is an absorption band, on the edge of which this line lies; but we have definite evidence against this supposition. Photographs of the disruptive discharge in helium show strong lines, due to impurities, throughout the whole region where such an absorption band would have to lie. There seems to be no obvious explanation of the behavior of this line under these circumstances. It is interesting to note that when argon is present as an impurity in neon, its line λ 1048.26 (which corresponds to λ 735 in neon) shows no such variations in intensity. The next line in the same neon series, namely $1p$–$2s_2$ at λ 626.9 is of normal intensity, as may be seen in the plate (*a*).

Mr. H. W. Leighton has carried out much of the experimental manipulation necessary to this investigation. It is a pleasure to acknowledge the debt which we owe to his patience and skill.

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THE FREE PATH OF PROTONS IN HELIUM

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In a former paper[1] experiments were described with protons that had been accelerated through 900 volts' potential difference. The particles were found to have a much longer free path in hydrogen than would be expected from Rüchardt's observation with faster rays (13,000 to 16,000 volts). These experiments have since been extended to pressures five times as great as previously used, with similar results.

Experiments with the same apparatus have been made with protons in helium. The source was an anode of lithium that had been allowed to oxidize, and probably form the hydroxide. On bombardment with electrons it served as a source of protons, although other ions were also given off, hydrogen molecules, water vapor and nitrogen molecules. The rays were accelerated through a definite potential and deflected into a semicircular path by a magnetic field. They then fell through a slit onto an electrode where their charge was measured by an electrometer. As described in former papers,[2] the strength of the magnetic field and accelerating voltage serves to determine the nature of the charged particles falling on the electrode. The length of the path completed by the charged particles was 17 cms.

Helium gas was admitted at various pressures, and the different rays were observed by varying the magnetic field so as to bring them past the slit in front of the collecting electrode. At comparatively low pressures all the ions present except the hydrogen atoms were much reduced in intensity and disappeared at a pressure that had very little influence on the intensity of the bundle of protons. As the pressure increased, this bundle was broadened, but, with 930 volts accelerating potential, protons were observed as a definite group of rays with a pressure of 0.53 mm. of mercury. At this pressure the mean free path for a rapidly moving particle, assuming the kinetic gas theory value for the diameter of the helium atom, is 1.4 mms., so that the protons must have passed through more than 120 atoms without having their velocity or direction radically altered. Protons were observed with an applied accelerating potential difference as low as 14 volts. The slower rays were weaker and were not observed at such high pressures. This is probably to be accounted for by greater scattering rather than by any difference in their ability to penetrate the atoms. Rays obtained with 14 volts were observed with pressures up to 0.03 mm., at which pressure they would make seven collisions in the path completed.

Observations were made to test whether the protons lost energy in passing through the atoms, by noticing whether the magnetic field required to keep the rays in the same path remained the same when the pressure was increased. No certain indications of any loss of velocity were obtained.

We are thus led to the conclusion that protons with the velocities used in these experiments will pass freely through atoms of helium, with only slight changes in their velocity or direction.

Recent experiments by Henderson[3] and Rutherford[4] have shown that the alpha particle alternates rapidly between a doubly and singly charged condition. The free path for the capture of an electron decreases rapidly as the velocity decreases and approximates the kinetic theory free path for the lowest velocity. Rüchardt[5] has found that the free path for neutralization of protons accelerated by 13,000 to 16,000 volts, is slightly less than the free path between collisions on the kinetic theory. Theories have been proposed by Rüchardt[6] and Fowler[7] for the rate at which these rapidly moving charges should capture electrons. Both theories suppose electrons to be present that are free to combine with the moving nucleus at every collision. The slower the velocity of the nucleus, the more likely is the capture of an electron to take place.

We might explain the absence of neutralization observed in the experiments with slow protons as due to the inability of the proton of the speed used to produce free electrons, or to ionize the helium atom. J. J. Thomson[8] has pointed out that the maximum energy transferred to an electron of mass m by the direct impact of a mass M is only a small fraction $4m/M$ of the energy of the larger mass, provided the laws of mechanics apply. We should thus expect no ionization in helium with protons that have fallen through less than 11,270 volts. The application of simple mechanical considerations to this problem is quite doubtful, however, since the development of our ideas of excited states in the atom and the transformation of this atomic energy into kinetic energy of electron or atom. A discussion of the ionization potential of positive ions from this point of view has been given by Franck.[9]

In order to account for the ionization observed by many experimenters when gases are bombarded by ions from hot salts, Thomson suggests that positive particles may be able to capture an electron from an atom and so leave a gas ion, if it is moving with sufficient velocity to pass through the neutral atom. Analogous considerations have been advanced by Franck[10] in discussing the rôle of electron affinity in the change of sign in canal rays, and also in the paper just referred to. The failure of the proton to capture an electron may be associated on this point of view with the fact that the ionization potential of helium is 24.5 volts, while the energy of formation of a neutral hydrogen atom is only 13.6 volts, so that there is no tendency for an electron to leave the helium atom in order to join with the hydrogen nucleus. Ionization tracks in air due to rapidly moving protons have been observed by Blackett[11] in the Wilson drop track apparatus, and we should expect that at some speed protons would acquire the ability of disrupting the helium atom. The ratio of the velocity of the proton to the velocities of the electrons in their orbits may be the determining element in the interaction. The protons used in these experiments have much slower velocities than the electrons in the atom, so that they may be thought of as causing only a slow modification of the electronic orbits during their passage through the atom, without producing any permanent disturbance or ionization.

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