Es scheint mir überhaupt die Untersuchung dieser Vorgänge an der Grenze zwischen Gasen und festen Körpern respektive Flüssigkeiten einen Weg zu bieten, um über die Natur der letzteren näheren Aufschluß zu erlangen; insbesondere dürfte diesbezüglich auch das Phänomen des Gleitens der Gase eine noch größere Beachtung verdienen, als sie ihm bisher zu Teil wurde.

X. ON CONDUCTION OF HEAT BY RAREFIED GASES

(Philosophical Magazine Vol. 46, 1898; pp. 192–206).

1. At the same time when this year's first number of the Philosophical Magazine appeared, containing Mr. C. F. Brush's[1]) very interesting paper „On Transmission of Radiant Heat by Gases at Varying Pressures", I published in Wiedemann's *Annalen* (vol. lxiv. p. 101, 1898) the results of an experimental investigation of mine on quite a similar subject, and conducted in quite a similar way, though quite independently, of course, of Mr. Brush's.

The design of my work was somewhat different, however. His research, which is of a purely experimental character, extends over the general laws of cooling of bodies in gases at various pressures, including the effects of convection-currents, of radiation, and conduction of heat. I tried, on the contrary, to eliminate the first two effects, considering former researches of Kundt and Warburg, and confined my attention to the conduction of heat, and especially to its modifications arising at very low gas-pressures, in respect of which the kinetic theory of gases gives some remarkable suggestions which had not been examined before.

In order to explain these, I may be allowed to remind the reader of certain points in the mathematical theory of conduction of heat.

2. As is known, Fourier based his theory upon the assumption that the quantity of heat flowing through a body in a given direction is proportional to the corresponding gradient of temper-

[1]) Would it not have been preferable to omit the word „radiant"? It can be used only in connexion with the „aether-line" in Mr Brush's observations, not with convection or conduction of heat.

ature which he supposed to be distributed everywhere in a continuous manner.

Poisson, however, constructing his theory on the supposition of a special mechanism of conduction (defined, in a somewhat vague way, as „molecular radiation“), inferred that there must be a discontinuity of temperature-distribution at the surface of separation between two bodies of different conductivities when an exchange of heat between them is going on.

The difference of temperature $\theta_1 - \theta_2$ (ordinarily very small) at both sides of this surface should be proportional to the flow of heat passing through it, and therefore also to the slope of temperature in either of them. This is expressed by the equation

$$\theta_1 - \theta_2 = \gamma \frac{\partial \theta_1}{\partial n_1}, \tag{1}$$

where γ may be called the coefficient of discontinuity of temperature.

But until now there has been no experimental evidence for the existence of such a discontinuity, and the coefficient γ was supposed commonly to be zero, so much the more as Poisson's theory of „molecular radiation“ has lost all credit and the kinetic nature of the conduction of heat is generally accepted.

Kundt and Warburg, however, who discovered the slipping of rarefied gases moving along solid surfaces thought it probable that something analogous — viz. a discontinuity of temperature — may arise in such gases when conduction of heat is going on.

To decide whether this is the case or not, was the scope of the present work.

Praxis and Theory of Experiment.

3. The chief difficulty in examining the conduction of heat by gases consists in separating the pure conductive effect from the effects of the convection-currents and of the direct radiation, which always are present to some degree where conduction is going on.

The convective currents can be avoided to a great extent by a proper shape of the vessel containing the gas, so as to leave the least possible free space for their development. Besides, their effect can be still diminished, and made practically negligible, by rarefying the gas; since its viscosity remains the same, whereas the disturbing forces decrease proportionally with the density. (See Kundt and Warburg, Pogg. *Ann.* clv. p. 156).

Then we have still conduction and radiation. These two can be separated by comparing experiments made with vessels of different sizes (Winkelmann), or by measuring the effect of radiation by itself, when the best possible vacuum has been obtained (Kundt and Warburg).

In the experiments described below both these methods were used.

4. The experimental arrangement was quite similar to that of Mr. Brush (and others before); but the shape and dimensions of the thermometer and the glass vessel were adapted to my special purpose.

The thermometer BT (see figs. 1 and 2) had a cylindrical mercury-bulb B and a very thin stem S, thickened in the middle in the shape of a stopper P, so as to fit air-tight in the mouth of either of two cylindrical glass vessels, V_{I} and V_{II}, formed alike, and differing only in the value of the diameter. The outer diameter of the mercury-bulb was $r = 0{\cdot}4566$ cm., its length $l = 6{\cdot}57$ cm.; the inner diameter of vessel I. $R = 0{\cdot}653$ cm., of vessel II. $R = 1{\cdot}573$ cm. These vessels were connected by glass tubing with a mercury air-pump (Töpler's construction), which was adapted also to the measurement of low gas-pressures by an arrangement similar to McLeod's gauge. (See Bessel-Hagen, Wied. *Ann.* xii. p. 434).

Greatest care was taken for dryness of the pump and apparatus, and for the air-tight fitting by means of some mercury poured in at the mouth M and at the stopcock C.

The mode of experimenting was quite simple. When the gas was brought to the desired density, the vessel, with the thermometer in, was heated by hot water to nearly 100° C; then it was suddenly immersed in ice, and now the cooling down of the thermometer was observed by measuring the time which the mercury column took for creeping back from the point 100 of the scale to the zero point (corresponding in reality to the temperatures 47·99° and 20·04° C).

5. Let us consider now in what way we might be able to de-

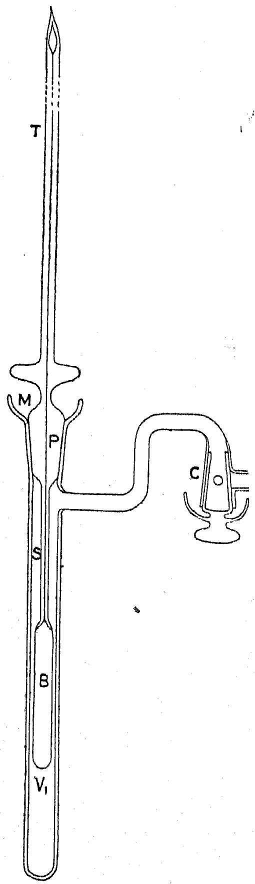

Fig. 1.

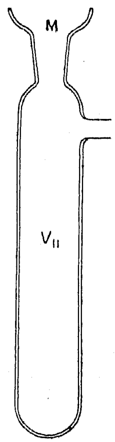

Fig. 2.

cide, by observing the time of cooling, whether there is any discontinuity of temperature between the gas and the solid, or not.

If we denote by C the caloric capacity of the thermometer bulb, by σS the quantity of heat radiated from its surface to the sides of the glass vessel, and by $\varkappa L$ the quantity conducted in the same way through the gas when there is a difference of one degree between them, the temperature θ of the thermometer-bulb (which approximately can be considered to be uniform through the whole body) is defined by the equation

$$-C\frac{\partial\theta}{\partial t}=(\varkappa L+\sigma S)\theta,$$

which by integration gives

$$\varkappa L+\sigma S=\frac{1}{t}C\log\frac{\theta_1}{\theta}$$

if θ_1 corresponds to the time 0.

The cooling in the best vacuum, in the time t_s, is supposed to be due only to radiation; this gives

$$\sigma S=\frac{1}{t_s}C\log\frac{\theta_1}{\theta};$$

whence

(2) $$\varkappa L=\left[\frac{1}{t}-\frac{1}{t_s}\right]C\log\frac{\theta_1}{\theta}$$

L is given by the expression

$$(\theta-\theta_0)L=-2\pi l\rho\frac{\partial\vartheta}{\partial\rho},$$

where ϑ means the temperature of the gas, θ_0 the temperature of the glass vessel: since this must be independent of the radius ρ, we must have

$$\rho\frac{\partial\vartheta}{\partial\rho}=\text{const.}=a,$$

which, together with the two equations for the boundaries $\rho=r$ and $\rho=R$, formed after equation (1),

$$\gamma\left(\frac{\partial\vartheta}{\partial\rho}\right)_R=\theta_0-\vartheta_R,\qquad \gamma\left(\frac{\partial\vartheta}{\partial\rho}\right)_r=\vartheta_r-\theta,$$

gives

$$a=\frac{\theta_0-\theta}{\log\frac{R}{r}+\gamma\left(\frac{1}{R}+\frac{1}{r}\right)},$$

(3)
$$L=\frac{2\pi l}{\log\frac{R}{r}+\gamma\left(\frac{1}{R}+\frac{1}{r}\right)}$$

The value of L, when $\gamma=0$, may be put $=L_0$:

(4)
$$L_0=\frac{2\pi l}{\log\frac{R}{r}},$$

The ratio of $\varkappa L$ to the normal value $\varkappa L_0$ at higher gas pressures, as calculated from (2), may be called the relative apparent conductivity.

Now, if the increase of cooling time, at high exhaustions, is caused by a decrease in the conductivity $\varkappa$, the value of γ being put $=0$, the relative apparent conductivity must, nevertheless, be the same at identical pressures in both vessels. This will not be the case, on the contrary, if it is to be explained by a finite discontinuity of temperature arising at low pressures, according to formula (1), while $\varkappa$ remains constant; but now the value of γ, which is given by (3) and (4) as

(5)
$$\gamma=\frac{\log\frac{R}{r}}{\frac{1}{R}+\frac{1}{r}}\left[\frac{L_0}{L}-1\right],$$

where $\frac{L_0}{L}=\frac{\varkappa L_0}{\varkappa L}$ follows from (2), must be the same at equal pressures in both vessels.

To the above-calculated expressions (2) and (3) several correction-terms must be added — first, on account of the quantity of heat flowing to the ends of the thermometer bulb and through its glass stem; secondly, on account of the conductivity of the glass and mercury not being infinitely great in comparison with that of the gas, as tacitly supposed in the above calculations. They are taken into consideration in the final results, though their omission would not produce any considerable difference.

Results and Conclusions.

6. The following table gives several examples of observations and the therefrom calculated quantities for air in vessels I. and II.; t means the observed time of cooling in seconds, p the pressure in millimetres of mercury, K the apparent relative conductivity, γ the coefficient of discontinuity of temperature, and γ/λ its ratio to the mean length of free path of molecules.

Air in Vessel I.

t	184·0	184·05*	187·8	202·4	255·8	411·1	644·1	763·5
p	710	41·0	4·74	0·90	0·213	0·0466	0·0086	0·0013
K	—	1·00	0·973	0·876	0·621	0·267	0·0641	0·0095
γ	—	—	0·00271	0·0136	0·0587	0·264	1·41	10·1
$\frac{\gamma}{\lambda}$	—	—	1·69	1·61	1·64	1·61	(1·59)	(1·72)

Air in Vessel II.

t	311	380	380·2*	383·7	398·5	443·9	509·8	628·2	698·7
p	770	211	37·9	1·72	0·34	0·086	0·033	0·010	0·0043
K	—	—	1·00	0·983	0·917	0·736	0·524	0·249	0·126
γ	—	—	—	0·00734	0·0398	0·158	0·398	1·33	3·04
$\frac{\gamma}{\lambda}$	—	—	—	1·66	1·78	1·78	1·72	1·83	(1·73)

Similar experiments were made with hydrogen.

The bracketed values are not to be relied upon, as a considerable source of error arises in them from the vapour pressure of mercury; also the theory, exposed later on, is not quite justified for them, as the free path of molecules is too great; nevertheless they agree very well with the other values.

7. The observations are sufficient to justify the following conclusions:

(1) If the convection-currents were producing any sensible effect, the time of cooling would have shown a marked increase when the pressure began to decrease down from 1 atmo; but neither hydrogen nor air in the smaller vessel (I.) shows any appreciable influence of pressure between 760 and about 50 mm.; with air in the wider vessel (II.) an increase of cooling time can be

noticed from 760 to 210 mm.; then it remains constant to about 40 mm.; it is this value (marked with an asterisk) which was supposed to be due to pure conduction and radiation.

(2) For eliminating the effect of radiation, it was supposed that in the best possible vacuum obtained there was no longer conduction of heat, only radiation. This assumption is supported by the fact that the time of cooling, which at normal higher pressures was 37 resp. 94 sec. for hydrogen, and 184 resp. 380 sec. for air, appeared to be 790 sec. in the vacuum, independent of the size of the vessel used and of the nature of the gas with which it had been filled. It was increased to 6807 sec. by roughly silvering the thermometer bulb.

Also the second method of eliminating the radiation, by applying the formulae (4) and (2) to corresponding measurements at normal higher pressures in both vessels (of known dimensions), gives well agreeing results.

(3) The increase of the time of cooling at pressures below several millimetres of mercury cannot be due to a diminution of the coefficient of conductivity, which ought to be the same for both vessels at corresponding densities, because the apparent conductivity (as shown by the values of K) varies in a different way in the two vessels, being for instance in air at the pressure $p = 0.04$ mm. in vessel I., $K = 0.23$, and in vessel II., $K = 0.56$.

(4) It is explained, however, by introducing a discontinuity of temperature, according to formula (1), at the surface between the gas and the solid; the values of the coefficient γ, calculated on this supposition, are in fact very nearly the same for both vessels; they are inversely proportional to the pressure, therefore proportional to the free path of molecules of the gas — exactly the same law which has been found by the before-named experimenters for the coefficient of slipping. The mean value, derived from a great number of observations, is for air in contact with glass

$$\gamma = 0.0000171 \text{ cm. } \frac{760}{p},$$

for hydrogen

$$\gamma = 0.000129 \text{ cm. } \frac{760}{p},$$

or by using the values of the mean free path calculated by O. E. Meyer:

$$\gamma = 1.70\,\lambda, \qquad \gamma = 6.96\,\lambda.$$

Considering the wide range of pressures experimented upon, which correspond in some cases to a reduction of the apparent conductivity to less than $^1/_{100}$ of its normal value, the agreement between observations and calculations, as shown by the constancy of the coefficient γ/λ, must be considered very satisfactory.

Comparison with Mr. C. F. Brush's Experiments.

8. Mr. Brush's experiments were not undertaken with the same express intention as our own, but as they are made evidently with great carefulness, and extend over a great range of pressures, it is very interesting to look into them from a theoretical point of view, and it is very satisfactory to find best agreement with accepted theories, and also with the conclusions drawn in the above from my experiments.

According to what has been said in the beginning of this paper, and to Mr. Brush's own interpretation of his results, the „aether line" in his diagrams gives the effect of pure radiation; the remaining part of the ordinates is due to convection currents and conduction.

The effect of the first ones is very considerable in the larger bulb, much less in the smaller one; it was not perceptible at all in my experiments with vessel I.

With diminishing pressure it decreases very rapidly (as found already by Kundt and Warburg, see above) — hence the sloping-down of the curves A — and from a certain limit we have only pure conduction of heat, just as in solids; this is indicated by the horizontal part of the curves A and B, since the coefficient of conductivity for [heat] is] independent of the gas pressure, just as well as the coefficient of viscosity. This fact is not so very surprising, it was foretold by Maxwell before even any measurements of it had been made, as the conductivity depends on the product of the number of molecules and the mean length of their free paths, which are varying with pressure in an inverse way.

The final bending down of the curves, shown on a larger scale in part of B and in C, is exactly the phenomenon here discussed, which I attribute to the discontinuity of temperature. This theory explains why this effect is more conspicuous and begins at higher pressures in the small vessel than in the large one, exactly as in my experiments, and its largeness in hydrogen is accounted for by the great value of (γp) found for this gas.

I have tried even to calculate the values of γ from the curves for air and hydrogen in the small bulb, which had the cylindrical form required for the application of formula (5), and I have found the product (γp) (of course also γ/λ) to be as nearly constant as can be expected considering the inaccuracy of such a method.

Taking for example the curves for air with the ordinates

$\frac{1}{T}$: 45·5 [1]) 43·1 42·3 41·3 31·7 27·7 23·5 16·6

and abscissae

p: $0{\cdot}0^{3}62$ $0{\cdot}0^{3}44$ $0{\cdot}0^{3}35$ $0{\cdot}0^{4}644$ $0{\cdot}0^{4}362$ $0{\cdot}0^{4}192$ 0

we get the values of γp:

$0{\cdot}0^{4}149$ 146 159 157 154 164,

whence the mean value for $\gamma = 0{\cdot}000155\ \text{cm.}\ \frac{760}{p}$,

and similarly for hydrogen $\gamma = 0{\cdot}000724\ \text{cm.}\ \frac{760}{p}$.

These values, though somewhat smaller, are of the same order of magnitude as those found in my experiments; the difference is probably due, apart from the inexactness of such a rough calculation, to the fact that the surface of Mr. Brush's thermometer was coated with shellac, which of course may produce another value of γ than glass.

I should like to say some words concerning another point.

Mr. Brush proves that Newton's law of cooling is not strictly true, since the curves representing the cooling down from 15° to 10°, from 9° to 6°, &c. do not coincide, as would be required by an exponential formula. The cooling is going on faster with increasing difference of temperature than would follow from Newton's law.

[1]) The curves for the small bulb are not quite horizontal, but show a minimum at intermediate pressures, which does not seem to have been noticed by other observers before; what its cause may be, it is difficult to say, it may be due to a more complicated effect of the currents.

I think this is not surprising at all, since it is known that the coefficient of conductivity, and also the radiation, are increasing with rise of temperature. By assuming Stefan's law of radiation to be true, according to which the quantity of heat radiated away from a body is proportional to the fourth power of its absolute temperature, and by assuming the coefficient of conductivity to increase by about 0·2 per cent. for one degree (according to Winkelmann, Wied. *Ann.* xliv. pp. 177, 429), we find just about such differences as exhibited by the air curves and, at the lowest pressures, by the hydrogen C curves.

The great value of these differences in the higher parts of the C curves, however, seems to suggest that γ is decreasing with rise of temperature.

A remarkable fact, too, seems to be the great influence of temperature-difference on the intensity of convection-currents, as shown especially by the air curves A in the larger bulb, which may be compared with a theoretical formula put forward by Lorenz [1]) — for a less complicated case, however — according to which convection-currents produce an effect proportional to the $^5/_4$ power of the temperature-difference.

But these phenomena are not in immediate connexion with the subject here discussed; for our purpose it is sufficient to note that Mr. Brush's experiments are quite in accordance with our theory, supposing the existence of a discontinuity of temperature proportional to the free path of the molecules.

Explanation by the Kinetic Theory of Gases.

9. Now the question arises how this remarkable phenomenon is to be explained.

It cannot be reduced to any effects of radiation (in the sense now used), in Poisson's way, as has been mentioned at the beginning of this paper; this is seen to be impossible by the radiation being altogether eliminated, in the above-described manner.

The very simplest way of explanation, however, is afforded by the kinetic theory of gases, which in quite a similar way also explains the slipping of a gas moving along the surface of a solid,

[1]) Wied. *Ann.* xiii. p. 582.

as has been shown by Kundt and Warburg (and afterwards by Maxwell too).

Suppose two plane parallel plates, at different temperatures, separated by a layer of gas, the thickness of which may be great in comparison with the mean length of free path of the molecules.

The temperature at any point of the gas is the mean value of the *vis viva* of the molecules travelling from the colder to the hotter plate and in the opposite direction.

Now consider the state of things near the surface of the cold one PP'. The molecules going towards it are endowed with a greater energy than that which would correspond to the temperature of the plate, since they are coming from hotter regions; those going out from it, after rebounding, have only its exact temperature (resp. energy) during the act of impact on the plate; therefore the mean value of both must be greater than the temperature of the plate itself; there must be a finite break in the distribution of temperature [1]).

In reality this will be still greater than would follow from this reasoning, since it is not probable — and is disproved by our experiments, as will be shown afterwards — that the molecules of the gas assume, at one impact only, the exact temperature of the body.

I have tried to make an approximate calculation of these effects after both theories of molecular action developed until now, Clausius' and Maxwell's, and the results are quite similar, only differing in the numerical value of the coefficients.

10. The first one, the theory considering molecules as elastic balls, requires several simplifying suppositions in order to allow of an easy reckoning, which make the result appear only as a rough approximation.

Then the condition that the flow of heat be stationary = const. can be expressed by the equation

(6) $$\int_0^\infty \theta(x+\xi)\varphi(\xi)\,d\xi - \int_0^\infty \theta(x-\xi)\varphi(\xi)\,d\xi = \text{const.} + \vartheta\int_x^\infty \varphi(\xi)\,d\xi$$

[1]) As I notice now, something similar has been pointed out by Dr. Johnstone Stoney in his very suggestive paper „On the Penetration of Heat across Layers of Gas" (Phil. Mag. vol. iv. p. 424, v. p. 457), the understanding of which is rendered difficult, however, in consequence of wrong reasoning about conduction of heat.

where

(7) $$\vartheta = \frac{\theta_m + \beta\theta_0}{1+\beta} \quad\text{and}\quad \theta_m = \frac{\int_0^\infty \theta(\xi)\varphi(\xi)\,d\xi}{\int_0^\infty \varphi(\xi)\,d\xi}$$

θ_0 means the temperature of the plate, and $\varphi(\xi)$ is an abbreviation for the integral $\varphi(\xi) = \int_0^1 e^{-\frac{\xi}{\lambda y}}\,dy$; the meaning of β is explained later on. This is the same equation as has been found, in a somewhat specialized form, by Kundt and Warburg, and applied to the slipping of a gas.

Its solution, which can be effected by several methods of approximation, gives the curve CC', representing the temperature $\theta(x)$ as a function of the distance from the plate x, as shown in fig. 3, where the value of β is supposed to be $\beta = 1/7$.

For x sensibly greater than the mean free path this curve is identical with a straight line, as was to be expected beforehand, but it is so situated as if the wall had not the temperature θ_0 but $\theta_0 + OA$, or as if the wall, keeping the temperature θ_0, were put back by the distance $OB = \gamma$.

Without further calculation so much is evident, considering the linear form of the equation, that the ordinates, when the value of the constant is changed, are proportional to it; the value of γ, however, remains unchanged.

In the same way it is easy to see that the abscissae corresponding to given ordinates must be proportional to the value of λ, the only parameter of the curve. But the value of the coefficient of proportionality can be found only by solving the above equation, which involves very long and tedious calculations. I have found as an approximate result [1]),

(8) $$\gamma = \left[0{\cdot}70 + \frac{4\beta}{3(1-\beta)}\right]\lambda.$$

β is a factor which is used in order to determine the exchange of temperature produced by the impact of a molecule on the wall,

[1]) Sitzungsber. d. Wien. Akad. Bd. CVII. Abt. II a, 1898; pp. 304–329.

viz., in this way that the average temperature of the rebounding molecules ϑ will be in the following relation to their average temperature θ_m before the impact:

$$\vartheta = \frac{\theta_m + \beta\theta_0}{1+\beta}, \tag{9}$$

which is the same equation as (7).

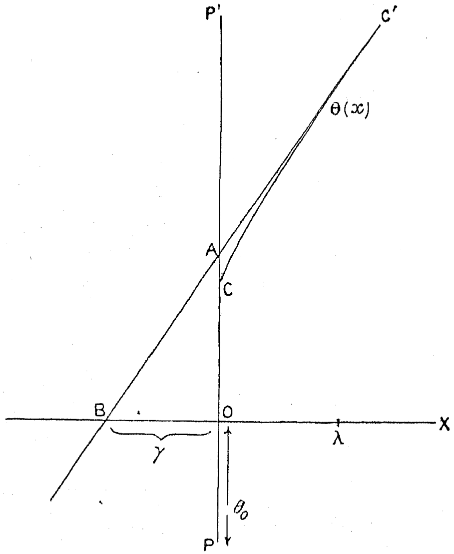

Fig. 3.

11. The way in which Maxwell calculated the coefficient of slipping in his paper „On Stresses in Rarefied Gases" [1]), supposing the molecules to be centres of a repulsive force proportional to the reciprocal fifth power of distance, is much superior, in some respects, to the above as the effects of the encounters and the changing distribution of velocities among the molecules are taken into

[1]) Phil. Trans. R. S. vol. i. 1879.

account quite rigorously, but it is to be considered only as an approximation too, since Maxwell supposes the state of the gas at the surface to be the same as in the interior, which evidently is not quite correct.

The action of the surface of the solid body is supposed by him to consist

(1) In reflecting the fraction $1-f$ of the incident molecules with unchanged velocities

(2) In absorbing and evaporating again the fraction f of the incident molecules with velocities equal on an average to the velocity of the body.

His way of reckoning can be applied, with some little modifications also to the case of conduction of heat; I have found by these means:

$$\gamma = \frac{15\sqrt{2\pi}}{16}\,\frac{\mu}{\sqrt{p\rho}}\,\frac{2-f}{f} \tag{10}$$

where μ is the coefficient of viscosity and ρ the density of the gas.

By introducing the mean length of free path, after Meyer, as equal to

$$\lambda = \frac{\mu\pi\sqrt{2\pi}}{4\sqrt{p\rho}},$$

this will be

$$\gamma = \frac{15}{4\pi}\,\frac{2-f}{f}\,\lambda.$$

Now it is easy to see that Maxwell's supposition about the reflected and evaporated molecules is equivalent to the supposition made before in formula (9) if β is put equal to $1-f$. Then the last formula turns out to be:

$$\gamma = \frac{15}{4\pi}\left(1+\frac{2\beta}{1-\beta}\right)\lambda, \tag{11}$$

quite analogous to the one deduced before in (8), but with somewhat larger numerical coefficients.

Also in respect to several other phenomena, these two theories give somewhat different numerical results; the actual state of gases has been found usually to be intermediate between them; probably here also this will be the case.

At any rate, it is a very satisfactory result that both theories agree in proving the existence of a discontinuity of temperature, as expressed in (1), and the proportionality of the factor γ with the mean length of free path of molecules in the gas; exactly the conclusion drawn from the experiment in § 7 (4). This perfect agreement between the experimental facts and the kinetic theory of gases might be considered as a new strong evidence in favour of the latter, if such evidence were wanted any more.

12. A very suggestive fact is the great difference found in my experiments between γ/λ in air and in hydrogen (1·70) and (6·96). It would not be surprising to find the factor β or f, and in consequence also γ, different for different solid surfaces, but it is remarkable that its value depends so much also on the nature of the gas. In hydrogen, at least, the term depending on β must be several times greater than the first term independent of it, whereas it is comparatively small for air.

I believe an explanation may be afforded by the following reasoning: — The molecules of the gas, striking against the particles (molecules?) of the solid body, will be different generally from them in respect to size or mass. Now the impact between two bodies generally tends towards producing an equalization of their *vis viva*, but it is easy to show that this equalizing effect is so much the smaller, the greater the difference is between the masses of the colliding bodies. Therefore β will be great, and γ too, if the molecules of the gas have a much smaller mass than those of the solid body, which certainly is the case in the above example for hydrogen in contact with glass.

It seems to be possible to arrive by similar arguments at conclusions about the mass of the particles of the solid, the motion of which constitutes the heat of the body, and about which we do not know anything at present; but as this requires a great deal more experimental data, I am first going to carry on further such experimental investigations.

It would be very interesting, too, to verify some other conclusions of the kinetic theory of gases, easily arrived at, concerning the conduction of heat between solid walls the distance of which is much less than the mean length of free path (for instance with high exhaustions); in this case the quantity of heat

carried over by the molecules of the gas ought to be the same as if — with unchanging $\varkappa$, and γ put equal zero — the plates were at the distance $2\lambda\frac{1+\beta}{1-\beta}$ (of course, apart from radiation); and this quantity ought to be independent of the distance of the plates, provided this is very small in comparison with λ.