Dr. H. KAMERLINGH ONNES, *Remarks on the liquefaction of hydrogen, on thermodynamical similarity and on the use of vacuum vessels.* [1])

1. Subsequently to a communication by SOLVAY, CAILLETET Dec. 30 last in the »Académie des Sciences" commented on the liquefaction of hydrogen for the purpose of making experiments with it. I was occupied with the study of a method tending to this end for some years. A method relying on a similar principle as mine, has as I see now been traced out and patented by SOLVAY, with the aim of liquefying gases for industrial purposes.

When induced by CAILLETET's communication I was writing down some of the remarks, that had presented themselves to me during the aforesaid study, I learned from the Proceedings of the Chemical Society of 19 Dec. last (issued 19 January 1896) the splendid researches of DEWAR on cooling by means of a spray of compressed gas. I have therefore extended my observations to these experiments also.

2. The means and circumstances of the Leiden laboratory do not permit to put the question of experiments

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[1]) In this translation have been inserted some explaining phrases to be given as addenda in. *Versl. d. Afd. Natuurk. d. Kon. Akad. v. Wet.* 29 Febr. 96.

with liquid hydrogen in the foremost place. But the desirability of coming a step nearer to the secrets of the absolute zero of temperature, and the fascination of the struggle against the unsubmissive hydrogen in the country, where van Marum first liquefied a gas are too strong, to allow the question to be forced away from one's thoughts.

Accordingly in my communication of Dec. 29 '94 [1] some apparatus designed for the purpose was mentioned, the construction of which progresses, when the opportunity for this work presents itself. These apparatus when completed will allow me to enlarge the permanent liquid oxygen bath to such a scale that the decantation of liquid hydrogen will become possible. Since the same date I am trying for the sake of the measurements mentioned in that communication, to realise the possibility of evaporating oxygen (or nitrogen) in sufficient quantity under the pressure of only a few millimeters. The pump used to this end will also give the opportunity to cool a sufficient quantity of hydrogen to extremely low temperatures in the liquid oxygen bath.

3. The temperature to which the hydrogen can be cooled and the quantity available per unit of time being given, the most advantageous construction of the apparatus to cool the hydrogen further by its own expansion can be studied with the aid of a model, working with a

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[1] H. Kamerlingh Onnes. On the cryogenic laboratory at Leiden and the production of very low temperatures. Versl. der Zitt. v. d. Kon. Akad. v. Wet. Amsterdam, 29 Dec. 1894. Communic. from the Labor. of Physics. at Leiden, n°14.

more suitable substance at more convenient temperatures.

To make the apparatus comparable to the model and to foretell from the experience with the model what is to be expected from the apparatus for the cooling of hydrogen, my theorem [1] concerning the law of the corresponding states of v. d. Waals can be applied. According to it, the corresponding states are such, that the motions of the molecules of all substances when in corresponding states are dynamically similar. All mechanical quantities therefore, the derived absolute units of which can be given as powers of the fundamental units of length, mass and time, will be expressed in these systems of molecules by the same numbers, when measured in the system of absolute units, deduced from the fundamental units of length, mass and time belonging to each substance. And all such mechanical quantities of a substance in an arbitrary state, can be calculated from those observed with the other substance in the corresponding state by the ratio of the derived absolute units, in which these quantities are measured. The fundamental units of length, mass and time are computed from the molecular weight and the critical state. If M is the molecular weight, v_k the critical volume of the unit of weight, and t_k the critical temperature of a substance, then for this substance the unit of mass is proportional to M, the unit of length to $M^{1/3} v_k^{1/3}$ the unit of time to $M^{5/6} v_k^{1/3} t_k^{-1/2}$.

To these mechanical quantities belong in the first

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[1] H. Kamerlingh Onnes. General theory of the fluid state. Verhandl. d. Kon. Akad. v. Wet. Amsterdam, Deel XXI, 1881.

place pressure, surface, volume, temperature (kinetic energy of the centrum of a molecule), energy of the molecular forces, together with the quantities derived from these like coefficient of dilatation, isothermic compressibility, isothermic surface tension etc. Further viscosity and conduction of heat by the progressive motion of the molecules.

We will now consider the quantities which occur when production of work is accompanied by change of temperature. The change of temperature in these cases depends on the quantity of heat that can be given out by the molecule. In the demonstration of the theorem mentioned above only the kinetic energy of the centre of mass of the molecule is taken into account. An adiabatic change of temperature will therefore only take place with two substances in a corresponding manner, if in both cases the same proportion exists between the kinetic energy of progressive motion of a molecule and the total energy contained in it. Otherwise expressed: the number of degrees of freedom (the number of atoms in the molecule) must be the same to make heating and cooling go on in corresponding manner. For normal substances with the same number of atoms in the molecule the corresponding states are at the same time thermodynamically corresponding.[1] A

[1] RIECKE (Ann. d. Phys. und Chem. 53 p. 388, 1894) has introduced in the entropy and the thermodynamic potential, calculated from the isothermal of v. D. WAALS the reduced values of pressure, volume and temperature and remarks that there remain functions of the indivudual properties of substances in the thermodynamic potential. If according to a friendly remark

classification of the substances in groups according to the number of atoms in the molecule is therefore very suitable.

That the number of atoms in the molecule influences the adiabatic phenomena appears very elegantly from the calculations made by v. D. WAALS in 1878.[1] As early as that v. D. WAALS indicated that the superheating of ethervapour when adiabatically expanded, contrary to what happens to watervapour, is to be ascribed to the great number of atoms in the ethermolecule. He further pointed out that the formation of visible vapour say by oxygen in the tube of CAILLETET, regarded by many scientists as an obvious consequence of oxygen being liquefiable, could only take place to such extent, because this possibility coïncides with a very limited number of atoms in the oxygen molecule.

From the considerations developed above on the thermodynamical similarity or non similarity of normal

of prof. LORENTZ as zero of entropy is taken the entropy in the critical state, then RIECKE's formulae also give for all substances with the same number of atoms in the molecule the same functions of reduced pressure, volume and temperature for the entropy and the reduced thermodynamic potential or what comes to the same, RIECKE finds the surface of GIBBS expressed in the reduced quantities the same for all substances with the same number of atoms in the molecule. For the calculation of the reduced thermodynamic potential the energy has to be reckoned from the critical state and the thermodynamic potential to be divided by the critical temperature.

The deduction given above is independent of the special form of the isothermal.

[1] v. D. WAALS, On specific heat of saturated vapour. Versl. en Med. d. Kon. Akad. Amsterdam, 1878.

substances the inference is obvious that the reserving point of the sign of the specific heat of saturated vapour will not be found in general at corresponding temperatures in different groups of substances.[1]) According to a friendly communication by prof. v. d. Waals, this consequence as well as the whole consideration of thermodynamically similar and non similar states, were given by himself in his lectures a long time ago.

But let us return to the thermodynamically corresponding substances. If two such substances are brought in corresponding engines and if these engines are set in motion with corresponding velocities, then they will run correspondingly as long as there is given off a corresponding quantity of heat in the corresponding times by the walls of the machine.

If then in a model, working with oxygen, after a given time a given volume of liquid oxygen is obtained, there will be obtained in the corresponding hydrogen apparatus after the corresponding time a corresponding volume of liquid hydrogen.

There are some difficulties in the application of this rule to an actual apparatus. For instance gravity is no corresponding force for two substances in corresponding states. The mutual accelerations by the effect of the molecular forces of two pairs of molecules of substances in corresponding states when these pairs of molecules are in conform situations will be expressed for each pair by the same number, when measured with the unit of acce-

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[1]) In opposition to the hypothesis of Natanson, Bull de l' Acad. d. Sc. de Cracovie, 1895, p. 141.

leration proper to the system. But the acceleration of gravity will in general be represented by different numbers, when measured in the two cases by the said units and the similarity in the motion will be disturbed. The theorem therefore can only strictly be applied if the influence of gravity (and accordingly also the influence of convectional transport of heat) is to be neglected.

The condition of heat by the motion of the atoms in the molecule is a non similar process to which we wished to draw the attention on pag. 5 by speaking of that conduction that takes place by the progressive molecular motion only.

And lastly it will not be possible in general without special artifices to obtain walls of such conductive power and such specific heat, that these can give off corresponding quantities of heat in corresponding times.

Still with these restrictions it can be of use in the questions we have in view to consider the gas in the machine as part of the machine itself.

An important example of thermodynamically corresponding operations gives the method sagaciously devised by Olszewski for the determination of the critical pressure, which enabled him to find the long sought for critical constants of hydrogen[1]) with extremely small appliances — probably less in different respect, than those which are at my disposal.

4. The method by which I intended to reach the low temperatures necessary for the liquefaction of hydrogen, relied upon the possession of the permanent liquid oxygen

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[1]) Bullet. Intern. Cracovie 1891. S. 192, 1895 Juin, S. 192.

bath. When hydrogen is expanded in a tube of CAILLETET the' low temperature exists for a moment only in reason of the extremely small water equivalent of the compressed gas in comparison with that of the walls of the vessel in which it is enclosed. Repeated expansions with continuously supplied fresh quantities of hydrogen, cooled in the oxygen bath, as can be realised in a motor, will make the temperature of the walls fall, until the hydrogen is streaming out at a temperature nearly in accordance with the degree of expansion chosen. I wished to hasten and to continue this process by cooling the supplied hydrogen with the blown off hydrogen. What the problem comes to therefore is: to withdraw in a given time a maximum of work from a gas with the aid of a motor of minimum volume and to insert this motor in a regenerative process. I supposed that a solution of this problem might be arrived at in the following manner.

The compressed and cooled hydrogen is conveyed by a copper coil to a little, fast running motor (0,1 Liter volume of cylinder) driven by the hydrogen. The inner wall of the cylinder and the piston are coated with isolating substances. The piston in the case of a double acting and the plunger in the case of a single acting motor is ground accurately in the cylinder and moves therein without friction. [1]) The expansion is regulated by valves, moved by rods, working without conduction of heat and the packings of which are out of reach of the

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[1]) A similar contrivance has been executed in the case of the auxiliary compressor (l. c. § 3) and satisfies well.

cold, in the same manner as the packings of the non conduction stopcock in my oxygen boiling glass (l. c. § 8).

The packings of the piston-rod or plunger are isolated in a similar manner from the walls of the cylinder and are removed from the working gas by prolonging tubes. The shaft and gearing which must take work from the engine if the latter will run properly, is isolated from the working parts. The exhaust-hydrogen is lead away round a second copper hydrogen-supplying coil provided at the end with a cock, and escapes through an india rubber tube which encloses both coils.

In the first place the difficulties of mechanical kind were to be overcome. In order to study the mechanical working a little motor with regenerative coil had to be made, that would cool itself, working with compressed air.

The coils in an isolating cover for the exhange of heat were easily made, and also a wooden cylinder with piston was connected with a shaft and gearing, very imperfect indeed, in order to try the experiment, but the experiment has not been carried out. Friction of the piston could not be avoided without considerable leaking. The only possibility in this respect which remained was to run the motor very fast, and this the gearing did not admit. But especially I did not succeed well in regulating the expansion. Since the beginning of 1892 I have consulted different constructors in order to obtain a self cooling motor, or otherwise a motor for working under ordinary circumstances with 10fold or even 5fold expansion by valves and with a cylinder volume of 0,1 Liter, in order to work out after this example a self cooling motor, fit for the laboratory. But I have not succeeded in obtaining such an engine.

If a little self cooling motor could be made after my design (and then of course easily also a cascade) it would become an important appliance for laboratories, for compressed air can be easily stored [1]) and will probably soon become a cheap article of trade.

It appears now that SOLVAY before me developed the idea of a self cooling motor from an industrial point of view, but has no more arrived to a satisfactory result, though he obtained temperatures (—95°) very desirable for a laboratory.

If we suppose the fall of temperature obtained by SOLVAY to be further extended in the direction of the lower temperatures, it has to be taken into account also that the regenerative process will become more defective as the gas approaches the critical state. In general only *a cascade of theoretically perfect cooling apparatus* will prove able to withdraw at extremely low temperatures quantities of heat, that come in comparison with those, which we might deduce from the work spended, when utilized in a reversible cycle.

If we suppose that we have also taken up in this cascade evaporating fluids, the motor mentioned is again required in the character of the »Speise cylinder" to which attention was drawn by ZEUNER many years ago. Indeed this Speisecylinder serves to neutralize the theoretically important loss that occurs, because in a circulation of evaporating liquid, the jet of liquid coming from the condensator enters by a regulation valve into the refri-

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[1]) Than especially in view in this respect the so well adapted BROTHERHOOD compressors (l. c. §10).

gerator where a much lower pressure prevails. With a cascade such as has been brought about at Leiden this disadvantageous deviation from the theoretical process repeats itself in every circulation. Oxygen gives in this case the most important factor in the product.

The problems treated in this § without doubt will more and more occupy practical engineers and perhaps the preceding remarks may be of some use in the repetition of experiments in the manner of SOLVAY. If an apparatus for liquefying oxygen according to this principle has been found, the theorem of § 3 gives the corresponding hydrogen apparatus.

For collecting liquid hydrogen according to the expansion principle there remains provisionally the following method. We have to introduce into a cylinder with piston or plunger (for which purpose a thick walled tube as used by WROBLEWSKI and OLSZEWSKI in liquefying oxygen may be used) compressed hydrogen by the aid of handworked cocks, and to blow it off through a regenerator after sufficient expansion. For the supply of hydrogen the well known steel capillaries may be used (Cf. l. c. § 3). The thick walled expansion tube ought to be protected against supply of heat by a narrowly enclosing vacuum tube of DEWAR as I have prepared for similar purposes.

5. After the difficulties I met with in the execution of the project of a self cooling motor treated in the preceding §, it was quite natural to ask as soon as the ingenious invention of LINDE became known, whether this method could be applied to the liquefaction of hydrogen.

In LINDE's method[1]) gas flows from a compressor under high pressure along a regenerative coil and through a reducing valve where it does work against the molecular forces and is accordingly cooled, and then returns by the regenerative coil to the compressor.

The part that in my project and in SOLVAY's apparatus is played by the motor, in LINDE's apparatus is taken by the reducing valve.

Theoretically this gives a loss. The use of the reducing valve has the effect that power is sacrificed that could have been used for cooling. If afterwards it will be sought to make in the method of LINDE the loss by friction as little as possible, one will come to the addition of a motor as treated in § 4.

Theoretically the regenerator of LINDE's apparatus also is defective by the very nature of the molecular forces as will be further elucidated at the end of this §. So far as I can form an opinion on the method of LINDE, in order to make the regenerator a perfect one, there would have to be added to LINDE's apparatus a cooling machine, withdrawing at every temperature as much heat from the supplied gas, as it must give off between two temperature grades more than the gas flowing back can take in. But the case of liquefying hydrogen the utmost compendiousness of the apparatus is of the greatest importance and to friction and non reversible trans-

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[1]) M. SCHRÖTER, LINDE's Verfahren der Sauerstoffgewinnung mittelst verflüssigter Luft. Ztschr. d. Ver. deutscher Ingenieure 28 Sept. 1895. Bd. 39; 1157.

fers of heat may be sacrificed what is economised on the disadvantageous supply of heat to the apparatus.

The most important question is without doubt this one : are the molecular forces on which the experiment of JOULE and THOMSON and therefore also the method of LINDE depends, sufficient to get noticeable cooling by the flowing through the reducing valve and to give within a not too long interval of time the wished for low temperature. Under ordinary circumstances these temperature variations are very small for hydrogen. At ordinary temperature and at 90° JOULE and THOMSON in their 1862 experiments found even a heating effect. In fact if in the formula by which v. D. WAALS in 1873 first calculated the variations measured by JOULE and THOMSON (V. D. WAALS, Continuity etc. p. 110) are substituted the values of the molecular constants given elsewhere in the same work, a negative value is found for the cooling. When all this is correct, then a LINDE apparatus put in working with hydrogen under ordinary circumstances far from giving a cooling would give a progressive heating of the gas streaming through the reducing valve.

But if one will form an opinion of what happens if hydrogen is brought at low temperatures into the apparatus, one must take into account the variation of the molecular effects with temperature. In view of these changes v. D. WAALS has given a new value for the molecular attraction instead of the original constant value, namely $a_k \, e^{\frac{T_k - T}{T_k}}$ where a_k again is a constant, T the absolute temperature of the substance in question, so that a increases when the temperature decreases.

In fact the theory of the dynamical similarity of corresponding states (§ 3) includes that the molecular energy in all normal substances varies with great approximation in corresponding manner with temperature. According to this theorem we shall find with hydrogen at lower temperatures the normal behaviour in the experiment of JOULE and THOMSON. Hence according to the 1862 experiments there must be a reversing point in the phenomenon of JOULE and THOMSON from which follows that this must occur with all normal substances at the corresponding i. e. a sufficient high temperature. Further we have to expect with hydrogen at sufficiently low temperatures a relatively great molecular potential energy, so that we have to expect a sensible cooling in the experiment of JOULE and THOMSON and therefore also a good working of the LINDE apparatus.

As soon as I became acquainted with LINDE's original method, it therefore seemed to me that it gave the appropriated method to liquefy hydrogen. The hydrogen liquefied in this manner can be taken off from the apparatus into a boiling glass like that described l. c. § 8.

From OLSZEWSKI's critical data for hydrogen and from the theorem of § 3 follows, that if we can dispose in a LINDE apparatus of hydrogen supplied at a temperature of $-210°$, an apparatus, operating with oxygen cooled to $-20°$ can be used as model to study the most economical working. To this apparatus in 2.33 units of time the same number of oxygen molecules must be supplied that we intend to supply to the hydrogen apparatus in the unit of time. In the hydrogen apparatus the pressure can be 2.54 times less and the inner

dimensions can be 1.164 times less than they are in the oxygen apparatus. In a given interval in the hydrogen apparatus a volume of liquid hydrogen will be obtained 1.58 times less than the volume of liquid oxygen produced in the model in a 2.33 times longer interval.

We did not have to take special notice of the law of variation of the molecular energy with the temperature as long as we were treating the question if LINDE's method is fit to be used in liquefying hydrogen. If we are satisfied with the working of the oxygen model, we shall also be content with the corresponding hydrogen apparatus. As the first finds its application now in industry, the last may perhaps soon be admired by us.

It is another question in how far we may be satisfied from a theoretical point of view with our model working with oxygen, apart from the reducing valve, that has been treated already. To judge in how far the regenerator in LINDE's apparatus deviates from a perfect regenerator the law of variation of molecular energy with temperature is a most important factor. Indeed this variability will reveal itself in the difference of specific heat at different pressures increasing with decreasing temperature, a given weight of returning gas, being under low pressure between two temperatures giving off less heat than the same quantity of supplied gas under higher pressure requires to undergo the temperature-changes between the same temperatures in reversed direction. When the liquefying apparatus has come to stationary working conditions there must be cooled beside a quantity of supplied gas equal to the returning quantity so much fresh gas as is poured out in liquid state from the

apparatus. And for this cooling is only disposable the gas returning from the second apparatus wherein the liquid has been poured out, which gas is again at a lower pressure and gives consequently a greater deficiency of the regenerative process. The increase of the molecular potential energy with decreasing temperature, which in one respect promotes the success of LINDE's method by increasing the THOMSON-JOULE-effect, in another respect therefore necessarily lessens the output of liquefied gas by increasing the deficiency of the regenerative process at decreasing temperatures.

An essential part of LINDE's method is that for saving power the gas is only a little expanded and that in view of this saving the most advantageous beginning and finishing pressure have been sought for. A process with the second power of this expansion can be considered as two successive processes of LINDE in which the second and also therefore the total is less advantageous than the first. The process with expansion until the gas has the ordinary atmosferic pressure, which is used in LINDE's oxygen apparatus, is therefore very disadvantageous. If we start in this less appropriate manner with the same disposable power and the same liquefying apparatus as we had in view before, we shall have to wait much longer before we get liquid. Accordingly we have to take more care to prevent that heat finds its way to the apparatus.

6. DEWAR beginning with much higher pressures than LINDE expands in his spray the condensed gas immediately until it has the ordinary pressure. By going further in the wasting of power disposable for cooling

than LINDE even in his oxygen apparatus he departs yet further from the theoretically most favourable cooling process. But the water equivalent of his apparatus divided by the waterequivalent of the quantity of gas passing in the unit of time being much smaller he proceeds in this manner in order to get for a little part of the substance in a very short time an extreme lowering of temperature.

In my boiling glass just as in DEWAR's apparatus the supply-coil has a cock at the end and is wound round the cock-supporter. This part of my apparatus is also immersed in the gas flowing away (l. c. § 8). What is blown away from the jet as liquid and mist serves to cool the supply coil and further to take away heat, that would otherwise find its way to the bath of liquid oxygen. But in the supply-coil the oxygen is already in liquid state. As soon as no more liquid issues from the needle regulating cock, this cock is shut (l. c. pag. 178) and this is done in order to avoid wasting of gas as much as possible. In previous constructions of my boiling glass, I had supply-coils of greater cooling surface immersed in the gas flowing away for the sake of making a liquid jet with gas cooled to little below the critical temperature or even to temperatures in the neighbourhood of the critical. It proved more effective for the construction of the permanent liquid oxygen bath, to reckon upon the oxygen being intensely cooled before it is tranported to the boiling glass. The spiral was therefore shortened to only such length as seemed necessary to catch the liquid blown away and to utilize the evaporation ot this liquid to cool

the adducing coil. DEWAR on the contrary has not been discouraged by the less economical employment of gas and armed with his vacuum vessel that leaves the returning gas wholly disposable to cool the coming gas has directed his attention exclusively to the lowering of the temperature.

He succeeded in this manner even in freezing oxygen by means of his hydrogen-spray, a splendid outcome of his prosperous researches.

Let us apply the theorem of § 3 also to the experiments of DEWAR. DEWAR proceeds indeed according to this theorem as far as the choice of the temperatures is concerned. The apparatus giving by means of a spray a sufficient quantity of liquid oxygen, can serve as the model to build an hydrogen apparatus. The same ratios as those, which we have given in treating the LINDE liquefying apparatus are applicable here for the choice of the dimensions, pressures and temperatures. The percentage of the hydrogen used, that will be reduced to the liquid state after a certain time, will be the same as the percentage, that after a 2.33fold longer time becomes liquid in the oxygen model.

The theorem of § 3 may not be applied to the quantity of liquid that will be collected on the bottom of a corresponding vessel. For the acceleration of gravity is expressed in the system of units derived from the molecules by a 3.43 times greater number in the case of oxygen than in the case of hydrogen, and one would have to go with the oxygen model to a place where gravity was 3.43 times less, to deduce-from the quantity of liquid that collects in that case on the bottom, how much we may expect with hydrogen in the ordinary cir-

cumstances. It is obvious that the oxygen spray under these circumstances would give off liquid oxygen with more difficulty. It will therefore probably be necessary to give the compressed hydrogen the opportunity to liquefy in a special cylindrical or coil shaped vessel under the cooling effect of the spray. This liquid may then flow out under less pressure than the spray into a vessel, constructed in the main part as the boiling glass with boiling case, described by me for liquid oxygen (cf. l. c. § 8). In this boiling case the regenerative coil would find an appropriate place [1].

7. In the same degree as it becomes of more importance to effectuate adiabatic processes at very low temperatures, the importance of the vacuum vessels of DEWAR will increase. It seems to me that they are the most important addition since 1883 to the appliances for low temperature research.

The perfection of these vacuum jackets was again made evident in the experiments treated in the preceding §.

The vacuum jackets make it easy to work with liquid oxygen in a different room from where the cryogenic apparatuses are placed and enable one to do this even in other laboratories. On one occasion when paying a visit to show the properties of liquid oxygen, I took a vacuum vessel filled with liquid oxygen with me in my hand and after returning to the laboratory there was a rest of liquid oxygen left which I could pour

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[1] To liquefy hydrogen it appears from a communication of RAMSAY that OLSZEWSKI has cooled a little quantity by the expansion of another quantity.

again into my boiling glass. To transport liquid oxygen from my boiling glass into a vacuum glass, a little glass bucket is used, hanging from a glass rod, that can be pushed up and down through an india rubber stopper, fitting on the boiling glass. In withdrawing the bucket this stopper is replaced temporarily by another.

In many cases vacuum jackets can also be used to improve the construction of my boiling glass in making the evaporation of the bath less still than it is without this appliance. I have prepared for this purpose a cup shaped vacuum vessel just fitting round the lower part of the boiling glass, where the liquid gas is accumulated. Only when measurements are to be made exclusively across parallel walls, this auxiliary appliance is of no avail. (l. c. § 8.)

In § 4 I mentioned the application of a vacuum vessel in the form of a long double test tube to furnish a thick walled tube with a vacuum jacket.

Even if the vacuum glasses are not prepared with the same painful care as the most beautiful ones of DEWAR have been, they are apt to render great services. To judge of this it is sufficient to consult the table of KUNDT and WARBURG in their research on the conduction of heat in high vacua [1].

To isolate objects of greater size, one can pile up straight, egg-shaped, ring-shaped or otherwise shaped exhausted and sealed tubes of convenient dimensions (incandescent lamp glasses) and unite these by parafine, wool, paper and varnish as shape giving substances in

[1] Monatsber. Kön. Akad. Berlin, 25 Febr. 1875, pag. 171.

order to get continuous walls preventing convection. In this manner vessels of arbitrary form and bulk can be built up, with very badly conducting walls of very little water equivalent the cells of which consist of vacuum tubes. These walls recall the covering, that protects my ethylene boiling flask. (l. c. § 2.)

If it is wished to have an exhausted space between two metal walls isolated from each other, it may be profitable to build the walls that are to be isolated with strengthening ribs in the manner followed in the construction of the very thin walled ethylene boiling flask (l. c. § 5) and oxygen boiling case (l. c. § 8.).

It is a rejoicing prospect that practical engineers will doubtless soon feel the want of such non conducting mantles. For as soon as this stage is reached number of heads and hands are disposed to take over the problem from the scientific researcher.