A REPLY TO MR. IRVING LANGMUIR'S PAPER "THE EFFECT OF SPACE CHARGE AND RESIDUAL GASES ON THERMIONIC CURRENTS IN HIGH VACUUM."[1]

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1. Mr. Langmuir does not mention (p. 450), that the author called attention to the experiment of Soddy[2] and first proved[3] that the current from a Wehnelt electrode decreases with the pressure in the tube, not because the decrease of the pressure changes some of the properties of the electrode, but because the electromotive force which is needed to cross the space between the electrodes increases with each improvement of the vacuum owing to the electron density in the space. The author is very glad that Mr. Langmuir has the same opinion on this point.

2. Mr. Langmuir does not mention, that the law

$$i = \text{constant } V^{3/2}$$

has been published[4] by the author as holding accurately for a range of current densities below an upper limiting value of i.

3. For values of i larger than this limiting value of i the author established[5] the law

$$i = \alpha V^2 + \beta.$$

4. If Mr. Langmuir finds in his experiments solely the law i = constant $V^{3/2}$ holding with a rather rough approximation, this is due to the fact that his current densities are below the limiting value mentioned above.

5. Mr. Langmuir claims (p. 483) that he obtained a much higher vacuum than the author. Adopting a criterion suggested by Mr. Langmuir (p. 470) we come rather to the contrary conclusion. Mr. Langmuir's opinion is that the exponent ϵ in the equation i = constant V^{ϵ} has to be = 3/2 as far as perfect vacuum is considered. Any increase of pressure increases ϵ. Now the lower part of Curve III., Fig. 5, obtained in Mr. Langmuir's "perfect vacuum" is represented by the equation i = constant V^{1,F_1}. Mr. Langmuir attributes this difference to residual gas. Indeed the author has shown[6] that in the lower part of

[1] PHYS. REV., December, 1913, p. 450.

[2] Nature, 77, 54, 1907; also Physik. Ztschr., 9, p. 1 (1), 1908.

[3] Physik. Ztschr., 9 (16), p. 193, 1908; also Ann. d. Phys., 32, p. 674, 1910.

[4] Ann. d. Phys., 32, p. 717–719; also p. 736, 1910.

[5] Ber de Math. Phys. Classe der Kgl. Ges. d. Wiss. zu Leipzig, 9, July 20, 1908; Ann. d. Phys., 32, p. 699.

[6] Ann. d. Phys., 32, p. 717–719; also p. 736, 1910.

his experimental curves the condition $\epsilon = 3/2$ is fulfilled with absolute accuracy. Considering that even in this part of the author's curves the current densities are larger than Mr. Langmuir's, we ought to conclude that the author's vacuum was by no means inferior to the vacuum Mr. Langmuir worked with.

6. Besides, there are other points proving that the author's vacuum was of the very highest degree, for he used liquid and solid hydrogen, with very large and short vacuum connections without changing in any way his results.

As to Mr. Langmuir's conviction that his essential advantage over the author's work consists in his using a pure metallic incandescent electrode instead of Wehnelt cathode, the author refers to the fact that changes of temperature and composition of the Wehnelt electrode do not involve any change in the discharge conditions.[1] Recently[2] the author published the results of his last three years' work, showing also, that not the least difference is caused by using an incandescent pure tantalum cathode instead of the Wehnelt cathode.

As to the anode, the principal thing is that it ought to be freed from gas at a temperature sufficiently higher (500°) than the temperature it assumes when the discharge is passing. The anode has a comparatively large surface, and can be directly cooled by liquid air. And the characteristic of the discharge is not altered by removing the liquid air bath. As the author tried all possible materials for the anodes,[3] obtaining always identical results, there is no possibility that the anodes would be of an essential influence in the experiments.

7. In his papers referred to the author proved by many other experiments that above a lower limit of the current density there is no dependence between the gas density and the discharge characteristic in a high vacuum. Moreover, he stated that above a certain current density there is practically no space charge in the perfect vacuum. He concluded from this as a matter of fact that there is formation of positive charges in the space independently of the gas. He did not call these positive charges ions, as Mr. Langmuir and also Mr. Coolidge[4] suggest in their papers, not having an exact evidence for their *nature*. But there is an absolute mathematical[5] evidence established for their *existence*.

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[1] Ann. d. Phys., 32, p. 714–715, 1910.

[2] Ann. d. Phys., 43, p. 37–40, 1914.

[3] Ann. d. Phys., 32, p. 706–710. 1910.

[4] Phys. Rev., December, 1913, p. 411.

[5] Ann. d. Phys., 32, p. 725–737 (1910); Ber. d. Math. Phys. Classe der Kgl. Ges. d. Wiss. zu Leipzig 63, 337–339 (1911); Ann. d. Phys. 43, p. 40–44, 1914.