. It was supported by the threaded rod E. This rod was connected at its upper end to the iron armature F by means of the threaded arms a. The armature was held at a constant height by the hollow cylinder H, concentric with the hollow cylinder I inside of which the rod moved. The armature was turned by an electromagnet. The rod E was kept from turning by a set screw K which fitted in a vertical slot in the rod. By these arrangements the anode could be set at any desired distance from the cathode. The plates were parallel to within a few tenths of one percent. The plate separation was read through a plane glass window with the aid of a cathetometer. Tube M contained the capsule N, into which sodium had been distilled, and the ballbearing R used for breaking the capsule. The ultraviolet radiation entered through a quartz window and fell on the lower plate.

Before the chamber was assembled, its glass and metal parts were cleaned with acid, grain alcohol, and distilled water, and great care was taken to prevent mercury vapor from coming into contact with any of the parts. After the tube was assembled a lubricated Apiezone stopcock was placed between the tube and a liquid-air trap. The stopcock was kept closed at all times unless liquid air completely surrounded the trap. The chamber was outgassed at 375°C for several hours.

During the course of the experiment, mercury was purposely admitted to the chamber. Complete removal of the mercury necessitated dismantling the entire chamber and cleaning each part with concentrated nitric acid.

The sodium used for coating the cathode was purified by repeated vacuum distillation before it was distilled into the capsule. Although the sodium may not have been absolutely pure, a surface was obtained that was so sensitive to ordinary light that it was necessary to enclose the chamber in a heavy black cloth and to darken the room to prevent photoelectrons from coming from the surface. In addition, the ultraviolet source was replaced by a Mazda lamp to keep the photoelectric current density from becoming large enough to cause space charge distortion.[6]

The usual source of radiation was a quartz mercury arc operated on 220 volts. A variable aperture was placed near the arc and an image of this aperture was formed at the center of the cathode by a quartz lens. The field between the plates was investigated by means of a full size cross-section model of the plates and found to be sensibly uniform over an area larger than that covered by the ultraviolet light.

Tank nitrogen was passed through a purifying train consisting of heated copper filings, $CaCl_2$, and P_2O_5. It was then passed very slowly through two liquid-air traps and admitted to the chamber. The pressure was measured by a McLeod gauge, which was accurate to one-half of one percent or better. Gas pressures were always reduced to a standard temperature of 22°C and hence all data given in this paper refer to this temperature.

Measurements were made by applying the field and measuring the current by a rate of deflection method. Each current was measured by five deflections which were corrected for leakage currents with no illumination. The usual mean deviation of the five readings was less than one and one-half percent.

The plate separation was varied and similar current measurements were made for the same field strength. The observations usually covered a range of plate separations varying from one to 2.2 cm at intervals of one mm except at the higher plate distances where the intervals were 0.5 mm. In most cases a current was measured for a plate separation within 0.5 mm of sparking. These plate separations were always changed from smaller to larger values.

The sequence of measurements under different conditions were as follows: A few runs using a platinum cathode were first made. Since these indicated a low value of α/p, mercury was admitted and three mercury runs for α/p were taken. The mercury was removed by dismantling and cleaning. The tube was reassembled and runs covering a range of X/p from 65 to 1000 were made. Sodium was then distilled onto the plates and a range of X/p extending from 155 to 1050 was covered. In removing the sodium by use of water, the armature stuck to the threaded rod. The tube was partially dismantled and the armature loosened. After the tube was reassembled, several runs were taken, scattered over the range of 59 to 660. Mercury was then admitted to the chamber and several runs were taken for both α/p and β/p. As a final check the mercury was again removed and two values of α/p and β/p in the lower range of X/p were found for the platinum cathode.

EXPERIMENTAL RESULTS

Curves giving $1/p \log i/i_0$ as a function of plate distance are shown in Figs. 3 and 4. The slopes of the lower portions of these curves give α/p directly.[7] These curves are typical ones

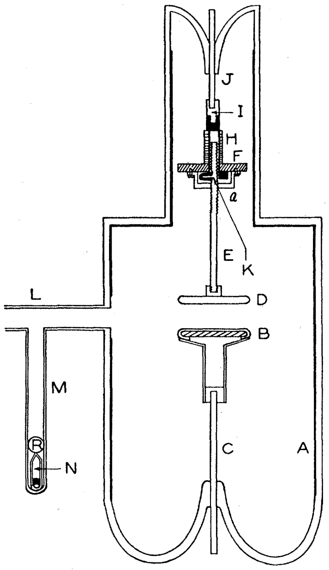

FIG. 2. Ionization chamber.

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[6] Varney, White, Loeb and Posin, Phys. Rev. **48**, 818 (1935).

[7] For terminology and the treatment and interpretation of the data the reader is referred to Loeb's summary of this field in Rev. Mod. Phys. **8**, 267 (1936).

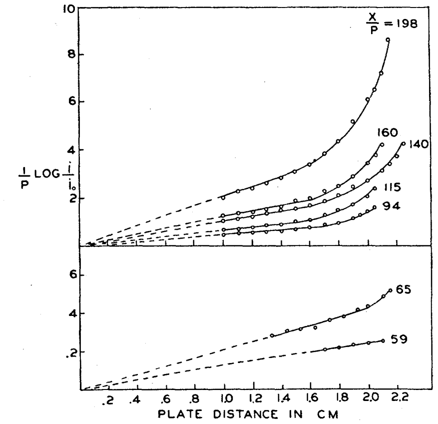

FIG. 3. Curves of various values of X/p from which the value of α/p may be obtained.

obtained with a platinum cathode. Curves of similar forms were obtained for the sodium and mercury covered cathodes. The values of α and of i_0 were determined by the method of least squares from the actual observations, by using data corresponding to the lower parts of the curves, where they are sensibly linear in form. A value of β was obtained for each value of α and i_0 by use of the Townsend equation

$$i=i_0\frac{(\alpha-\beta)e^{(\alpha-\beta)x}}{\alpha-\beta e^{(\alpha-\beta)x}}.^{8}$$

In general, five to eight values of β were computed from the upcurved portion of the figures. The values of β chosen were *not* least square averages but were determined by the average β that gave the best fit to the observed curves. Similar methods have been used by others.[1, 2]

The first values of α/p that were obtained were several percent lower than corresponding values found by previous investigators. A thorough check of the writer's experimental arrangement and technique of obtaining results was made and no cause for the apparently low values was found. Next, a survey of the literature revealed that mercury was probably present in the ionization chambers of the previous investigators. In the chambers of Townsend and Hurst[9] and of Posin,[10] liquid mercury was present as a necessary part of the chambers.

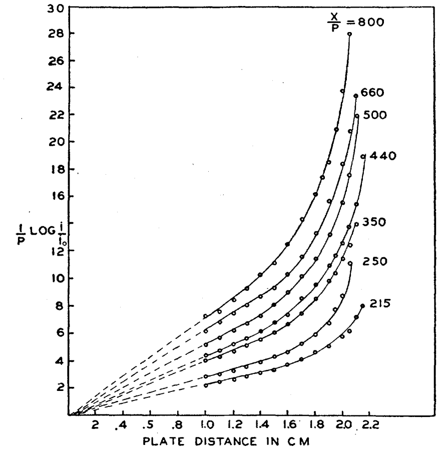

FIG. 4. Curves of various values of X/p from which the value of α/p may be obtained.

In the papers of Masch,[11] Gill[12] and of Ayres[13] no mention was made of keeping the mercury of the McLeod gauges out of the chambers. While these chambers were evacuated, mercury vapor from the McLeod gauges would have passed into the ionization chambers and contaminated the nitrogen. In order to ascertain if mercury vapor was a contributing factor to the high results of these workers, mercury was admitted to the writer's ionization chamber. The values of α/p then obtained were in close agreement with those of Townsend.

The values of α/p as $f(X/p)$ for the three cathodes investigated are shown in Fig. 5. The

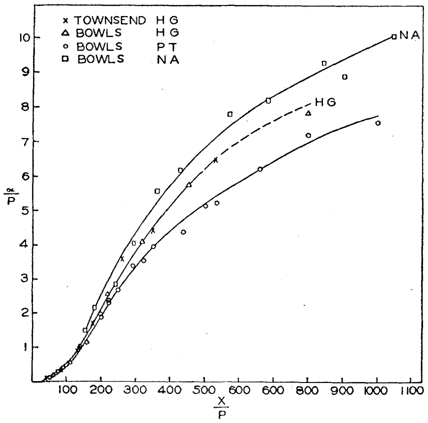

FIG. 5. Values of α/p as a function of X/p.

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[8] J. S. Townsend, *Electricity in Gases.*

[9] H. E. Hurst, Phil. Mag. **11**, 535 (1906).

[10] D. Q. Posin, Phys. Rev. **50**, 650 (1936).

[11] K. Masch, Archiv. f. Elek. **26**, 589 (1932).

[12] E. W. Gill, Phil. Mag. **42**, 852 (1921).

[13] T. L. R. Ayres, Phil. Mag. **45**, 353 (1923).

values of Townsend are represented by crosses and the values obtained by the writer for mercury-contaminated nitrogen are represented by triangles. A curve drawn through Townsend's observed points is seen to fit my observations as closely as it fits his. At the lower values of X/p this curve is scarcely distinguishable from my curve for pure nitrogen drawn through the circled observed points. At higher values of X/p the curve for pure nitrogen is as much as seventeen percent lower than the Townsend curve. The results for the case of a sodium cathode are shown as squares. At the higher values of X/p the nitrogen curve is approximately twenty-four percent lower than the sodium curve. The values of α/p in the latter case are more erratic than in the other cases studied. The probable errors are correspondingly larger.

In the case of a platinum cathode a value of β was obtained for an X/p of 65, but no value of β existed at an X/p of 59. These results are shown graphically in Fig. 3. A complete variation of β/p with X/p for the three cathodes is shown in Fig. 6. The same designations are employed as were previously used for α/p.

The variation of $\beta/\alpha=\gamma$ or $\eta\theta g/\alpha$ with X/p is shown in Fig. 7. The values of Posin[6] for a mercury-covered cathode are shown as black circles, and a curve is drawn through his points. The other designations are the same as those previously used.

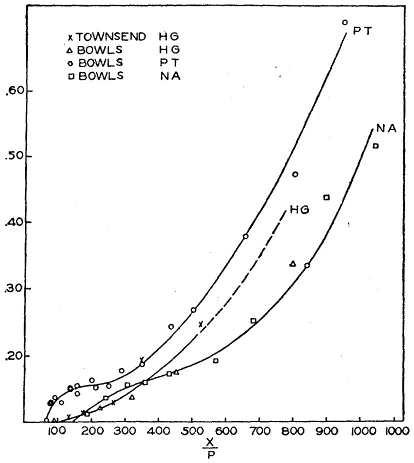

FIG. 6. Values of β/p as a function of X/p. (The circle appearing at an X/p of about 840 on the Na curve should be a square.)

DISCUSSION AND INTERPRETATION

The three methods by which α/p could be increased by the presence of impurities of mercury or sodium vapor in the nitrogen are ionization of the impurity by (1) electron impact, (2) metastable nitrogen, and (3) imprisoned radiation.

MERCURY

1. Quantitative calculations show that the high values of α/p that were obtained when mercury vapor was present may be partly explained as direct ionization of the mercury atoms by electrons. The vapor pressure of mercury at 22°C is 1.43×10^{-3} mm and consequently the number of mercury atoms present in the nitrogen is quite large. Since the first ionization potential of nitrogen is 16.7 volts and that of mercury is 10.4 volts, the latter should show a preferential ionization relative to that for nitrogen despite the paucity of mercury atoms.

The calculations utilized (1) the above data, (2) the efficiencies of ionization of electrons of known energies in nitrogen and mercury vapor as given by P. T. Smith,[14] (3) the Maxwell law of distribution of energies of electrons in an electric field, and (4) the experimental value of Townsend[15] for the average energy of an electron in nitrogen in an electric field.

These calculations showed that direct electron ionization of mercury vapor could account for an increase of α/p of the order of one percent at a

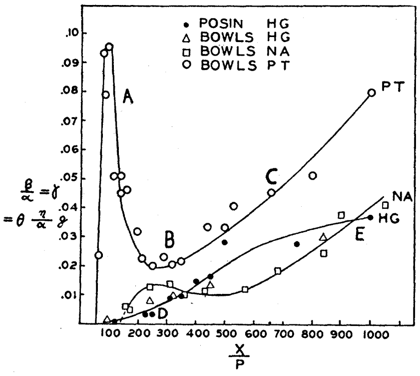

FIG. 7. Values of the ratio β/α as a function of X/p.

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[14] P. T. Smith, Phys. Rev. **37**, 808 (1931).

[15] J. S. Townsend, Phil. Mag. **42**, 873 (1921).

value of X/p of 100. At this value of X/p the α/p value for the mixture is higher than that for pure nitrogen by about six percent. We must, however, remember that this result was obtained by assuming a Maxwell distribution of energies. It has been shown in the recent work of Nielsen and Bradbury[16] and H. W. Allen that, depending on the change of electron free paths with energy, the distribution law may be far different from the Maxwell law. Since in nitrogen the Ramsauer free paths vary rapidly with energy, the calculated contribution of mercury to α/p may be too small.

For large values of X/p the gas pressure is smaller than for low values of X/p and therefore the fraction of mercury atoms present in the nitrogen is larger for the high values of X/p. Although the efficiency of ionization in mercury relative to that in nitrogen is less at high values of X/p than it is at low values, calculations showed that because of the fractional increase of mercury atoms the percent contribution of mercury to α/p should be greater for the high values of X/p.

2. Although the energy of the metastable state of the nitrogen molecule that is generally quoted is about 8.2 volts, a value of 9.77 volts is given as the probable energy by Saha and Mathur.[17] The latter value is still too small by 0.62 volt to ionize mercury, but Mulliken[18] has found that energies of 10.4 volts can be transferred by active nitrogen. This latter amount of energy is sufficient to ionize mercury, and it is possible that metastable molecules of nitrogen contribute to the high values of α/p in the case of a mercury contamination. Kruithof[1, 2] and Penning found that the values of α/p in neon containing a small amount of argon were very much higher than the values found in pure neon. As an example of the increase of α/p, the values at $X/p=10$ are chosen. In pure neon the value is 0.050 and in the mixture containing one-tenth percent argon the value is 0.322. This increase was proven to be due to ionization of argon by metastable neon atoms.

If more data regarding the energies and lifetimes of the metastable states of nitrogen were available, calculations could be made to determine the percent contribution of this mechanism to α/p. Since, however, we know nothing about the metastable states we can state only that this mechanism *may* have been active and *could* have been the predominating one. There is evidence that mercury vapor removes some exceedingly active agent instead of permitting it to reach the cathode. This agent cannot be a positive ion and must be either a radiation or a metastable state.

3. There is a possibility of ionization of the mercury vapor by radiation imprisoned in the gas. This process might account for some of the rise of α/p in the mixed gas, but it is the least likely mechanism and may not even exist in nitrogen.

SODIUM

The three mechanisms that cause the high values of α/p in the case of a mercury contamination must also be active in the case of a sodium contamination. The problem, however, is complicated in the case of sodium by its exceedingly low vapor pressure at ordinary temperatures. On the other hand, it is simplified by the low ionization potential of sodium (5.12 volts). This potential is so low that there is no doubt as to the ability of metastable and active nitrogen to ionize sodium.

The vapor pressure of sodium is not known at room temperature but estimates place it at about 10^{-10} mm of mercury. This means that there are present only 10^6 atoms of sodium per cm^3. For this reason ionization of the sodium vapor by electron impact can contribute very little to the value of α/p in spite of the low ionization potential. Ionization by imprisoned radiation and metastable ionization may be important but they could not contribute sufficient ionization to cause the observed increases of α/p in the case of the sodium contamination. One might question the validity of the extrapolated value for the vapor pressure of sodium. It is doubtful however if these could be so badly in error as to account for the effects observed with sodium which requires a pressure of at least 10^{-6} mm to be effective.

There is a possibility suggested by N. E. Bradbury that, despite repeated fractional distil-

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[16] Nielsen and Bradbury, Phys. Rev. **51**, 69 (1937): Phys. Rev. **50**, 950 (1936).

[17] Saha and Mathur, Proc. Nat. Acad. Sc. India **6**, 120 (1936).

[18] R. S. Mulliken, Phys. Rev. **32**, 186 (1928).

lation of the Na in vacuum, it still carried with it some H_2 gas. The danger of contamination by H_2 from the Na is sufficiently well known so that one cannot ignore the possibility. With the technique of filling the chamber, it would not have been impossible to have had 10^{-5} to 10^{-6} mm pressure of H_2 gas present in the N_2 as a result of distillation of Na into the chamber. According to Joseph Kaplan, H_2 is a most active agent in destroying the metastable states of N_2. In the present chamber with baking out and in the absence of Na the chance of H_2 contamination is small. The distillation of the Na, however, could introduce the pressure of H_2 suggested. H_2 ionizes at 15.3 volts and dissociates at 4.36 volts. H is ionized at 10.3 volts. It is clear that the H_2 cannot be directly much more effectively ionized by electron impact than N_2 of ionization potential 16.7 volts. Nor can H_2 be ionized directly by metastable states in N_2. Hence, one cannot ascribe the increase in α to the direct ionization of H_2 by electron impact or metastables, as was possibly the case with Hg. On the other hand with many metastables the H_2 could be completely dissociated by the N_2 metastables of low energy. The metastables of higher energy could ionize the H atoms, or, if these were present in appreciable numbers, they might be ionized by electron impact more effectively than is N_2. In this fashion, it is conceivable that α in N_2 in the presence of Na with its H_2 contamination could be increased above that in the absence of Na.

While the process suggested may seem somewhat unlikely, it is, if one accepts the low concentration of Na atoms, the only possible way to account for the increase of α with Na in N_2.*

THE SIGNIFICANCE OF β

By referring to Fig. 6, we see that the β/p curve for platinum differs greatly from the curves for mercury and sodium. The platinum curve starts at an X/p of about 65 and rises rather abruptly to a plateau extending from 140 to 240. The spread of values in this region is rather large but a sufficient number of points was obtained to indicate a definite flattening of the curve. The rise at an X/p of 65 was unexpected because of the fact that other observers had not obtained a measurable β below 100. Townsend had observed a slight departure from ionization by electrons alone, as low as 44, but stated that β was very small and the first numerical value quoted by him was for an X/p of 131. Posin[6] had obtained a value of β at 100. No one had observed a flattening of the curve. At the high values of X/p the curve for platinum lies above the other curves and is of the same form as those found by previous investigators.

The curve for sodium starts at an X/p of about 140 or possibly somewhat lower. There appears to be a plateau, after the gradual rise of β/p, extending from 300 to 350. In general, the sodium curve rises more slowly than the platinum one and the β/p values are very much smaller than for platinum.

The mercury curve is typical of the results obtained by former investigators,[6, 8] regardless of the apparent material of the cathode, since a mercury coating was probably always present on the cathode. The data of Townsend were somewhat erratic at the higher values of X/p. At the lower values the writer's results lay on the Townsend curve. The results were higher than those obtained by Posin, who used a brass cathode heavily coated with Hg. The differences in the shapes of the β/p curves for different cathode materials indicate that *the secondary ionizing mechanism is not ionization by positive ions in the gas*. This is in agreement with the cumulative evidence from other fields, which indicates that under the conditions of these experiments a positive ion cannot possibly gain enough energy to ionize a gas molecule.[5, 19, 20] Other mechanisms must, therefore, be considered.

CATHODE MECHANISMS

For the discussion of these mechanisms, considerations presented by Loeb[5] show that we

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* *Note added in proof.*—The results of Florence Ehrenkrantz on sparking potentials in N_2 with Na and Pt electrodes in progress here are in perfect agreement with these findings. Miss Ehrenkrantz has just shown that contamination of pure N_2 with Hg free Pt electrodes by up to 5 percent H_2 does not alter the sparking potential appreciably. Thus H_2 in the absence of Na cannot cause the increase of α observed. The results indicate the presence of some volatile Na compound formed in the process of sparking.

[19] Holst and Oosterhuis, Phil. Mag. **46**, 1117 (1923).

[20] Sutton and Mouzon, Phys. Rev. **35**, 695 (1930); O. Beeck, Physik. Zeits. **35**, 36 (1934); R. N. Varney, Phys. Rev. **47**, 483 (1935).

should plot $\beta/\alpha=\gamma=\eta\theta g/\alpha$ as a function of X/p, representing electron liberation at the cathode by positive ion impact (γ) or photoelectric liberation at the cathode ($\eta\theta g/\alpha$). By referring to Fig. 7, we see quite striking curves for the variation of γ or $\eta\theta g/\alpha$ with X/p. The curve for platinum rises steeply at low values of X/p. A sharp peak is reached at about 100. The curve then falls rapidly until it arrives at the X/p region of 240. It then rises more slowly with increasing values of X/p. The sodium curve rises less steeply and at higher values of X/p. The peak is broader and very much lower. The gradual rise resembles that of platinum. Complete curves of this character have never been observed previously. The curves of Penning and his co-workers, however, indicate that such a peak exists at low values of X/p for both very pure neon and very pure argon. The values of γ or $\eta\theta g/\alpha$ observed by the writer for the mercury surface agree fairly well with those of Posin.

The average *electron* energy at which the platinum curve first rises is about 4.8 volts.[16] At this average energy value the probability of ionizing nitrogen will be distinctly smaller than the probability of exciting it. As the values of X/p increase the average electron energy increases and the probability of excitation increases relative to the probability of ionization. When still higher values of X/p are reached, the probability of ionization increases relative to the probability of excitation. Under these conditions θ/α should at first rise and then decline with increasing X/p. It is likely that the point at which θ/α decreases is at considerably higher energies than the point $X/p=100$ at which the curve begins to decline. It is, therefore, doubtful whether the expected behavior of θ/α will account for the curve observed for a platinum cathode. Again, because of the absence of experimental data on the relative values of θ and α and a distribution of electron energies in nitrogen, we are unable to speculate further regarding this matter.

The curves of Penning[1–3] and his co-workers were obtained by using pure neon and pure argon, and copper cathodes. The current densities of the order of 10^{-8} amp./cm^2 used in the experiments were so high that really accurate values of γ could not have been obtained because of space charge distortion. It was, furthermore, impossible in these experiments to evaluate γ in the X/p region equivalent to low values of X/p in nitrogen.

Penning's curves in argon and in neon indicated a behavior similar to that in the region ABC of the curve for platinum. With the introduction of a small amount of argon to the neon, the curve partook characteristically of the shape of my mercury curve between D and E. It is thus seen that with the removal of the neon metastable atoms as a result of impact with the argon atoms, the shape of the curve changed and the values of γ were less than they had been in pure neon.

It is, therefore, not unreasonable to assume that in the present experiments the peak at low values of X/p in the absence of mercury is due to some action at the cathode depending on excited molecules. The effect of adding mercury was to destroy the ionizing agent (imprisoned radiation or metastable molecules) before it reached the cathode. That this action took place was also indicated by the increase in α/p with the addition of mercury vapor.

In the case of sodium the resulting γ curve is quite surprising. A sodium coated surface in vacuum has a work function of the order of two volts whereas that of platinum is about 4.8 volts. One would, therefore, have expected an enormous photoelectric liberation from the sodium surface relative to that from platinum. That the surface of the cathode was effectively coated and that it had a low work function was shown by the copious electron emission when light from a Mazda lamp was incident on the surface.

The curve for sodium does show an effect similar to that found in the case of platinum, but it rises at a higher energy and has a much lower and broader peak. It is possible to ascribe the shift of the peak toward higher energies to the great efficiency of sodium vapor in destroying the low energy states and so the soft radiation, and to ascribe the appearance of the small peak to the ability of high energy states and hard radiation to reach the cathode.

In view of the small concentration of Na vapor, the action suggested above might be questioned. It is, however, possible that with the Na there was present perhaps as much as 10^{-5} mm pressure of H_2. The possibility of some contamination by H_2 is indicated by the extreme photosensitivity of the Na coated cathode. Such activity in photo-cells is indicative of hydride formation on the Na surface. In any case, it would not be difficult to ascribe a very material destruction of the N_2 excited and metastable states which could have been active at the cathode in the absence of Na to the presence of H_2 contamination.

When the effects of the peaks are deducted, all of the curves indicate a rise from zero that is fairly sharp and in the X/p region between 200 and 300. In this region the positive ions strike the cathode with energies in the range of two to five volts. It is natural to ascribe these rises to positive ion bombardment of the cathodes. These rises, then, represent the true γ proposed by Townsend and Thomson and strongly favored by Holst, Oosterhuis, Penning and Druyvesteyn.

In conclusion the writer desires to express his thanks to Professor L. B. Loeb under whose direction this work was done, for his guidance in its prosecution and for his aid in the interpretation of the results. His thanks are also due to Mr. W. R. Stamper for his aid in the construction of the apparatus.

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Magnetic Interaction in Homogeneously Strained Ferromagnetic Crystals

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A well-known method of computing magnetostrains, as the strains necessary to minimize the sum of magnetic and elastic potential energies, is improved in detail, extended to include terms dependent upon the structure of atomic magnets, and is applied in the cases of body-centered cubic iron, face-centered cubic nickel and hexagonal close-packed cobalt. It is shown that magnetostriction is not important in fixing directions of easiest magnetization in these crystals.

IN a crystal composed of atoms having permanent magnetic moments the potential energy density includes terms depending upon these moments and upon their mean relative positions. Such magnetic terms are therefore strain-sensitive. The potential energy density also contains terms depending only upon the strain components of any existing strain and upon the several elastic moduli characteristic of the crystal. It is apparent, therefore, that a crystal under no applied forces will assume whatever state of strain and magnetization that may be required to make the sum of its magnetic and elastic potential energies minimum. If both strain and magnetization are uniform throughout the crystal the total potential energy is proportional to the potential energy density, also homogeneous, which will be denoted by E.

In nonferromagnetic crystals the magnetization under no forces will be zero and the self-imposed strain associated with the presence of atomic magnets cannot be separated from strains associated with other interatomic forces. In a ferromagnetic crystal the magnetization persists under no applied magnetic forces, so that the equilibrium between magnetic and elastic forces can be investigated. The magnetic part of the energy E, say E_m, will in general depend upon the direction along which the axes of the atomic magnets are lined up, that is upon the unit vector $\mathbf{p}$ in the direction of magnetization. In one case of great interest E_m seems at first glance to be independent of $\mathbf{p}$.

If the atomic magnets are magnetic dipoles (point magnets) and if their loci have strictly cubic symmetry, E_m in an unbounded crystal is independent of $\mathbf{p}$. As Akulov[1] first pointed out, this equilibrium at zero strain is unstable. If the elastic potential energy is denoted by E_e the

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[1] N. S. Akulov, Zeits. f. Physik **52**, 389–405 (1928).