EFFECT OF ACCOMMODATION ON THE HEAT CONDUCTION THROUGH NITROGEN, ARGON, HELIUM AND DEUTERIUM BETWEEN 0°C AND -186°C FROM THE ASPECT OF (1) THE TEMPERATURE DROP RELATION (2) THE HEAT CONDUCTION THROUGH GASES AT LOW PRESSURES

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Table of Contents

		Page
Abstract.	Heat Conduction in the Region of Temperature Drop Effect	1-2
Section 1.		1-73
	Introduction and Historical Accounts	
	Thermal Conduction	1-3
	Thermal Accommodation	3-7
	Summary of Experimental Investigation	7-8
	Temperature Drop Effect	9-13
	Radiation	14-15
	Principle of Compensation	16-20
	Thermostatic System	21-22
	Correction to the Platinum scale of Temperature	22-24
	Alternative Equation of the Temperature Drop Effect	25-27
	Mean Free Path	27-29
	Temperature Drop Across the Wall	29-30
	Description of Apparatus	31-33
	Experimental Procedure	34-36
	Key to Symbols	37-40
	Experimental Results	41-63
	Variation of K with Temperature and Calculation of the Factor f	64-73

Page

Section 2. Heat Conduction at Low Pressure 74-99

Principle of Compensation, the Modified Transport Law 74-82

Effect of Thermal Transpiration 83-86

Experimental Procedure at Low Pressure 87-88

Experimental Results 89-94

Discussions 94-99

Appendix 1-3

Abstract

The present paper deals with a modification of the experimental procedure which has been developed at the Imperial College in relation to observations of the Heat Transport through Gases and the related effect of accommodation.

A compensating system of wires and tubes was employed in conjunction with suitable thermostatic arrangements which enable the Heat Transport to be investigated in the neighbourhood of,

(1) The temperature of Melting Ice.

(2) The temperature of solid $C.O_2$ in spirit

(3) The temperature of Liquid Oxygen

The Gases tested were Nitrogen, Helium, Argon, and Deuterium, and the experiments were carried out over a range of pressures between 15 and 0.5 cms Hg on the one hand and between .003cms Hg and .0008 cms Hg on the other.

In this way a direct test of the Fourier Equation modified in respect of Temperature Drop was found possible, and at the same time Law of Heat Transport operating for strongly rarefied gases, could be also examined with the same apparatus.

Calculations of the coefficient of accommodation have been carried out from both aspects, and in this manner the validity of Knudsen's definitions, both in regard to Temperature Drop and Accommodation have been tested.

The principle of Compensation associated with the Hot Wire system has been theoretically examined in the important case of the Heat Transfer at low pressure.

The accuracy of the formulae relevant to calculations of the average collision paths used in conjunction with the Temperature Drop theory have been fully considered, and the corrections for the effect of Thermal Transpiration in relation to the pressures measured by the Mc-Leod gauges have been discussed in detail.

The effect of temperature on the Thermal conductivity of the gases under test was found to be satisfied in all cases by a relation of the form,

$$K/K_o = (T/T_o)^{n'}$$

where the value of n' has been found to vary with the nature of the gas. Values of the temperature coefficient of Thermal conductivity, corresponding to the various bath temperatures are given along with the magnitude of the factor f associated with the formula,

$$K = f.\eta\, C_v$$

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Section 1.

Introduction.

Very little information is available in regard to investigations relevant to the effect of temperature on the heat conduction and Thermal Accommodation of Gases between 0.deg. C. and -183.deg.C

Eklerein[0], using the almost obsolete Cooling Thermometer method investigated the Heat Conduction through H_2, Air and $C.O_2$ over the range 0.deg.C to -183.deg.C , but the results in view of the difficulty of properly interpreting the effects due to Convection and Radiation can hardly be regarded of serious importance in the strict light of modern accuracy. A Petrol-Ether thermometer in conjunction with two spherical enclosures of different radii were used in order to eliminate the effects due to Radiation and the Heat Losses along the stem, while the effect due to Convection was allowed for by suitably reducing the gas pressure. The results

regarded as absolute values are given below.

Thermal Conductivity in Cal., cm^{-1} sec^{-1} deg^{-1} x 10^{-5}

	-50°5C	-59°C	-73°5C	-149°5C	-150°C
Air		3.678		2.146	
H_2		23.93			11.75
CO_2	2.824		2.546		

Eucken[2] in a more recent investigation made use of a compensating system of metal tubes and wires arranged to form part of a Bridge circuit and similar in experimental detail to the earlier work of Schleirmacher. The procedure of lowering the gas pressure in order to eliminate the effect of Convection brought into existence the now well known Temperature Drop effect, but in this instance no attempt was made to allow for the effect, and the results might on this account be expected to be on the low side. All results for the gases tested were expressed in terms of a predetermined value for Air at 0.deg.C and are therefore only of comparative interest.

Still more recently, Weber[3] investigated the Heat Conduction through Neon between 0.deg.C and -183.deg.C.using a compensating system of tubes and wires in conjunction with the Potentiometer method of measuring the Heat Losses and Wire temperatures. A correction was made in respect of Temperature Drop in terms of the theory of Von Smoluchowski,[4] but again no systematic treatment was carried out in regard to the effect of Convection. The results vary from .0001087 Cals.

deg.$^{-1}$ cm^{-1} sec^{-1} at 0.deg.C. to .0000499 at -181.4 deg.C. The work of Weber represented a great advance on previous investigations on the subject of Heat Conduction.

In 1938 Gregory and Dock[5] employing a further modification of the Hot Wire method investigated both the Heat Conduction and the effect due to accomodation in respect of H_2 between 0.deg.C and -183.deg.C. The experimental results were in this case interpreted in terms of the Temperature Drop equation proposed by Gregory,[6] in which the effects due to temperature drop and Convection may be eliminated by one and the same experimental procedure.

In all cases at low temperature, using wires of small diameter the effects due to Radiation may be considered always of negligible importance in comparison with the Total Heat Losses.

The Effect of Thermal Accommodation

It is well known that the energy interchanges between heated solids and gas atoms are far from perfect and early experiments by Soddy and Berry[7] completely justified this aspect, more recently, the effect of accommodation has been considered more rigidly from the investigations of Knudsen[8] and other workers.

A quantitative aspect was first made possible by Knudsen's definition of the coefficient of accommodation viz.

If the average energies of molecular impinging

and rebounding from a solid surface are denoted by E' and E and if E_1 represents the average energy of molecules corresponding to the temperature T_1 of the solid surface, then from Knudsen the coefficient of accommodation α is defined as

$$\alpha = \frac{E - E'}{E_1 - E'} \qquad (1)$$

If the velocity distribution of the rebounding molecules is Maxwellian , then we can write

$$\alpha = \frac{(\beta + 1/2).\overset{k}{X}.T. - (\beta' + 1/2).\overset{k}{X}.T'}{(\beta_1 + 1/2).\overset{k}{X}.T_1 - (\beta' + 1/2).\overset{k}{X}.T'}$$

where $\beta\overset{k}{X}$ represents the molecular heat at a temperature T and $\overset{k}{X}$ the gas constant per molecule.

If the temperature differences $(T - T')$ and $(T_1 - T')$ are not too large, then since the quantity β changes only slowly with temperature we have

$$\alpha = \frac{(T - T')}{(T_1 - T')} \qquad (2)$$

It is emphasized that in this instance the mean energies E, E' , and E_1 are associated with surface distributions of velocities and therefore

$$E = (\beta + 1/2).\overset{k}{X}.T. \text{ etc} \qquad (3)$$

Investigations of the effect of accommodation have been for the most part confined to the method based on the Heat Conduction through rarefied gases and it was shewn by

Knudsen that the rate of Heat loss through a gas at low pressure may be expressed by the relation

$$Q = \mathcal{E} A.(T_1 - T_2).\alpha.p. \qquad (4)$$

where Q denotes the rate of heat loss (corrected for Radiation), p the gas pressure, T_1 and T_2 the temperatures (Abs.) of the heated solid surface and the internal wall of the enclosing vessel, α the coefficient of accommodation as defined by Knudsen, A an area and $\mathcal{E}$ the molecular conductivity.

Equation (4) as associated with the Hot Wire method may be written in the form

$$Q = 2.\pi.r_1.L.p\sqrt{R'/2.\pi.M.T_2}\ (\beta + 1/2)\alpha(T_1 - T_2) \qquad (5)$$

where β is a quantity defined as above, r_1 and L the radius and length of a uniformly heated wire, R' the gas constant, and M the Molecular Weight of the gas. Equation (5) has been widely used in investigations of the effect of accommodation, and in all cases Q is determined for various values of p at constant temperature T_1 of the wire, from which α may be calculated. In one such investigation by Roberts[9] an attempt was made to calculate a value of α corresponding to a perfectly clean surface of the heated solid, this was carried out by first heating the wire to a high temperature, in this way it was found that the coefficient of accommodation increased in a short space of time from a very low value to a value which corresponded to the normal saturation value at that temperature. This was interpreted as being due to the

adsorption of molecules by the surface after lowering the temperature. This aspect was afterwards revised by Mann[10] in a more exhaustive investigation from which it appeared that the effect of accommodation depended not only on the temperature but was intimately bound up with the physical condition of the surface.

The experiments of Roberts and Mann definitely related the effect of accommodation with the degree to which the adsorption of gas on the surface has taken place and for any temperature the coefficient of accommodation, calculated in terms of Knudsen's definition, represented the saturation and stable value at that temperature; at the same time it was established that the saturation values decreased as the temperature decreased, a fact which suggests immediately that at a sufficiently low temperature the coefficient of accommodation would approximate to unity, a value associated with a condition of complete adsorption. In support of this latter conclusion, it was shewn by Gregory and Dock[5] using the Hot Wire method under conditions when the gas was far from being rarefied that in the neighbourhood of -183.deg.C. the temperature coefficient of accommodation $d\alpha/dT$ for H_2 increased very rapidly with decrease of temperature.

In 1936 Keesom and Schmidt[11] applying Knudsen's theoretical formula for the molecular heat transport in conjunction with an experimental procedure similar to that

used by Schleirmacher and in which the Heating element consisted of a very thin Platinum wire coated with a thin layer of glass, carried out investigations on the effect of accommodation for the gases He, H_2 , Ne, and N_2 and obtained results at 0.deg.C. agreeing very closely with those obtained by Knudsen. The measurements[12] were afterwards continued to ranges of temperature between 12.deg.K and 20.deg.K and between 70 and 90.deg.K. The results confirm that for Ne. and Hg. the coefficient of accommodation would tend to approach unity in the region 12 to 20.deg.K when both gases are strongly adsorbed by a glass surface. For He α was found to increase from .383 at 77.deg.K to .57 at 18.deg.K and to .67 at 12.deg.K and there is every reason to expect that α = 1.00 for temperatures less than 5.25 deg.K (Critical Temperature). An important point of view is that α = 1.00 when the glass surface covers itself with a Mono-molecular layer of the gas in question.

The main aspects associated with the present investigation may be summarised under the following headings,

(1) The application of the Hot Wire method to determine the Thermal Conductivity of the Gases He, Ar, D_2 and N_2 at various temperatures between 0.deg.C and -183.deg.C.

(2) To justify the method proposed by Gregory in regard

to the calculation of the coefficient of accommodation from the aspect of the Temperature Drop Equation.

(3) To determine the coefficient of accommodation for the same gases, making use of the same apparatus and employing the same wire temperatures as in (1). To compare the values so obtained in terms of the Knudsen Heat Transport Law with those calculated from the aspect contained in (2).

(4) To compare the results obtained in (3) with the previous work referred to above.

In the Hot Wire method of investigating the Heat Conduction through Gases various errors arise as associated with the experimental procedure. In the first place the procedure of lowering the gas pressure in order to obviate the effect of Convection brings into prominence the troublesome Temperature Drop effect which is enhanced as the pressure is lowered and which has been found to depend on the quantity Q/p, where Q is the rate of heat loss and p the gas pressure, and r_1, the radius of the heated wire.

At the same time an increase of the wire radius although favorable in the light of a reduction of the Temperature Drop causes the Loss of Heat by Radiation to increase and this again is not desirable although on account of the low temperatures employed in the present experiments the correction for Radiation would not be of serious magnitude even for wires of 6 mils diameter.

Quite apart from the question of Radiation, fine wires of 2 or 3 mils diameter are necessary in the present instance owing to the question of accurately compensating for the heat losses along the leading-in wires of the system and this aspect is of marked importance when the system is employed over the low pressure range. It will also be necessary to consider the fall of temperature across the walls of the cylindrical tubes in which the wires are fused centrally. This has been rendered more difficult in the present instance on account of the dearth of experimental data in regard to the Thermal Conductivity of the material of the tubes at low temperatures. This has necessitated a seperate investigation in respect of the Thermal Conductivity of Lead Glass at temperatures between 0.deg.C and -183.deg.C.

The various corrections as outlined above will now be considered in order of their importance.

Temperature Drop Effect.

The first quantitative treatment of the Temperature Drop Effect was carried out by Von Smoluchowski[4] in terms of Maxwell's Hypothesis viz. that molecules behave as centres of forces of repulsion varying inversely as the fifth power of the distances of seperation. For a cylindrical distribution of temperature the Temperature Drop $\delta\theta$, as associated with the Hot Wire method is given by

$$\delta\theta = \frac{15.\lambda.(2-\alpha)}{2\pi \quad 2.\alpha} \cdot \frac{d\theta}{dr} , \qquad (6)$$

where λ is the Mean Collision path at the wire temperature, α the accommodation coefficient, and $d\theta/dr$ the temperature gradient at the surface of the wire. This formula is valid only for Gases in the Monatomic State and for values of λ small compared with the curvature of the wire. Following Smoluchowski's treatment it has been shewn by Gregory[6] that for gases in the Polyatomic state the more general relation for the Temperature Drop is given by,

$$\delta\theta = \frac{Q.\sqrt{T_1}}{p.r_1 A}\left(\sqrt{1 + \frac{Q^2.T_1^2}{(2-\alpha)^2 p^2.r_1^2.A^2.T_1^2}} - \frac{Q.\sqrt{T_1}}{(2-\alpha)p.r_1 A.T_1}\right)$$

$$= F\left(\frac{Q}{p}\right) \qquad (7)$$

where Q denotes the rate of Heat loss from a uniformly heated wire of length L, T_1 the temperature of the wire (Abs.) p the gas pressure, α the coefficient of accommodation, r_1 the radius of the wire, and A a quantity defined by

$$A = \frac{\sqrt{R'}.\ 2\pi L\ (\beta + 1/2).2.\alpha}{\sqrt{2\pi M}\ (2-\alpha)} \qquad (8)$$

where R' is the gas constant and M the molecular weight.

Formula (6) may also be written in the form,

$$\delta\theta = \frac{4\lambda.f.\beta}{\pi.(\beta+1/2)} \cdot \frac{(2-\alpha)}{2.\alpha} \cdot \frac{d\theta}{dr} \qquad (9)$$

in which the Smoluchowski factor is replaced by $\frac{4.\lambda f.\beta}{\pi.(\beta+1/2)}$

where f is a factor depending on the force operating in molecular collision and defined by the relation,

$$f = K/\eta C_v \qquad (10)$$

K being the Thermal Conductivity and C_v the Specific Heat at constant volume per gram.

In order to modify the Fourier Law of Heat Conduction in respect of Temperature Drop we have,

$$Q.\text{Log}\ \frac{(r_2 - \lambda')}{(r_1 + \lambda)} = 2.\pi.K.L.(T_1 - T_2 - \delta\theta_1 - \delta\theta_2) \qquad (11)$$

where r_1 and r_2 denote the radii of the wire and internal surface of the tube , λ and λ' the mean collision paths of the gas molecules at the temperature of the wire and wall respectively, $\delta\theta_1$ and $\delta\theta_2$ are the Temperature Drops adjacent to the wire and tube surfaces and T_1 and T_2 the Absolute temperatures of the wire and internal surface of the tube.

$$\text{Since } \delta\theta_1 = F_1(Q/p)$$
$$\text{and } \delta\theta_2 = F_2(Q/p) \qquad \text{from (7)}$$

we have by substitution and rearrangement the modified Fourier relation,

$$\frac{Q}{2.\pi.K.L.}\ \text{Log}\ \frac{(r_2 - \lambda')}{(r_1 + \lambda)} = T_1 - T_2$$

$$- \frac{Q\sqrt{T_1}}{p.r_1 A_1}\left(\sqrt{1 + \frac{Q^2.T_1}{(2-\alpha)^2 p^2 r_1^2 A_1^2 T_1^2}}\right)$$

$$- \frac{Q\sqrt{T_2}}{p.r_2 A_2}\left(\sqrt{1 + \frac{Q^2.T_2}{(2-\alpha')^2 p^2 r_2^2 A_2^2 T_2^2}}\right)$$

$$+ \frac{Q^2}{p^2}\left(\frac{1}{(2-\alpha) r_1^2 A_1^2} + \frac{1}{(2-\alpha') r_2^2 A_2^2}\right) \quad (12)$$

In (12) r_2 denotes the radius of the internal surface of the tube coaxially disposed with respect to the heated wire and A_1 and A_2 the values of A at the surfaces of the wire and tube respectively. In Equation (12) since A_1 and A_2 will differ by virtue of the dependence on temperature of α and β and since we are only concerned with small differences of temperature between the wire and tube surface it is sufficiently accurate to write $A_1 = A_2 = A$ in (12). For reasons fully explained in the Appendix the terms λ and λ' must be reduced by the factor 2/3.

If also the range of pressures associated with the experimental procedure is such that the terms containing $(Q/p)^2$ are of negligible importance in comparison with the terms containing Q/p, then Equation (12) reduces to the more convenient working relation,

$$Y = 1/2.\pi.K.L_o + \frac{1}{A}\left(\sqrt{T_1}/r_1 + \sqrt{T_2}/r_2\right) X \quad (13)$$

$$\text{where } Y = \frac{\theta}{C^2.R.\text{Log}\ \frac{r_2 - 2/3\lambda'}{r_1 + 2/3\lambda}} \qquad (14)$$

$$\text{and } X = \frac{1}{p.\text{Log}\ \frac{(r_2 - 2/3\lambda')}{(r_1 + 2/3\lambda)}} \qquad (15)$$

where C^2R is written for Q (corrected for Radiation) C being the current strength in the wire, R its Resistance and θ is substituted for $(T_1 - T_2)$

The experimental procedure in relation to the investigation of Thermal Conduction in Gases is at once suggested from (13). If the temperature of the wire is maintained at a constant value T_1 while the pressure p of the gas is varied, then Y should satisfy a linear relation with X from which K and λ may be calculated.

In Equation (13) it is seen that due regard has also been paid to changes in θ arising from possible variations in the CO_2 and Oxygen baths used in the experiments.

It is also indicated that over the range of pressure for which Equation (13) is valid the effect of Convection on the heat losses may be neglected. In actual pratice the effect of Convection may be minimised by the use of narrow tubes and in applying Equation (13) care must also be taken to confine the pressure range to points below the region in which the effects of Temperature Drop and Convection overlap.

Radiation

It was shewn from theoretical considerations by Helfgott[13] that the rate of loss of heat by Radiation from bright Platinum may be expressed by the relation,

$$U = 2.\pi.r_1.L.\sigma T.^4 (1 - e^{-q.T.}) \text{ Watts} \quad (16)$$

where r_1 and L denote the radius and length of a uniformly heated wire at a temperature T (abs.) and q and σ are constants biven by,

$$\sigma = 5.72 \times 10^{-12} \text{ Watts . cm}^{-2} \quad (17)$$

$$q = 1.25 \times 10^{-4} \text{ for Platinum} \quad (18)$$

Hence the rate of loss of heat by Radiation from the wire at a temperature T_1 with reference to an enclosing surface at a temperature T_2 is represented by

$$U = 2.\pi.r_1.L\sigma\left[T_1^4(1 - e^{-qT_1^4}) - T_2^4(1 - e^{-qT_2})\right] \quad (19)$$

in which q is assumed to be the same for both surfaces.

In Table (I) the value of $\overset{\cup}{N}$ is tabulated for intervals of 1.deg rise of temperature above that of Liquid Oxygen along with the corresponding values of the quantity $U/(T_1 - T_2)$.

Table 1

$(T_1 - T_2)$	$U \times 10^7$ Watts	$U \times 10^7 / (T_1 - T_2)$
1	0.84	0.84
2	1.72	0.86
3	2.64	0.88
4	3.60	0.90
5	4.60	0.92
6	5.64	0.94
7	6.73	0.96
13	14.28	1.10
18	22.05	1.22
20	25.59	1.28

The quantity $U \times 10^7 / (T_1 - T_2)$ varies from a value 0.84 to a value 1.28 as $(T_1 - T_2)$ varies in value from 1.deg.C to 20. deg.C. Consider now the corresponding heat loss from the same wire under the same conditions of temperature when the space between the wire and tube wall is occupied by a gas at low pressure, for Argon using a liquid Oxygen bath with a temperature difference $(T_1 - T_2)$ of 19.9 deg.C, the value of the quantity $C^2.R / (T_1 - T_2)$ varies from 1340×10^{-7} Watts to 670×10^{-7} Watts as the pressure of the gas changes from .00313 cm Hg to .00152 cm Hg, hence for the same temperature difference the value of $U / (T_1 - T_2)$ represents between 1/5 to 1/13 of one percent of the corresponding quantity $C^2.R/(T_1 - T_2)$ associated with the heat losses through the gas at the pressures cited above.

Principle of Compensation

In order to realise a uniformly heated wire of length L in pratice a double system of tubes and wires is employed, Fig (/). They are dimensionally the same except for length and are also in gaseous connection, one, the longer tube forms the main arm of the Callendar and Griffiths Bridge while the other, the shorter tube is placed in the compensating arm. An electric current whose strength may be varied is passed through the Bridge system, which will be in balance for certain values of the Bridge coils and for this to operate we have the relation

$$R_L - R_S = (\text{Coils} \pm x) \text{ cms of Bridge wire}$$

where R_L and R_S represent the resistance of the long and short wires and x the distance of the contact slider from the true mid-point of the Bridge.

It will now be shewn that at the point of balance of the Bridge system the quantity $(R_L - R_S)$ represents the resistance of a wire whose length L is equal to the difference between the long and short wires and whose temperature is uniform throughout its length. It is emphasised that such a condition depends as will be explained on a carefully considered design of the tube and wire system.

Consider the thermal equilibrium of an element δx of an electrically heated thin platinum wire disposed concentrically with a cylindrical tube and surrounded by a gas

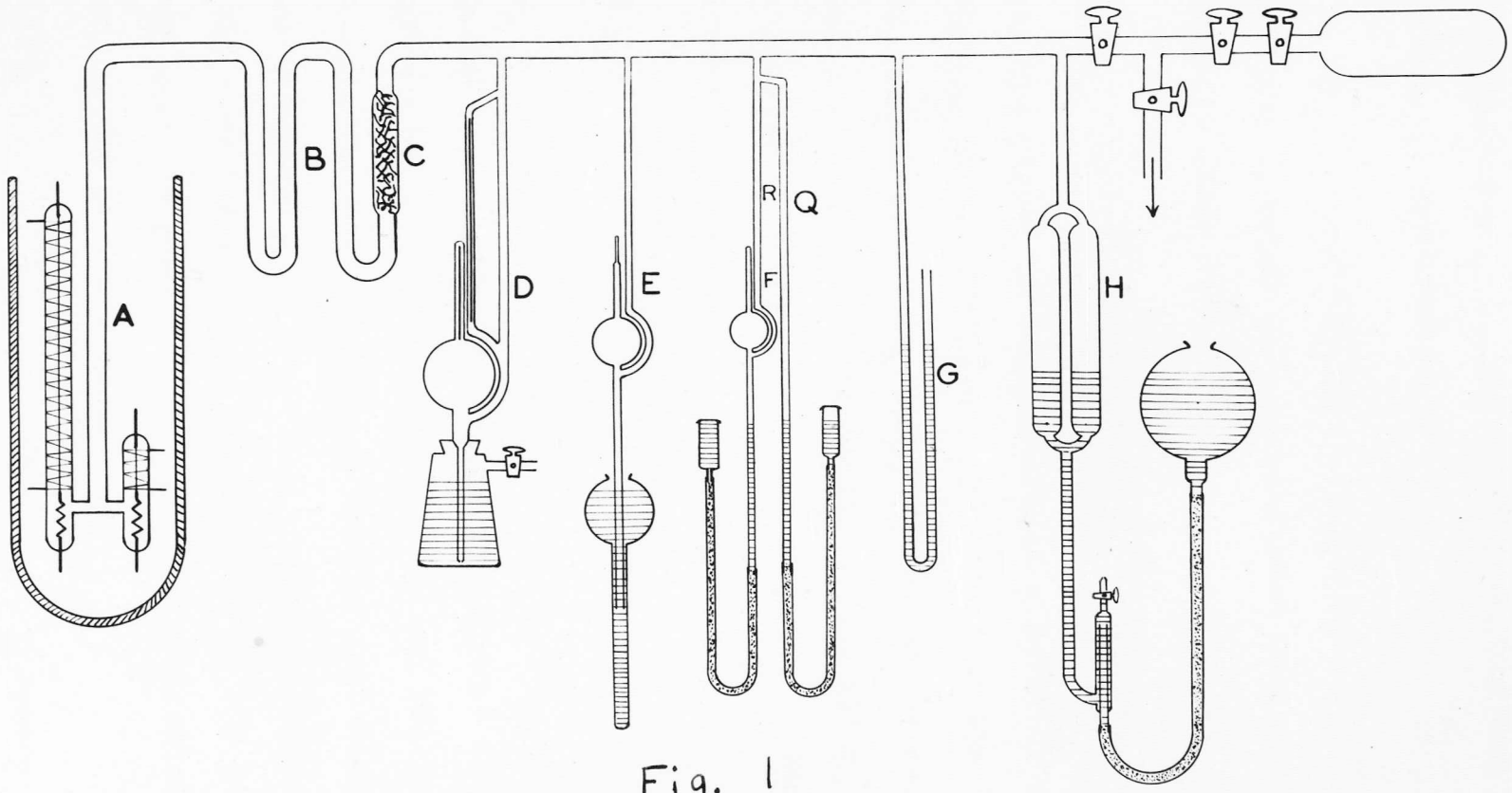


Fig. 1

whose thermal conductivity is K. The equation satisfying such thermal equilibrium is represented by

$$H_i - H_o + \{ C^2.R/L - B\theta - z.\theta \}\delta x = 0 \quad (20)$$

where H_i is the rate at which heat is conducted into the element and which is given by

$$H_i = -JK_m.\pi.r_1^2 \frac{d\theta}{dx} = F(x) \quad (21)$$

where θ denotes the excess of temperature at a point at a distance x from the middle of the wire over that of the temperature of the surface of the tube, K_m is the thermal conductivity of Platinum, and r_1 the radius of the wire.

Similarly, H_o the rate at which heat is conducted out of the element is given by

$$H_o = F(x + \delta x) = F(x) + \delta x.F'(x) \quad (22)$$

hence $H_i - H_o = -\delta x.F'(x) = +JK_m.\pi.r_1^2.d^2\theta/dx^2$ (23)
Also the term $C^2R\frac{\delta x}{L}$ represents the rate of development of heat in the element δx by the current strength C, and the term $Z.\theta.\delta x$ represents the rate of loss of heat by Radiation from considerations discussed in a preceding section on Radiation.

The term B depends on the pressure of the gas and for a range of pressure such that the thermal conductivity K is independent of the pressure we have

$$B = \frac{2.\pi.K.J}{\text{Log}.r_2/r_1}$$ (24) where r_1 and r_2 denote the radii of the wire and internal surface of the tube.

For gases at low pressure B is given by

$$B = 2.\pi.r_1.p.\sqrt{R'/2.\pi.M T_2}\,\alpha(\beta + 1/2) \quad (25)$$

Equation (20) may now be written in the form

$$J K_m .\pi.r_1^2 . \frac{d^2\theta}{dx^2}\,\delta x. + \frac{C^2 \rho_0 (1 + a.\theta)\delta x}{\pi.r_1^2} = (B.\theta + Z.\theta)\,\delta x \quad (26)$$

where a denotes the temperature coefficient of resistance, ρ_0 the specific resistance of Platinum at the temperature of the tube.

Writing Equation (26) in the form

$$\frac{d^2\theta}{dx^2} - P(\theta - S/P) = 0 \quad (27)$$

$$\text{where } P = 1/K_m.\pi r_1^2.J\left(B + Z - \frac{C^2.\rho_0\, a}{\pi.r_1^2}\right) \quad (28)$$

$$\text{and } S = C^2.\rho_0 / K_m.J.(\pi.r_1^2)^2 \quad (29)$$

and solving we have

$$\theta = S/P + c_1 e^{\sqrt{P}.\,x} + c_2 e^{-\sqrt{P}.\,x} \quad (30)$$

where c_1 and c_2 are constants of integration obtained from the boundary conditions viz

$$d\theta/dx = 0 \text{ when } x = 0$$

$$\text{and } \theta = 0 \text{ when } x = L/2$$

$$\text{hence } \theta = \frac{S}{P}\left(1 - \frac{\cosh \sqrt{P}\,x}{\cosh \sqrt{P}.L/2}\right) \quad (31)$$

Now (31) represents the distribution of temperature along either the main or compensating wires of the system, and the

corresponding resistance of either wire is represented by the integral

$$R = 2 \int_0^{\frac{L}{2}} \frac{\rho_0 (1 + a.\theta)\, dx.}{\pi . r_1^2}$$

$$R = \frac{L \rho_0}{\pi . r_1^2} \left(1 + a. \frac{S}{P}\right) - \frac{2 . \rho_0 a.S}{\pi . r_1^2 . P^{3/2}} \tanh \frac{\sqrt{P}. L}{2} \qquad (32)$$

The quantity S/P represents the theoretical temperature of the mid-point of either the long or short wires providing their lengths L_1 and L_2 are such that the terms $\cosh \sqrt{P}.L_1/2$ and $\cosh \sqrt{P}.L_2/2$ are large compared with unity.

If R_L and R_S denote the seperate resistances of the long and short wires, then from (32) we have

$$R_L - R_S = \frac{\rho_0}{\pi . r_1^2} \left(1 + \frac{a.S}{P}\right) (L_1 - L_2)$$

$$- \frac{2 . \rho_0 a.S}{\pi . r_1^2 . P^{3/2}} \left(\tanh \sqrt{P}\, L_1/2 - \tanh \sqrt{P}\, L_2/2 \right) \qquad (33)$$

hence the difference of the resistances of the long and short wires at the point of bridge balance will be equal to the resistance of a wire whose length is equal to the difference $(L_1 - L_2)$ of the lengths of the long and short wires and for which the temperature is uniform and of value S/P, providing the term on the extreme right hand side of Equation (33) is small compared with other terms.

This condition will now be tested in respect of the present system of tubes in the special case of the gas

Argon for which the necessary data is tabulated below,

The term in Equation (33) under consideration may be written in the form

$$- \frac{2.a}{(L_1 - L_2)} \; R_o \frac{S}{p^{3/2}} \; (\tanh \sqrt{P}.L_1/2 \; - \; \tanh \sqrt{P}.L_2/2)$$

where R_o denotes the resistance of a wire of length $(L_1 - L_2)$ at a temperature corresponding to that of the tube wall.

Temperature of Bath	=	-183 deg.C
R	=	0.80416 Ohms
C	=	0.10835 Amps
K_m	=	0.182 Cal
K Argon	=	1.26×10^{-5}
S (calc.)	=	18.75
$\sqrt{P}$ (calc.)	=	1.273

hence the calculated value of the correcting term is

$$- 0.80416 \times (2.55 \times 10^{-4})$$

which satisfies the criterion of compensation to the order of 1/40 of one per cent.

In passing it is emphasised that at low pressures where the collision paths of the gas molecules are comparable with the tube diameters, the above considerations are no longer valid and this aspect of the application of the present system to investigations at low pressure will be discussed later in the paper.

Thermostatic System

The production of temperatures in the neighbourhood of -78 deg C. and -183.deg.C was faciliated by employing a vacuum vessel of approximately one gallon capacity in conjunction with pure liquid Oxygen in one instance and adding powdered CO_2 to aviation spirit in order to form a sludge for the other case ~~CASE~~. A motor driven propeller was also used in order to ensure constancy of temperature throughout the thermostatic fluid while the experiments were in progress. The temperatures of the fluids were calculated in all cases from a knowledge of the resistance of the platinum wire WOUNd on the walls of the tubes and in the case of the Oxygen bath, the maximum variation of temperature recorded throughout an experiment was found to be of the order of about 0.04 deg.C. and in the most cases was considerably less. The temperature of the $C.O_2$ sludge was found to depend on the degree of saturation and for an initially highly saturated state, the temperature fell rapidly at first, attained a minimum and then rose fairly slowly, in all cases it was found possible by adjusting the amount of $C.O_2$ to ensure constancy of temperature throughout the experiment to within .5 deg C and to which conditions the modified Fourier Equation was found to be applicable.

The effect on the calculated values of the thermal conductivity due to such variations of the bath temperature were found to be not greater than two parts in one thousand.

A plan of the Thermostatic system is shewn diagrammatically

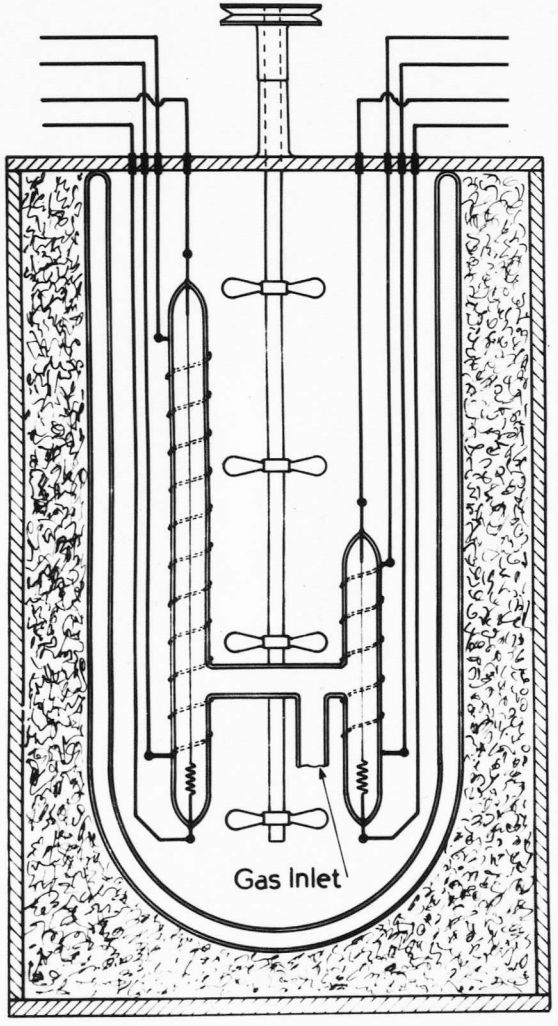

Gas Inlet

Fig. 2

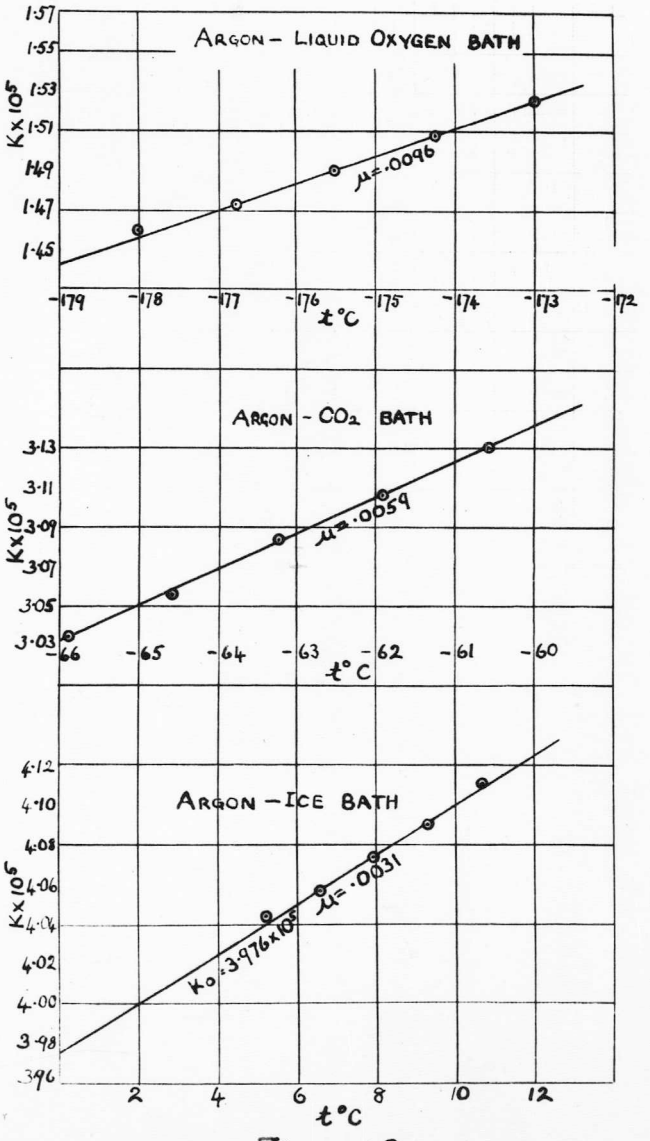

ARGON – LIQUID OXYGEN BATH
K x 10⁵
1·57
1·55
1·53
1·51
1·49
1·47
1·45
μ = .0096
-179
-178
-177
-176
-175
-174
-173
-172
t °C
ARGON – CO₂ BATH
K x 10⁵
3·13
3·11
3·09
3·07
3·05
3·03
μ = .0059
-66
-65
-64
-63
-62
-61
-60
t °C
ARGON – ICE BATH
K x 10⁵
4·12
4·10
4·08
4·06
4·04
4·02
4·00
3·98
3·96
μ = .0031
K₀ = 3·976 x 10⁵
2
4
6
8
10
12
t °C

Fig. 10

in Fig (2) along with the system of tubes and wires.

Calculation of the temperature of the wire in terms of its resistance.

Between 0.deg.C. and 660.deg.C. the temperature t on the international scale is calculable from the measured resistance of the compensated element of Platinum wire by means of the relation,

$$R_t = R_{(0)}(1 + b_1 t + b_2 t^2) \qquad (34)$$

where b_1 and b_2 are constants and $R_{(0)}$ the resistance at 0.deg.C

Now Platinum temperature is defined by the relation

$$pt = 100. \frac{R_t - R_{(0)}}{R_{(100)} - R_{(0)}} \qquad (35)$$

where $R_{(100)}$ is the resistance at 100 deg.C.

From (34) and (35) we have

$$t - pt = \delta \left(\frac{t}{100} - 1 \right) \frac{t}{100} \qquad (36)$$

where $$\delta = - \frac{100^2 . b_2}{b_1 + 100 . b_2} \qquad (37)$$

For pure Platinum δ has been found to be very nearly equal to 1.50

At low temperatures equation (34) is replaced by the relation

$$R_t = R_{(0)}\left[1 + b_1 t + b_2 t^2 + b_3 t^3 (t - 100)\right] \qquad (38)$$

by introducing the corresponding platinum temperature pt we have from (38)

$$t - pt = \delta \frac{t}{100}\left(\frac{t}{100} - 1\right) + h\left(\frac{t^3}{100^3}\right)\left(\frac{t}{100} - 1\right) \quad (39)$$

$$\text{where } h = -\frac{b_3\, 100^4}{b_1 + 100.b_2} \quad (40)$$

From the known value of pt and since h is also known the value of t can be found from (39)

If the resistance of the wire is measured at the three fixed temperatures 0.deg C. , 100 deg.C., and that corresponding to the boiling point of pure Liquid Oxygen t(p) then the value of h may be calculated, where t(p) is obtained from the formula

$$t(p) = -182.97 + .0126(p - 760) + .0000065(p - 760)^2$$

where p denotes the Barometric pressure in mm. of Hg

The experimental procedure of determining the fixed point resistances was similar in each case. After the wire had been thouroughly annealed, a series of currents of small strength C was passed through the Bridge system with the tubes open to the atmosphere and the corresponding balance points obtained. The problem is strictly related to the thermal conduction of the gas surrounding the wires and it has been shewn by Gregory (14) that an appropriate working relation is given by

$$W = m.x + c$$

where W denotes the rate of heat development in the wire and x

the corresponding distance of the balance point from the true mid-point of the bridge system, in this way a value of x corresponding to W = 0 can be found by extrapolation and hence the resistance of the wire at the temperature of the bath is known.

Examples of the above procedure are shewn graphically in Fig (3) and the collected data in Tab.(2)

Table (2)

	$R_{(0)}$	$R_{(100)}$	$R_{(100)}/R_{(0)}$	R(-182.84)	h
Internal system of Wires	3.2552 ohms	4.5290 ohms	1.3913	.80416 ohm	.1053
External system of Wires	3.5770 ohms	4.9614 ohms	1.3870	.9080 ohm	.1267

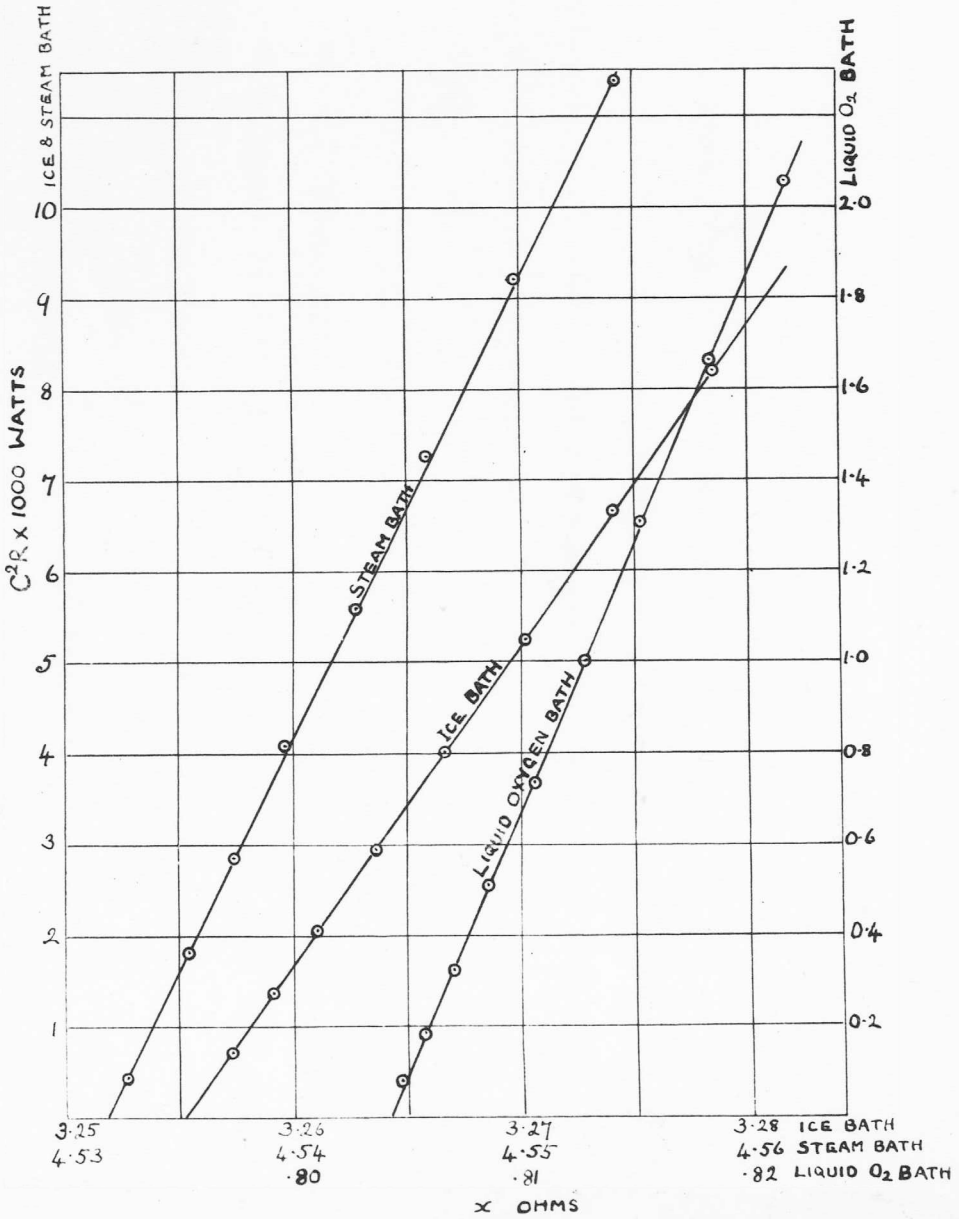

ICE & STEAM BATH
LIQUID O_2 BATH
$C^2R \times 1000$ WATTS
STEAM BATH
ICE BATH
LIQUID OXYGEN BATH
3·25
4·53
3·26
4·54
·80
3·27
4·55
·81
3·28 ICE BATH
4·56 STEAM BATH
·82 LIQUID O_2 BATH
x OHMS

Fig. 3

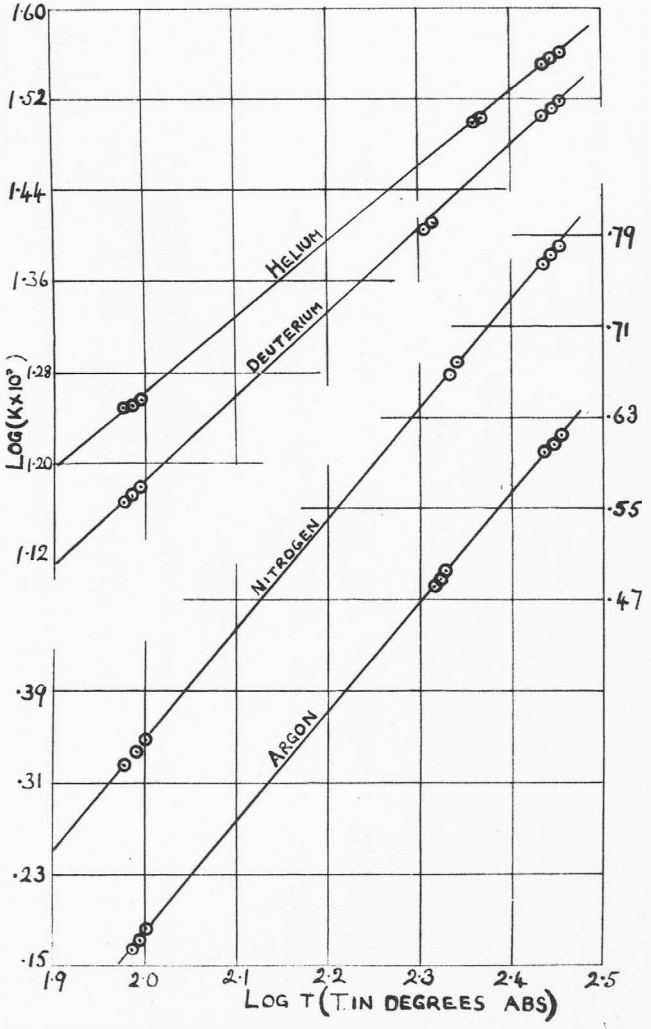

LOG ($K \times 10^7$)
HELIUM
DEUTERIUM
NITROGEN
ARGON
LOG T (T IN DEGREES ABS)

Fig. 9

Alternative treatment of the Temperature Drop Equation

The original treatment of the Temperature Drop by Smoluchowski was based on Knudsen's[8] definitions both in respect of the temperature discontinuity at the gas - solid interface and also in regard to the definition of the coefficient of accommodation.

From Knudsen the temperature drop is defined as

$$\delta\theta = T_1 - 1/2(T + T') \qquad (41)$$

where T' and T are the mean temperatures of the molecules colliding and rebounding from the solid surface and T_1 the temperature of the surface.

Since also from Knudsen,

$$\alpha = \frac{T - T'}{T_1 - T'} \qquad (2)$$

we have from (41) and (2)

$$\delta\theta = (T_1 - T')(1 - \alpha/2) \qquad (42)$$

Now it is the opinion of the author that an alternative treatment might be suggested by writing (41) in the form

$$\delta\theta = T_1 - T' \qquad (43)$$

and if Gregory's treatment of the problem is carried out from the aspect of (43) instead of (41) then we have for the temperature drop the formula

$$\delta\theta = \frac{Q.\sqrt{T'}}{p.r_1 A'} \qquad (44)$$

instead of the relation given previously in the text, viz

$$\delta\theta = \frac{Q.\sqrt{T'}}{p.r_1 A} \qquad (45)$$

where the value of A in (45) is replaced by A' and A' is defined by

$$A' = \sqrt{\frac{R'}{2.\pi.M}}\, 2.\pi.L.(\beta + 1/2).\alpha \qquad (46)$$

The form for $\delta\theta$ is the same in both cases except that the term α is substituted for $2.\alpha/(2-\alpha)$

If T' is eliminated from (43) and (44) the complete expression for $\delta\theta$ is given by

$$\delta\theta = \frac{Q.\sqrt{T_1}}{p.r_1 A'}\left(\sqrt{1 + \frac{Q^2.T_1}{4.p^2.r_1^2(A')^2T_1^2}} - \frac{Q.\sqrt{T_1}}{2.p.r_1.A'.T_1}\right) \qquad (47)$$

in comparison with the previous form for $\delta\theta$.

In Knudsen's original definition it was assumed that the average temperature of the gas molecules adjacent to the wire is represented by the arithmetic mean of the temperatures T and T' whereas it is here regarded as T'. This alternative aspect of $\delta\theta$ has recieved support from the investigations of Langmuir[15] in relation to the accommodation coefficient, and the values of α calculated in terms of the modified Fourier relation from (44) have been found to differ appreciably from thode calculated from the aspect contained in (45).

The modified form of Equation (45) is simply derived by substituting A' for A.

Calculations of the coefficient of accommodation from both aspects are included in the Tables (3) to (14)

Calculation of the Mean Collision Paths

The values of the mean collision paths on which the terms

$$\frac{1}{p.\mathrm{Log}\left(\frac{r_2 - 2/3\lambda'}{r_1 + 2/3\lambda}\right)} \quad \text{and} \quad \frac{(T_1 - T_2)}{Q.\mathrm{Log}\left(\frac{r_2 - 2/3.\lambda'}{r_1 + 2/3.\lambda}\right)}$$

in Equation (13) depend, have been calculated at the appropriate temperatures and pressures from the relation of Chapman for the viscosity of the gas,

$$\eta = .499\ v.\lambda\rho \qquad (48)$$

where ρ is the density of the gas at a pressure p and a temperature T , v the mean velocity of agitation and η the coefficient of viscosity at the same temperature. The experimental values of η for the gases under consideration were taken from the most accurate data available, with the exception of D_2 for which experimental values of η at the temperatures -78.deg.C and -183.deg.C are not yet available, and the procedure requires modification on this account.

Since Equation (13) may be written in the form

$$Q.\mathrm{Log}.r_2/r_1 = 2.\pi.K.L.\theta - 2\pi.K.L.\frac{Q}{p.A.}(\sqrt{T_1}/r_1 + \sqrt{T_2}/r_2) + \frac{Q}{p}\frac{2}{3}(\lambda p/r_1 + \lambda' p/r_2) \qquad (49)$$

which has been obtained by expanding the term $\mathrm{Log}\left(\frac{r_2 - \frac{2}{3}\lambda'}{r_1 + \frac{2}{3}\lambda}\right)$ in (13) and neglecting powers of λ/r_1 and λ'/r_2 higher than the first.

Since also $\lambda p = \frac{K.\gamma\sqrt{T}}{f.C_v}$ (50)

where $\gamma = \frac{\sqrt{\pi}.R!}{.499\sqrt{8}.M}$ and C_v denotes the specific heat per gram at constant volume.

Equation (49) may now be written in the form,

$$\frac{\theta}{Q} = \frac{\mathrm{Log}.r_2/r_1}{2.\pi.K.L.} + \frac{1}{p}\left(\sqrt{T_1}/r_1 + \sqrt{T_2}/r_2\right)\left(1/A - \frac{\gamma}{3.\pi.L.f.C_v}\right) \quad (51)$$

If m denotes the slope of (51) taking $\frac{\theta}{Q}$ and $\frac{1}{p}$ as variables then we have

$$\frac{1}{A} = \frac{m}{\left(\sqrt{T_1}/r_1 + \sqrt{T_2}/r_2\right)} + \frac{\gamma}{3.\pi.L.f.C_v} \quad (52)$$

Substituting the value of A from (8) in (52) we have

$$\frac{1}{2.\alpha/(2-\alpha)} = \frac{1}{2.\alpha'/(2-\alpha')} + \frac{.334(\beta + 1/2)}{f.\beta} \quad (53)$$

where α' represents an approximate value of α calculated from the Equation,

$$A = \frac{m}{\sqrt{T_1}/r_1 + \sqrt{T_2}/r_2} \quad (54)$$

The above procedure relevant to the calculation of α in the absence of experimental data for η is concerned solely with the

gas Deuterium, and the results of such considerations are tabulated in detail in Tables (12) to (14).

Correction in respect of the drop of temperature across the glass wall of the Tube.

Since the term $\theta = (T_1 - T_2)$ refers strictly to the difference of temperature between the centrally situated wire and the internal surface of the tube, and since also the value of T_2 is related to the measured temperature T_3 of the external surface of the tube by the relation,

$$C^2.R = 2.\pi.K_g L.(T_2 - T_3)/\log_e \frac{r_3}{r_2}$$

where $C^2.R$ denotes the rate of heat loss through the gas, r_2 and r_3 the radii of the internal and external surfaces of the wall of the tube and K_g the thermal conductivity of the material of the tube at a temperature T_3, it is necessary therefore, in order to calculate the value of T_2 from the above relation to know the values of the thermal conductivity of Lead Glass over a range of temperature between 0.deg.C. and -183.deg.C.

A seperate investigation in respect of this was carried out by the author in the following manner. A Platinum wire (diameter 4 mils) whose resistance was known over the range of temperature considered, was fused centrally into a piece of lead glass capillary tubing, the ends of which were cupped so as to form mercury reservoirs. A current of appropriate strength was passed along the wire, the whole

apparatus being immersed alternately in baths maintained at temperatures of 100.deg.C , 0.deg.C , and -183deg.C respectively. For a condition of thermal equilibrium the value of K_g may be obtained from the equation

$$K_g = \frac{W.\ \mathrm{Log}\ (R_2/R_1)}{2.\pi.L_1.\Delta\theta}$$

where W is the rate of heat development in the wire of length L_1 , R_1 and R_2 the radii of the wire and that of the capillary tube while $\Delta\theta$ denotes the temperature difference between the wire and the bath. In the actual investigation for a fixed temperature of the bath W was found to be proportional to $\Delta\theta$ and a value of K_g obtained from the graph.

The values of K_g obtained in this way for Lead Glass are tabulated below.

Bath Temperature (deg.C)	100	0	-183
K_g (Cals.cm^{-1} deg^{-1} sec^{-1})	0.00196	.00175	.000684

The correction $\Delta\theta = (T_2 - T_3)$ was found in most cases to be less than 0.12 deg.C , hence it is not necessary to know the value of K_g to a high degree of accuracy.

Description of the Apparatus

The experimental tube system was constructed of Lead Glass, carefully calibrated in regard to uniformity of bore and the specimen eventually used satisfied this condition to an accuracy of about 1 in 400. The wires were obtained from Messrs Johnson and Matthey and termed Pure Thermo-Platinum. Two lengths, silver soldered to thick Platinum springs and leads were sealed centrally along the tubes. The radius r_1 of the wires was determined by weighing a length of the wire on an Assay pattern balance.

Lengths of Platinum wire were also wound round the external surfaces of the tubes and fixed by means of a solution of shellac which served to prevent any possibility of electrical conduction through the thermostatic liquid.

The arrangement of the apparatus is shewn diagrammatically in Fig (1). A denotes the tubes, B and C are Liquid Oxygen traps D , E and F the Mcleod Gauges while G represents an open limb Hg Manometer and H a Mercury reservoir. The traps were U shaped, one of which (C) was loosely packed with tinfoil in order to prevent the diffusion of Hg vapour into the experimental tube system, the other (B) was of uniform bore in order to obviate the possibility of a pressure difference arising on the two sides of the trap, caused by the effect of Thermal Transpiration at the low temperatures and pressures employed in some of the experiments.

The Mc-Leod gauges were of the usual type and were designed to ensure the greatest possible accuracy over three ranges of pressure viz

Gauge	(D)	6×10^{-3}	cms Hg	to	8×10^{-5}	cms Hg
"	(E)	0.8	cms Hg	to	0.002	cms Hg
"	(F)	0.5	cms Hg	to	13	cms Hg

In conjunction with F a device was employed in order to compensate for the changes of volume arising from the rise of Mercury in the tube R, a similar tube Q of equal bore was connected to a second reservoir of Mercury and lowered through a distance equal to that by which the Mercury in R was raised.

The reservoir H possessed a capacity of about 1700 ccs and was employed to provide the necessary variation of pressure throughout the duration of the experiments.

The Pumping system consisted of a Steel Diffusion Pump backed by a Hyvac, the former pump being of the three stage type.

The electrical connections of the experimental system are shewn in Fig (4), the main and compensating tubes occupy the P and C arms of a Callendar and Griffiths Bridge, the current through which is varied by a system of wire and mercury Rheostats.

The leading-in wires from the tubes to the bridge were formed of heavily insulated copper wires of equal length and arranged so as to compensate for the temperature variation

along their length. The current flowing through the wires corresponding to any fixed setting of the bridge was determined by measureing the potential drop across a standard resistance of 1 ohm in conjunction with a Diesselhorst Potentiometer. A compensating one ohm resistance was inserted in the opposite branch of the bridge in order that the mid-point of the bridge should not be altered by a large amount.

A Callendar and Griffiths bridge was also used in conjunction with the platinum wire wound on the external surface of the tubes in order to determine the temperature of the bath.

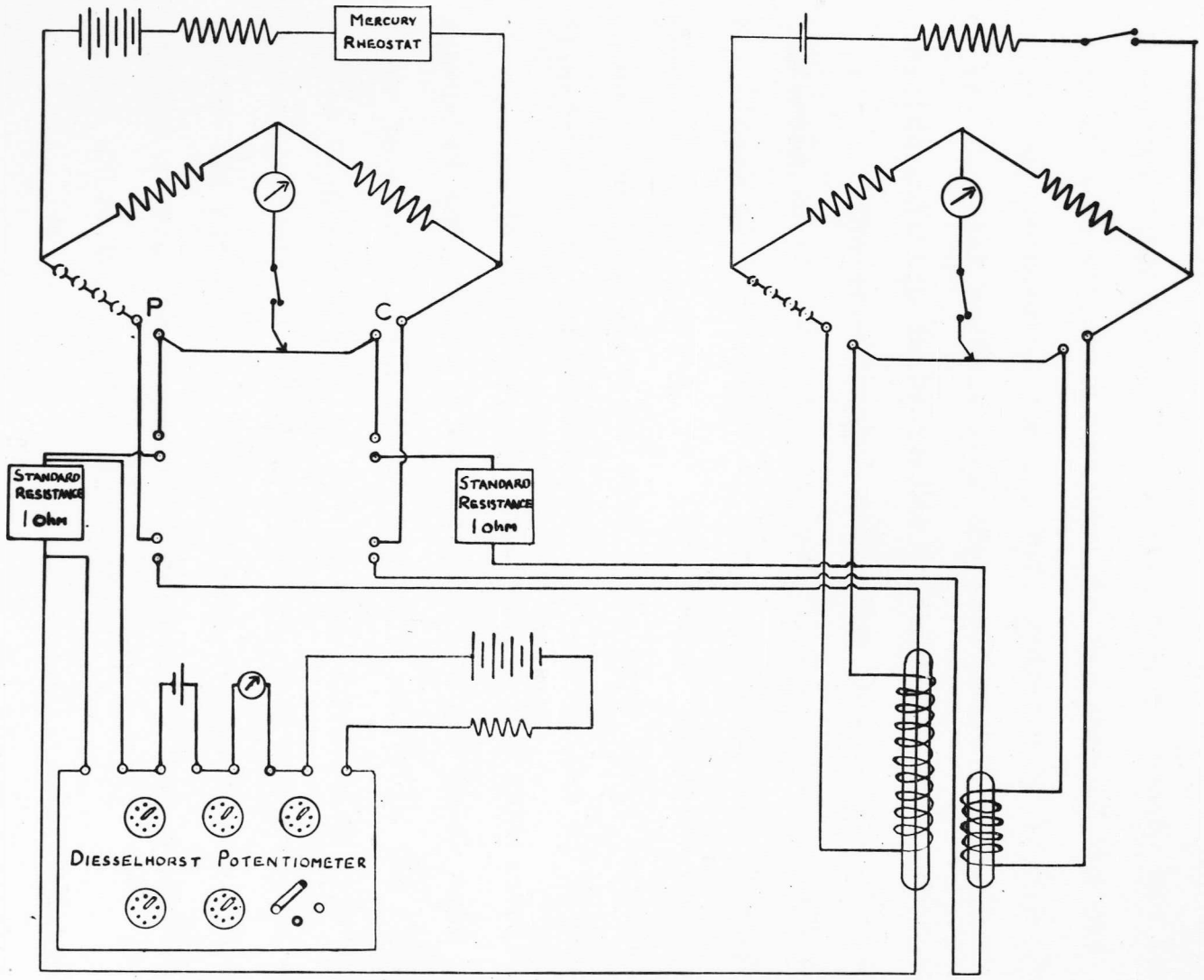

MERCURY
RHEOSTAT
P
C
STANDARD
RESISTANCE
1 ohm
STANDARD
RESISTANCE
1 ohm
DIESSELHORST POTENTIOMETER

Fig 4

Experimental Procedure

Of the gases associated with the present investigations, three were supplied by the British Oxygen Company and found to be of high spectroscopic purity, in the case of the gas Deuterium, samples of the gas were prepared by Mr R.E. Roberts of the Imperial College from the Electrolysis of Sodium Peroxide solution in Deuterium Oxide of 99.96 per cent purity.

The experimental procedure in general details conformed to the method developed by Gregory in relation to the effect of temperature on the Heat Conduction through Hydrogen above 0.deg.C but the theoretical basis in the present instance might be said to be more exact in particular relation to the calculation of the coefficient of accommodation.

In all cases the tube system was alternately exhausted and partially filled with the gas under test in order to ensure the greatest possible purity in the final sample of gas admitted to the system. Commencing with some convenient value of the gas pressure, the bridge coils and slider was adjusted so that the temperature of the compensated element of wire corresponded to a definite and predetermined amount above that of the thermostat.

In order to fulfill this condition of equilibrium the strength of the current through the bridge circuit was adjusted by means of a series of Rheostats in which all forms of sliding contacts had been eliminated, in this manner the balance of the Bridge system could be maintained for each of a

series of gas pressures and at the same time corresponding to each pair of values of the balancing current C and pressure p the temperature of the external surface of the tube could be determined from observations of the resistance of the platinum wire wound on the glass surface.

Such related data for C and p are recorded in Tables (3) to (14) for various temperatures of the wire above that of the bath.

After lowering the pressure of the gas by a definite amount the time required for attainment of the stationary state from the point of view of adjusting the balancing current was of the order of a few minutes and when complete represents an operation whose sensitivity is of the order of about 1/5000 of a degree.C. It was thus found possible to maintain the constancy of temperature of the compensated element of wire to an accuracy within 1/5000 of a degree throughout the duration of the experiment. Such control is only possible if proper use is made of the sensitive Mercury Rheostats designed and used by Gregory and Archer in their earlier work on the subject.

It is emphasised that the usual procedure of balancing the bridge circuit by adjusting a resistance is replaced in these measurements by the far more sensitive method of adjusting the heating effect in the wire by an alteration in the current strength, an adjustment whose magnitude might reasonably be of the order of .000001 Amps and at the same time

quite beyond the capacity of the Potentiometer to measure such small changes of current.

From Equation (13) a linear relation should exist between the quantities X and Y where X and Y are defined above and the graphical interpretation of the many observations recorded from this point of view are fully represented in the Figs (5) to (8)

Values of the Thermal conductivity corresponding to a mean gas temperature T_m where $T_m = (T_1 + T_2)/2$ and of the coefficient of accommodation at the various wire temperatures have been calculated from aspects of the intercepts and slopes of such lines and the results included in Tables (3) to (14).

Key to the System of Symbols used in the text

a = Temperature coefficient of Resistance of Platinum

$A = \sqrt{R'}.2.\pi.L.(\beta + 1/2).2.\alpha / \sqrt{2.\pi.M}.(2-\alpha)$

$A' = \sqrt{R'}.2.\pi.L.(\beta + 1/2)\alpha / \sqrt{2.\pi.M}.$

b_1, b_2, b_3 } Constants associated with the expression for the resistance of the Platinum Wire.

$R_t = R_{(0)}\left[1 + b_1 t. + b_2 t^2 + b_3 t^3 (t - 100)\right]$

$B = 2.\pi.KJ / \text{Log} \frac{r_2}{r_1}$ (Temperature Drop Relation)

$B = 2.\pi.r_1.p.(\beta + 1/2).\alpha \sqrt{\frac{R'}{2.\pi.M.T_2}}$ (Low Pressure)

= Rate of Heat Loss through the gas per cm. of wire / θ

C = Current strength in the wire

C_v = Specific Heat of the gas per gram at constant volume

$D = (R - R_o)$

E, E' and E are the average energies of the gas molecules corresponding to the temperatures T, T' and T_1

$\delta\theta$ = Temperature discontinuity at the (gas - solid) interface.

$= F(Q/p)$

$f = K/C_v\eta$

g = Factor in the relation $\eta = g.T^n$

g' = Factor in the relation $K = g' T^{n'}$

$G = a.R_o$

$h = - \frac{b_3 \times 100^4}{b_1 + 100.b_2}$

H_λ = Rate at which heat is conducted into element of wire δx

H_o = Rate at which heat is conducted out of element of wire δx

i = Constant in the Equation of Knudsen for Thermal Transpiration

$$dp/p = \frac{dT}{2.T.} \quad \frac{1}{1 + 2.i.r./\lambda}$$

J = Joule's Equivalent

k = Gas constant per molecule

K = Thermal Conductivity of the Gas

K_m = " " " Platinum

K_g = " " " Glass

L_1 = Length of the long wire

L_2 = " " " Short wire

$$L = (L_1 - L_2)$$

M = Molecular Weight of Gas

p = Gas pressure

p_2 = Pressure as measured by the Mc-Leod Gauge

p_1' , p_1'' , and p_1''' pressures calculated from Knudsen's formula for values of i = 1,2 and 3 respectively

$$P = \frac{1}{\pi.r_1^2.K_m.J.} \left(B + Z - \frac{C^2.\rho_o a.}{\pi.r_1^2} \right)$$

pt = Temperature on the Platinum scale.

q and σ constants associated with the Helfgott Radiation formula

$$U = 2.\pi.r_1.L.\sigma T^4(1 - e^{-qT})$$

Q = Rate of Heat Loss through the Gas corrected for Radiation

r_1 = radius of the Platinum Wire

r_2 and r_3 are the radii of the internal and external surfaces of the glass tube.

R' = Gas constant per gram molecule

R_L = Resistance of the long wire

R_S = " " " short wire

R = $R_L - R_S$ = Resistance of the compensated length of platinum wire

R_o = Resistance of compensated element at the temperature of the Bath

$R_{(o)}$ = Resistance at 0.deg.C

$R_{(100)}$ = Resistance at 100.deg.C

$$S = \frac{C^2 . \rho_o}{\pi . r_1^2 . K_m . J .} \qquad \phi = \frac{C^2 . \rho_o . a}{(\pi . r_1^2)^2 . K_m . J}$$

$$X = \frac{1}{p \log (r_2 - \frac{2}{3}\lambda')/(r_1 + \frac{2}{3}\lambda)}$$

$$Y = \frac{\theta}{Q \log (r_2 - \frac{2}{3}\lambda')/(r_1 + \frac{2}{3}\lambda)}$$

Z = Rate of loss of Heat by Radiation per unit length of wire per unit difference in Temperature between wire and Wall

α = coefficient of accommodation

$\alpha(K)$ = α calculated from Knudsen's definition

$\alpha(L)$ = α " " Author's "

$\beta . R'$ = Molecular Heat of the gas at constant volume

$\gamma = \sqrt{\pi . R'} / .499 \sqrt{8 . M .}$

v = Mean Velocity of Agitation at a temperature T

$\Delta\theta = T_2 - T_3$ = Fall of temperature across wall of tube

$\mathcal{E}$ = Molecular conductivity

ρ_0 = Specific resistance of Platinum at the temperature of the Bath

λ and χ the Mean collision paths at the temperatures of the wire and wall

μ = Temperature coefficient of the Thermal conductivity of the Gas

η = The coefficient of Viscosity of the gas

$\theta = T_1 - T_2$

Constants of the Apparatus

r_1	=	.003766 cms	L_1	=	18.854 cms
r_2	=	.5705 cms	L_2	=	4.0172 cms
r_3	=	.6742 cms			

Table 3

He ---------- Ice bath

(1) T_1 = 290.40 R = 3.4799 θ = 17.11 U = .000133 Δθ = .11

p(cm Hg)	C(Amps)	X	$\frac{Y}{\theta}$
16.07	.36702	.02863	.98231
13.36	.36575	.03446	.98983
11.70	.36469	.03937	.99611
10.59	.36339	.04351	1.0037
9.526	.36257	.04840	1.0087
8.335	.36058	.05536	1.0207
7.461	.35948	.06189	1.0277
6.716	.35767	.06880	1.0388
5.843	.35609	.07918	1.0493
5.105	.35338	.09072	1.0667
4.633	.35127	.1001	1.0806

K = 3.660 x 10^{-4} α(K) = .349

T m = 281.85 α(L) = .423

(2) T_1 = 287.29 R = 3.4379 θ = 14.02 U = .000104 Δθ = .09

p	C	X	$\frac{Y}{\theta}$
16.07	.33374	.02863	1.2018
13.36	.33251	.03446	1.2115
11.70	.33160	.03937	1.2188
10.59	.33012	.04351	1.2302
9.526	.32967	.04840	1.2342
8.335	.32761	.05535	1.2507
7.461	.32683	.06188	1.2575
6.716	.32519	.06879	1.2712
5.843	.32388	.07917	1.2829
5.105	.32132	.09071	1.3050
4.633	.31983	.1001	1.3185

K = 3.642 x 10^{-4} α(K) = .353

Tm = 280.28 α(L) = .429

$T_m = \frac{1}{2}(T_1 + T_2)$

Table3(Continued)

(3) T_1= 284.17 R = 3.3979 θ = 10.92 U = .000081 $\Delta\theta$= .07

p	C	X	$\frac{Y}{\theta}$
16.07	.29602	.02863	1.5455
13.36	.29490	.03446	1.5583
11.70	.29403	.03937	1.5683
10.59	.29264	.04350	1.5839
9.526	.29224	.04840	1.5890
8.335	.29045	.05535	1.6099
7.461	.28983	.06188	1.6179
6.716	.28833	.06879	1.6359
5.843	.28728	.07916	1.6496
5.105	.28503	.09069	1.6778
4.633	.28378	.1000	1.6942

K = 3.627×10^{-4} α(K) = .361
Tm = 278.71 α(L) = .441

(4) T_1= 281.07 R = 3.3579 θ = 7.84 U =.000057 $\Delta\theta$ = .05

p	C	X	$\frac{Y}{\theta}$
16.07	.25169	.02863	2.1632
13.36	.25056	.03426	2.1842
11.70	.24978	.03936	2.1990
10.59	.24874	.04350	2.2183
9.526	.24847	.04849	2.2242
8.335	.24689	.05535	2.2544
7.461	.24635	.06187	2.2568
6.716	.24520	.06878	2.2888
5.843	.24432	.07915	2.3078
5.105	.24243	.09068	2.3467
4.633	.24143	.1000	2.3683

K = 3.605×10^{-4} α(K) = .359
Tm = 277.15 α(L) = .438

Table 4

He ---------- CO_2 bath

(1) T_1 = 240.57 R = 2.8328 U = .0000574

p	C	t_3	$\Delta\theta$	θ	X	Y
15.55	.36660	-48.63	.12	15.90	.02957	19.21
13.11	.36603	-48.66	.12	15.93	.03509	19.31
11.29	.36543	-48.68	.12	15.95	.04077	19.41
9.157	.36318	-48.64	.11	15.92	.05031	19.63
7.820	.36053	-48.54	.11	15.82	.05895	19.81
6.552	.35988	-48.68	.11	15.96	.07043	20.08
5.529	.35663	-48.57	.11	15.85	.08356	20.33
4.521	.35492	-48.71	.11	15.99	.1024	20.74

K = 3.177×10^{-4} α(K) = .354

Tm = 232.61 α(L) = .431

(2) T_1 = 237.50 R = 2.7928 U = .0000423 $\Delta\theta$ = .09

p	C	t_3	θ	X	Y
15.55	.33252	-48.68	12.91	.02957	19.23
13.11	.33141	-48.66	12.89	.03509	19.34
11.29	.33028	-48.65	12.88	.04077	19.46
9.157	.32953	-48.68	12.91	.05031	19.61
7.820	.32509	-48.44	12.67	.05895	19.79
6.552	.32533	-48.61	12.84	.07042	20.05
5.529	.32383	-48.68	12.91	.08356	20.37
4.521	.32067	-48.63	12.86	.1024	20.72

K = 3.170×10^{-4} α(K) = .360

Tm = 231.07 α(L) = .438

(3) T_1 = 234.45 R = 2.7528 U = .0000338 $\Delta\theta$ = .07

p	C	t_3	θ	X	Y
15.55	.29425	-48.75	9.95	.02957	19.20
13.11	.29225	-48.68	9.88	.03509	19.33
11.29	.29139	-48.67	9.87	.04077	19.44
9.157	.28996	-48.66	9.86	.05031	19.63
7.820	.28923	-48.68	9.88	.05895	19.78
6.552	.28699	-48.65	9.85	.07042	20.05
5.529	.28507	-48.64	9.84	.08354	20.32
4.521	.28230	-48.61	9.81	.1023	20.69

K = 3.166×10^{-4} α(K) = .366

Tm = 229.51 α(L) = .449

Table 5

Helium ---------- Liquid Oxygen bath

(1) T_1 = 103.48 R = .9908 U = .0000015 $\Delta\theta$ = .09

p(cm Hg)	C(Amps)	t_3	θ	X	Y
.9765	.39557	-182.98	13.19	.4770	39.63
.8679	.39164	-182.98	13.19	.5377	40.50
.7615	.38690	-182.97	13.18	.6142	41.57
.6573	.38175	-182.97	13.18	.7138	42.82
.5991	.37655	-182.95	13.16	.7848	44.04
.5267	.37084	-182.94	13.15	.8955	45.52

$K = 1.798 \times 10^{-4}$ $\alpha(K) = .351$

$T_m = 96.89$ $\alpha(L) = .426$

(2) T_1 = 100.62 R = .9508 U = .0000012 $\Delta\theta$ = .07

p	C	t_3	θ	X	Y
.9765	.35756	-182.98	10.35	.4768	39.64
.8679	.35379	-182.98	10.35	.5374	40.56
.7615	.34798	-182.97	10.34	.6138	41.98
.6573	.34477	-182.97	10.34	.7133	42.89
.5991	.34145	-182.95	10.32	.7842	43.73
.5267	.33550	-182.94	10.31	.8947	45.40

$K = 1.782 \times 10^{-4}$ $\alpha(K) = .358$

$T_m = 95.45$ $\alpha(L) = .435$

(3) T_1 = 99.18 R = .9307 U = .0000010 $\Delta\theta$ = .06

p	C	t_3	θ	X	Y
.9765	.33586	-182.98	8.92	.4767	39.55
.8679	.33232	-182.98	8.92	.5372	40.47
.7615	.32714	-182.97	8.91	.6137	41.80
.6573	.32432	-182.97	8.91	.7131	42.66
.5991	.32111	-182.95	8.89	.7839	43.50

$K = 1.773 \times 10^{-4}$ $\alpha(K) = .368$

$T_m = 94.72$ $\alpha(L) = .450$

Table 5 (Continued)

(4) T_1 = 97.75 R = .9107 U = .0000008 $\Delta\theta$ = .05

p	C	t_3	θ	X	Y
.9765	.31135	-182.98	7.50	.4766	39.48
.8679	.30841	-182.98	7.50	.5371	40.36
.7615	.30381	-182.97	7.49	.6135	41.63
.6573	.30125	-182.97	7.49	.7128	42.46
.5991	.29793	-182.95	7.47	.7836	43.38
.5867	.29294	-182.94	7.46	.8940	44.95

$K = 1.768 \times 10^{-4}$ $\alpha(K) = .371$
Tm = 94.00 $\alpha(L) = .456$

(5) T_1 = 96.33 R = .8907 U = .0000007 $\Delta\theta$ = .04

p	C	t_3	θ	X	Y
.9765	.28431	-182.98	6.09	.4765	39.35
.8679	.28128	-182.98	6.09	.5370	40.28
.7615	.27743	-182.97	6.08	.6133	41.42
.6573	.27410	-182.97	6.08	.7126	42.55
.5991	.27141	-182,95	6.06	.7833	43.34

$K = 1.761 \times 10^{-4}$ $\alpha(K) = .377$
Tm = 93.29 $\alpha(L) = .464$

Table 6

Nitrogen ------- Ice bath

(1) T_1 = 294.59 R = 3.5311 θ = 21.39 U = .000171 $\Delta\theta$ = .02

p (cm Hg)	C(Amps)	X	$\frac{Y}{\theta}$
4.287	.16711	.1074	4.6779
3.215	.16662	.1434	4.7119
2.614	.16611	.1766	4.7466
2.188	.16565	.2114	4.7799
1.878	.16521	.2465	4.8108
1.673	.16483	.2770	4.8382
1.500	.16447	.3092	4.8648
1.326	.16400	.3503	4.9000

K = 6.020×10^{-5} α(K) = .630

Tm = 283.40 α(L) = .921

(2) T_1 = 291.87 R = 3.4961 θ = 18.67 U = .000147 $\Delta\theta$ = .02

p	C	X	$\frac{Y}{\theta}$
4.287	.15656	.1074	5.3826
3.251	.15609	.1434	5.4222
2.614	.15560	.1766	5.4629
2.188	.15520	.2113	5.4979
1.878	.15476	.2465	5.5366
1.673	.15441	.2769	5.5677
1.500	.15405	.3091	5.6001
1.326	.15366	.3502	5.6365

K = 5.995×10^{-5} α(K) = .626

Tm = 282.54 α(L) = .910

(3) T_1 = 289.14 R = 3.4611 θ = 15.94 U = .000121 $\Delta\theta$ = .02

p	C	X	$\frac{Y}{\theta}$
4.287	.14511	.1074	6.3284
3.215	.14468	.1434	6.3744
2.614	.14420	.1766	6.4246
2.188	.14385	.2113	6.4640
1.878	.14345	.2465	6.5084
1.673	.14312	.2769	6.5451
1.500	.14279	.3091	6.5828
1.326	.14242	.3502	6.6265

K = 5.970×10^{-5} α(K) = .629

Tm = 281.17 α(L) = .917

Table 6(Continued)

(4) T_1= 286.43 R = 3.4261 θ = 13.24 U = .000100 $\Delta\theta$ = .01

p	C	X	$\frac{Y}{\theta}$
4.287	.13265	.1074	7.6498
3.215	.13224	.1434	7.7074
2.614	.13181	.1766	7.7667
2.188	.13148	.2113	7.8155
1.878	.13112	.2464	7.8585
1.673	.13081	.2769	7.9140
1.500	.13052	.3090	7.9582
1.326	.13019	.3501	8.0096

K = 5.949×10^{-5} α(K) = .617
Tm = 279.81 α(L) = .892

(5) T_1= 283.71 R = 3.3911 θ = 10.52 U = .000078 $\Delta\theta$ = .01

p	C	X	$\frac{Y}{\theta}$
4.287	.11863	.1074	9.6634
3.215	.11828	.1434	9.7328
2.614	.11786	.1766	9.8136
2.188	.11754	.2112	9.8789
1.878	.11727	.2464	9.9372
1.673	.11699	.2768	9.9949
1.500	.11670	.3090	10.059
1.326	.11643	.3501	10.116

K = 5.929×10^{-5} α(K) = .612
Tm = 278.45 α(L) = .882

Table 7

Nitrogen -------- CO_2 bath

(1) T_1 = 231.38 R = 2.7113 U = .000067 $\Delta\theta$ = .026

p (cm Hg)	C (Amps)	t_3	θ	X	Y
4.626	.17753	-65.054	23.230	.09942	125.12
3.397	.17698	-64.970	23.146	.1355	125.57
2.670	.17698	-65.054	23.230	.1726	126.15
2.213	.17670	-65.040	23.216	.2085	126.59
1.894	.17623	-65.026	23.202	.2437	127.31
1.653	.17588	-64.991	23.167	.2795	127.75
1.449	.17562	-65.019	23.195	.3194	128.42
1.310	.17534	-64.991	23.167	.3535	128.79

K = 4.775×10^{-5} α(K) = .698

Tm = 219.81 α(L) = 1.07

(2) T_1 = 228.71 R = 2.6763 U = .000058 $\Delta\theta$ = .023

p	C	t_3	θ	X	Y
4.626	.16757	-65.047	20.556	.09941	125.89
3.397	.16720	-65.026	20.535	.1355	126.44
2.670	.16696	-65.019	20.528	.1726	126.88
2.213	.16679	-65.033	20.542	.2084	127.35
1.894	.16626	-64.991	20.500	.2437	128.02
1.653	.16606	-65.033	20.542	.2795	128.71
1.449	.16578	-65.019	20.528	.3193	129.19
1.310	.16526	-64.950	20.459	.3535	129.69

K = 4.744×10^{-5} α(K) = .693

Tm = 218.47 α(L) = 1.06

(3) T_1 = 226.04 R = 2.6413 U = .000049 $\Delta\theta$ = .020

p	C	t_3	θ	X	Y
4.626	.15697	-65.054	17.897	.09941	126.55
3.397	.15674	-65.047	17.890	.1355	127.00
2.670	.15651	-65.061	17.904	.1726	127.60
2.213	.15607	-65.026	17.869	.2084	128.18
1.894	.15560	-64.991	17.834	.2437	128.82
1.653	.15554	-65.033	17.876	.2795	129.35
1.449	.15521	-64.998	17.841	.3193	129.78
1.310	.15495	-65.005	17.848	.3534	130.38

K = 4.718×10^{-5} α(K) = .694

Tm = 217.13 α(L) = 1.06

Table 7(Continued)

(4) T_1 = 223.38 R = 2.6063 U = .000041 $\Delta\theta$ = .017

p	C	t_3	θ	X	Y
4.626	.14520	-65.054	15.234	.09940	127.57
3.397	.14504	-65.047	15.227	.1355	127.92
2.670	.14491	-65.061	15.241	.1726	128.39
2.213	.14459	-65.033	15.213	.2084	128.84
1.894	.14412	-65.005	15.185	.2436	129.56
1.653	.14382	-64.985	15.165	.2794	130.22
1.449	.14362	-64.968	15.178	.3192	130.65
1.310	.14319	-64.942	15.122	.3534	131.07

K = 4.688 x 10^{-5} α(K) = .689
Tm = 215.78 α(L) = 1.05

(5) T_1 = 220.71 R = 2.5713 U = .000033 $\Delta\theta$ = .014

p	C	t_3	θ	X	Y
4.626	.13216	-65.026	12.547	.09940	128.55
3.397	.13216	-65.047	12.568	.1355	128.57
2.670	.13203	-65.040	12.561	.1726	129.19
2.213	.13184	-65.061	12.582	.2084	129.90
1.894	.13142	-65.040	12.561	.2436	130.63
1.653	.13116	-65.013	12.534	.2794	130.98
1.449	.13079	-64.978	12.499	.3192	131.49
1.310	.14319	-64.963	12.484	.3533	132.07

K = 4.662 x 10^{-5} α(K) = .666
Tm = 214.44 α(L) = .998

Table 8

Nitrogen --------- Liquid Oxygen bath

(1) T_1 = 110.15 R = 1.0814 U = .0000025 $\Delta\theta$ = .021

p(cm Hg)	C(Amps)	t_3	θ	X	Y
1.214	.17757	-182.91	19.86	.3792	268.1
.9360	.17737	-182.91	19.86	.4924	269.0
.7505	.17708	-182.91	19.86	.6147	270.2
.6275	.17683	-182.91	19.86	.7362	271.3
.5313	.17642	-182.90	19.85	.8704	272.8
.4863	.17635	-182.92	19.87	.9518	273.5

$K = 2.231 \times 10^{-5}$ $\alpha(K) = .739$

Tm = 100.22 $\alpha(L) = 1.17$

(2) T_1 = 107.64 R = 1.0464 U = .0000021 $\Delta\theta$ = .018

p	C	t_3	θ	X	Y
1.214	.16777	-182.91	17.35	.3792	271.2
.9360	.16755	-182.91	17.35	.4923	272.2
.7505	.16731	-182.91	17.35	.6146	273.3
.6275	.16707	-182.91	17.35	.7360	274.4
.5313	.16672	-182.90	17.34	.8702	275.7
.4863	.16663	-182.92	17.36	.9515	276.6

$K = 2.206 \times 10^{-5}$ $\alpha(K) = .744$

Tm = 98.96 $\alpha(L) = 1.19$

(3) T_1 = 105.13 R = 1.0114 U = .0000017 $\Delta\theta$ = .015

p	C	t_3	θ	X	Y
1.214	.15690	-182.91	14.85	.3791	274.4
.9360	.15664	-182.91	14.85	.4922	275.6
.7505	.15646	-182.91	14.85	.6145	276.6
.6275	.15623	-182.91	14.85	.7358	277.7
.5313	.15589	-182.90	14.84	.8699	279.0
.4863	.15584	-182.92	14.86	.9512	279.8

$K = 2.179 \times 10^{-5}$ $\alpha(K) = .734$

Tm = 97.71 $\alpha(L) = 1.16$

Table 8 (Continued)

(4) T_1 = 102.62 R = .9764 U = .0000013 $\Delta\theta$ = .013

p	C	t_3	θ	X	Y
1.214	.14470	-182.91	12.34	.3790	277.7
.9360	.14450	-182.91	12.34	.4921	278.8
.7505	.14437	-182.91	12.34	.6144	279.5
.6275	.14413	-182.91	12.34	.7357	280.8
.5313	.14381	-182.90	12.33	.8697	282.1
.4863	.14382	-182.92	12.35	.9509	282.7

$K = 2.152 \times 10^{-5}$ $\alpha(K) = .755$

$T_m = 96.45$ $\alpha(L) = 1.21$

Table 9

Argon ---------- Ice bath

(1) T_1 = 294.59 R = 3.53212 θ = 21.39 U = .000173 $\Delta\theta$ = .017

p cm Hg	C (Amps)	X	$\frac{Y}{\theta}$
9.184	.13869	.05004	6.7830
6.657	.13847	.06906	6.8096
5.148	.13822	.08942	6.8402
4.289	.13798	.1074	6.8687
3.599	.13775	.1281	6.8975
3.234	.13758	.1426	6.9186
2.770	.13733	.1667	6.9503
2.535	.13716	.1822	6.9715

K = 4.111×10^{-5} α(K) = .680

Tm = 283.88 α(L) = 1.03

(2) T_1 = 291.87 R = 3.4962 θ = 18.67 U = .000147 $\Delta\theta$ = .014

p	C	X	$\frac{Y}{\theta}$
9.184	.12992	.05003	7.8064
6.657	.12971	.06009	7.8380
5.148	.12949	.08942	7.8711
4.289	.12929	.1074	7.9009
3.599	.12906	.1281	7.9353
3.234	.12891	.1426	7.9584
2.770	.12866	.1666	7.9968
2.535	.12852	.1822	8.0193

K = 4.090×10^{-5} α(K) = .692

Tm = 282.52 α(L) = 1.06

(3) T_1 = 289.14 R = 3.4612 θ = 15.95 U = .000123 $\Delta\theta$ = .012

p	C	X	$\frac{Y}{\theta}$
9.184	.12042	.05003	9.1781
6.657	.12023	.06908	9.2139
5.148	.12003	.08941	9.2525
4.289	.11985	.1074	9.2866
3.599	.11965	.1281	9.3250
3.234	.11950	.1426	9.3538
2.770	.11928	.1666	9.3972
2.535	.11913	.1822	9.4263

K = 4.074×10^{-5} α(K) = .689

Tm = 281.15 α(L) = 1.05

Table 9 (continued)

(4) T_1 = 286.43 R = 3.4262 θ = 13.24 U = .00010 $\Delta\theta$ = .010

p (Cm Hg)	C (Amps)	X	$\frac{Y}{\theta}$
9.184	.11006	.05003	11.099
6.657	.10990	.06908	11.139
5.148	.10971	.08941	11.187
4.289	.10957	.1074	11.223
3.599	.10938	.1281	11.273
3.234	.10926	.1426	11.303
2.770	.10905	.1666	11.356
2.535	.10893	.1822	11.388

K = 4.057×10^{-5} α(K) = .702
Tm = 279.80 α(L) = 1.08

(5) T_1 = 283.71 R = 3.3912 θ = 10.52 U = .000078 $\Delta\theta$ = .008

p	C	X	$\frac{Y}{\theta}$
9.184	.09847	.05003	14.008
6.657	.09835	.06908	14.052
5.148	.09818	.08940	14.112
4.289	.09807	.1074	14.153
3.599	.09791	.1281	14.211
3.234	.09778	.1426	14.255
2.770	.09762	.1666	14.315
2.535	.09751	.1822	14.357

K = 4.044×10^{-5} α(K) = .725
Tm = 278.44 α(L) = 1.14

Table 10

Argon ---------- CO_2 bath

(1) T_1 = 224.51 R = 2.6212 U = .000061 $\Delta\theta$ = .017

p cm.Hg	C (Amps)	t_3	θ	X	Y
2.687	.14743	-72.51	23.82	.1715	192.9
1.871	.14696	-72.53	23.85	.2469	194.8
1.491	.14610	-72.43	23.75	.3103	196.6
1.226	.14566	-72.42	23.73	.3779	197.9
1.031	.14527	-72.45	23.77	.4504	199.7
.8569	.14432	-72.40	23.71	.5432	202.4
.7138	.14356	-72.40	23.72	.6539	205.1

K = 3.131 x 10^{-5} α(K) = .709
Tm = 212.63 α(L) = 1.10

(2) T_1 = 221.85 R = 2.5862 U = .000052 $\Delta\theta$ = .015

p	C	t_3	θ	X	Y
2.687	.13915	-72.45	21.10	.1715	194.4
1.871	.13864	-72.44	21.09	.2468	196.1
1.491	.13822	-72.46	21.12	.3103	197.9
1.226	.13772	-72.43	21.08	.3779	199.4
1.031	.13755	-72.53	21.18	.4503	201.1
.8569	.13640	-72.40	21.05	.5430	203.8
.7138	.13598	-72.48	21.13	.6538	206.4

K = 3.107 x 10^{-5} α(K) = .707
Tm = 211.27 α(L) = 1.10

(3) T_1 = 219.19 R = 2.5512 U = .000045 $\Delta\theta$ = .013

p	C	t_3	θ	X	Y
2.687	.13081	-72.51	18.50	.1715	195.5
1.871	.13015	-72.49	18.48	.2468	197.6
1.491	.12985	-72.51	18.51	.3102	199.2
1.226	.12937	-72.47	18.46	.3778	200.5
1.031	.12886	-72.46	18.46	.4502	202.4
.8569	.12816	-72.46	18.45	.5429	205.1
.7138	.12755	-72.47	18.46	.6536	207.7

K = 3.084 x 10^{-5} α(K) = .711
Tm = 209.94 α(L) = 1.10

Table 10(Continued)

(4) T_1 = 216.52 R = 251.61 U = .000037 $\Delta\theta$ = .011

p cm.Hg	C (Amps)	t_3	θ	X	Y
2.687	.12155	-72.58	15.91	.1715	197.4
1.871	.12092	-72.52	15.85	.2468	199.1
1.491	.12040	-72.47	15.80	.3102	200.5
1.226	.12007	-72.46	15.79	.3778	201.9
1.031	.11952	-72.44	15.77	.4501	203.8
.8569	.11882	-72.41	15.74	.5428	206.3
.7138	.11759	-72.51	15.84	.6534	212.5

K = 3.057×10^{-5} α(K) = .722
Tm = 208.61 α(L) = 1.13

(5) T_1 = 213.86 R = 2.4811 U = .000030 $\Delta\theta$ = .009

p	C	t_3	θ	X	Y
2.687	.11002	-72.26	12.94	.1715	198.6
1.871	.11048	-72.49	13.16	.2468	200.8
1.491	.11014	-72.48	13.15	.3102	202.2
1.226	.10971	-72.45	13.12	.3777	203.7
1.031	.10922	-72.42	13.10	.4500	205.5
.8569	.10885	-72.46	13.13	.5427	207.9
.7138	.10845	-72.51	13.18	.6532	210.8

K = 3.035×10^{-5} α(K) = .707
Tm = 207.31 α(L) = 1.09

Table II

Argon ---------- Liquid Oxygen bath

(1) T_1 = 110.13 R = 1.0812 U = .00000256 $\Delta\theta$ = .015

p(cm Hg)	C (Amps)	t_3	θ	X	Y
1.958	.14697	-182.92	19.86	.2348	390.9
1.065	.14650	-182.93	19.87	.4326	394.4
.8526	.14626	-182.93	19.87	.5408	396.1
.7470	.14598	-182.93	19.87	.6178	397.9
.6519	.14584	-182.93	19.87	.7085	398.9
.5668	.14556	-182.93	19.87	.8157	401.0
.5164	.14536	-182.93	19.87	.8960	402.4
.4659	.14503	-182.94	19.88	.9941	404.9
.4246	.14491	-182.95	19.89	1.092	406.0

K = 1.526 x 10^{-5} α(K) = .712

Tm = 100.19 α(L) = 1.10

(2) T_1 = 107.62 R = 1.0462 U = .00000212 $\Delta\theta$ = .013

p	C	t_3	θ	X	Y
1.958	.13885	-182.92	17.35	.2348	395.4
1.065	.13848	-182.93	17.36	.4325	398.4
.8526	.13827	-182.93	17.36	.5407	400.1
.7470	.13803	-182.93	17.36	.6176	401.8
.6519	.13785	-182.93	17.36	.7083	403.2
.5668	.13758	-182.93	17.36	.8155	405.2
.5164	.13746	-182.93	17.36	.8957	406.2
.4659	.13728	-182.94	17.37	.9938	407.8
.4246	.13706	-182.95	17.38	1.091	409.8

K = 1.508 x 10^{-5} α(K) = .732

Tm = 98.94 α(L) = 1.15

(3) T_1 = 105.11 R = 1.0112 U = .00000172 $\Delta\theta$ = .011

p	C	t_3	θ	X	Y
1.958	.12990	-182.92	14.84	.2348	399.8
1.065	.12956	-182.93	14.85	.4324	402.9
.8526	.12935	-182.93	14.85	.5406	404.6
.7470	.12916	-182.93	14.85	.6175	406.1
.6519	.12898	-182.93	14.85	.7081	407.5
.5668	.12879	-182.93	14.86	.8153	409.1
.5164	.12864	-182.93	14.85	.8954	410.4
.4659	.12849	-182.94	14.86	.9935	411.9
.4246	.12829	-182.95	14.87	1.091	413.9

K = 1.491 x 10^{-5} α(K) = .743

Tm = 97.68 α(L) = 1.18

Table II (Continued)

(4) T_1 = 102.60 R = .9762 U = .0000014 $\Delta\theta$ = .009

p (cm Hg)	C (Amps)	t_3	θ	X	Y
1.958	.11981	-182.92	12.33	.2348	404.5
1.065	.11955	-182.93	12.34	.4324	407.3
.8526	.11939	-182.93	12.34	.5405	408.8
.7470	.11921	-182.93	12.34	.6174	410.3
.6519	.11908	-182.93	12.34	.7080	411.5
.5668	.11891	-182.93	12.34	.8150	413.0
.5164	.11880	-182.93	12.34	.8952	414.1
.4659	.11866	-182.94	12.35	.9931	415.8
.4246	.11849	-182.95	12.36	1.091	417.6

K = 1.473×10^{-5} α(K) = .766
Tm = 96.43 α(L) = 1.24

(5) T_1 = 100.08 R = .9411 U = .0000010 $\Delta\theta$ = .007

p	C	t_3	θ	X	Y
1.958	.10835	-182.92	9.81	.2348	408.2
1.065	.10820	-182.93	9.82	.4323	410.5
.8526	.10804	-182.93	9.82	.5404	413.0
.7470	.10789	-182.93	9.82	.6172	413.5
.6519	.10783	-182.93	9.82	.7078	414.3
.5668	.10767	-182.93	9.82	.8148	415.9
.5164	.10756	-182.93	9.82	.8949	417.0
.4659	.10744	-182.94	9.83	.9928	418.7
.4246	.10727	-182.95	9.84	1.090	420.8

K = 1.460×10^{-5} α(K) = .780
Tm = 95.17 α(L) = 1.28

Table 12

Deuterium ---------- Ice bath

(1) T_1 = 294.58 R = 3.5310 θ = 21.29 U = .000170 $\Delta\theta$ = .109

p (cm Hg)	C(Amps)	$\frac{1}{p}$	$\frac{1}{C^2R}$
3.538	.37415	.2827	2.0284
2.630	.36811	.3802	2.0907
2.113	.36280	.4732	2.1524
1.782	.35769	.5611	2.2144
1.530	.35262	.6537	2.2785
1.359	.34810	.7360	2.3386
1.205	.34381	.8299	2.3969
1.088	.33982	.9192	2.4535

K = 3.303 x 10^{-4} (K) = .350

T_m = 284.00 (L) = .425

(2) T_1 = 291.86 R = 3.4960 θ = 18.58 U = .000146 $\Delta\theta$ = .096

p	C	$\frac{1}{p}$	$\frac{1}{C^2R}$
3.538	.35084	.2827	2.3247
2.630	.34526	.3802	2.4004
2.113	.34035	.4732	2.4702
1.782	.33561	.5611	2.5405
1.530	.33087	.6537	2.6139
1.359	.32666	.7360	2.6817
1.205	.32271	.8299	2.7478
1.088	.31901	.9192	2.8120

K = 3.288 x 10^{-4} (K) = .353

T_m = 282.57 (L) = .429

(3) T_1 = 289.14 R = 3.4610 θ = 15.88 U = .000122 $\Delta\theta$ = .082

p	C	$\frac{1}{p}$	$\frac{1}{C^2R}$
3.538	.32556	.2827	2.7270
2.630	.32043	.3802	2.8150
2.113	.31581	.4732	2.8980
1.782	.31152	.5611	2.9784
1.530	.30715	.6537	3.0638
1.359	.30335	.7360	3.1410
1.205	.29974	.8299	3.2172
1.088	.29633	.9192	3.2916

K = 3.278 x 10^{-4} (K) = .354

T_m = 281.20 (L) = .429

Table 12 (Continued)

(4) T_1 = 286.42 R = 3.4260 θ = 13.17 U = .000099 $\Delta\theta$ = .070

p	C	$\frac{1}{p}$	$\frac{1}{C^2R}$
3.538	.29792	.2827	3.2897
2.630	.29322	.3802	3.3960
2.113	.28911	.4732	3.4933
1.782	.28516	.5611	3.5908
1.530	.28119	.6537	3.6929
1.359	.27766	.7360	3.7874
1.205	.27444	.8299	3.8769
1.088	.27128	.9192	3.9705

$K = 3.265 \times 10^{-4}$ $\alpha(K) = .356$
$T_m = 279.84$ $\alpha(L) = .434$

(5) T_1 = 283.70 R = 3.3910 θ = 10.47 U = .000077 $\Delta\theta$ = .053

p	C	$\frac{1}{p}$	$\frac{1}{C^2R}$
3.538	.26675	.2827	4.1458
2.630	.26258	.3802	4.2784
2.113	.25886	.4732	4.4024
1.782	.25539	.5611	4.5230
1.530	.25182	.6537	4.6522
1.359	.24872	.7360	4.7690
1.205	.24586	.8299	4.8804
1.088	.24300	.9192	4.9960

$K = 3.254 \times 10^{-4}$ $\alpha(K) = .358$
$T_m = 278.57$ $\alpha(L) = .436$

Table 13

Deuterium ---------- CO_2 bath

(1) T_1 = 214.62 R = 2.4911 U = .000042 $\Delta\theta = .299C^2R$

p	C	t_3	$\Delta\theta$	θ	$\frac{1}{p}$	$\frac{\theta}{C^2R}$
4.352	.38023	-77.62	.11	18.96	.2298	52.64
3.077	.37640	-77.64	.11	18.98	.3250	53.78
2.377	.37214	-77.58	.10	18.92	.4207	54.85
1.952	.36833	-77.53	.10	18.88	.5123	55.86
1.670	.36562	-77.58	.10	18.92	.5988	56.83
1.460	.36295	-77.64	.10	18.98	.6851	57.85
1.289	.35956	-77.58	.10	18.92	.7760	58.76
1.157	.35627	-77.53	.10	18.88	.8643	59.72

K = 2.567×10^{-4} $\alpha(K) = .379$

Tm = 205.16 $\alpha(L) = .468$

(2) T_1 = 211.97 R = 2.4561 U = .000035 $\Delta\theta = .299C^2R$

p	C	t_3	$\Delta\theta$	θ	$\frac{1}{p}$	$\frac{\theta}{C^2R}$
4.352	.35404	-77.62	.09	16.32	.2298	53.01
3.077	.35059	-77.64	.09	16.34	.3250	54.14
2.377	.34644	-77.55	.09	16.25	.4207	55.14
1.952	.34389	-77.61	.09	16.31	.5123	56.16
1.670	.34132	-77.66	.09	16.36	.5988	57.18
1.460	.33816	-77.61	.08	16.31	.6851	58.09
1.289	.33445	-77.51	.08	16.22	.7760	59.04
1.157	.33240	-77.58	.08	16.29	.8643	60.03

K = 2.547×10^{-4} $\alpha(K) = .382$

Tm = 203.82 $\alpha(L) = .472$

(3) T_1 = 209.31 R = 2.4211 U = .000029 $\Delta\theta = .299C^2R$

p	C	t_3	$\Delta\theta$	θ	$1/p$	θ/C^2R
4.352	.32556	-77.62	.08	13.68	.2298	53.32
3.077	.32279	-77.69	.08	13.75	.3250	54.53
2.377	.31975	-77.68	.07	13.74	.4207	55.52
1.952	.31608	-77.62	.07	13.68	.5123	56.56
1.670	.31353	-77.59	.07	13.66	.5988	57.39
1.460	.31070	-77.60	.07	13.67	.6851	58.49
1.289	.30855	-77.59	.07	13.65	.7760	59.24
1.157	.30628	-77.61	.07	13.68	.8643	60.23

K = 2.521×10^{-4} $\alpha(K) = .391$

Tm = 202.47 $\alpha(L) = .485$

Tables 13 (Continued)

(4) T_1 = 206.66 R = 2.3861 U = .000023 $\Delta\theta$ = .06

p	C	t_3	θ	$\frac{1}{p}$	$\frac{\theta}{C^2R}$
4.352	.29351	-77.63	11.05	.2298	53.78
3.077	.29024	-77.61	11.04	.3250	54.91
2.377	.28817	-77.65	11.08	.4207	55.91
1.952	.28869	-77.57	11.00	.5123	56.87
1.670	.28352	-77.67	11.09	.5988	57.84
1.460	.28075	-77.62	11.05	.6851	58.73
1.289	.27818	-77.57	11.00	.7760	59.57
1.157	.27651	-77.63	11.06	.8643	60.63

$K = 2.504 \times 10^{-4}$ $\alpha(K) = .386$

Tm = 201.14 $\alpha(L) = .478$

Table 14

Deuterium ---------Liquid Oxygen bath

(1) T_1= 106.54 R = 1.0311 T_3= 90.06 θ=16.36 U=.0000019 Δθ = .12

p(cm Hg)	C (Amps)	$\frac{1}{p}$	$\frac{1}{C^2}$ 1/C²
2.979	.42792	.3357	5.4610
2.321	.42650	.4309	5.4975
1.914	.42565	.5225	5.5194
1.631	.42440	.6132	5.5520
1.418	.42326	.7052	5.5819
1.258	.42221	.7947	5.6098
1.140	.42111	.8776	5.6391
1.029	.42004	.9723	5.6679

K = 1.516 x 10^{-4} α(K) = .479
T_m = 98.36 α(L) = .630

(2) T_1= 104.03 R = .9961 T_3= 90.06 θ = 13.87 U = .0000016 Δθ =.097

p	C	$\frac{1}{p}$	$\frac{1}{C^2}$ 1/C²
2.979	.39904	.3357	6.2801
2.321	.39774	.4309	6.3212
1.914	.39705	.5225	6.3432
1.631	.39590	.6132	6.3801
1.418	.39497	.7052	6.4102
1.258	.39391	.7947	6.4447
1.140	.39297	.8776	6.4756
1.029	.39204	.9723	6.5064

K = 1.500 x 10^{-4} α(K) = .491
T_m = 97.09 α (L) = .650

(3) T_1= 101.52 R = .9611 T_3= 90.06 θ = 11.38 U = .0000012 Δθ = .079

p	C	$\frac{1}{p}$	$\frac{1}{C^2}$ 1/C²
2.979	.36635	.3357	7.4509
2.321	.36515	.4309	7.4999
1.914	.36449	.5225	7.5271
1.631	.36340	.6132	7.5723
1.418	.36278	.7052	7.5982
1.258	.36181	.7947	7.6390
1.140	.36085	.8776	7.6797
1.029	.36007	.9723	7.7131

K = 1.485 x 10^{-4} α(K) = .495
T_m = 95.83 α(L) = .658

Table 14 (Continued)

(4) T_1= 99.02 R = .9260 T_3= 90.06 θ = 8.90 U = .00000090
$\Delta\theta$ = .062

p	C	$\frac{1}{p}$	$\frac{1}{C^2}$
2.979	.32834	.3357	9.2758
2.321	.32754	.4309	9.3212
1.914	.32672	.5225	9.3680
1.631	.32616	.6132	9.4002
1.418	.32540	.7054	9.4442
1.258	.32463	.7947	9.4890
1.140	.32371	.8776	9.5431
1.029	.32316	.9723	9.5756

$K = 1.468 \times 10^{-4}$
Tm = 94.57

$\alpha(K) = .513$
$\alpha(L) = .690$

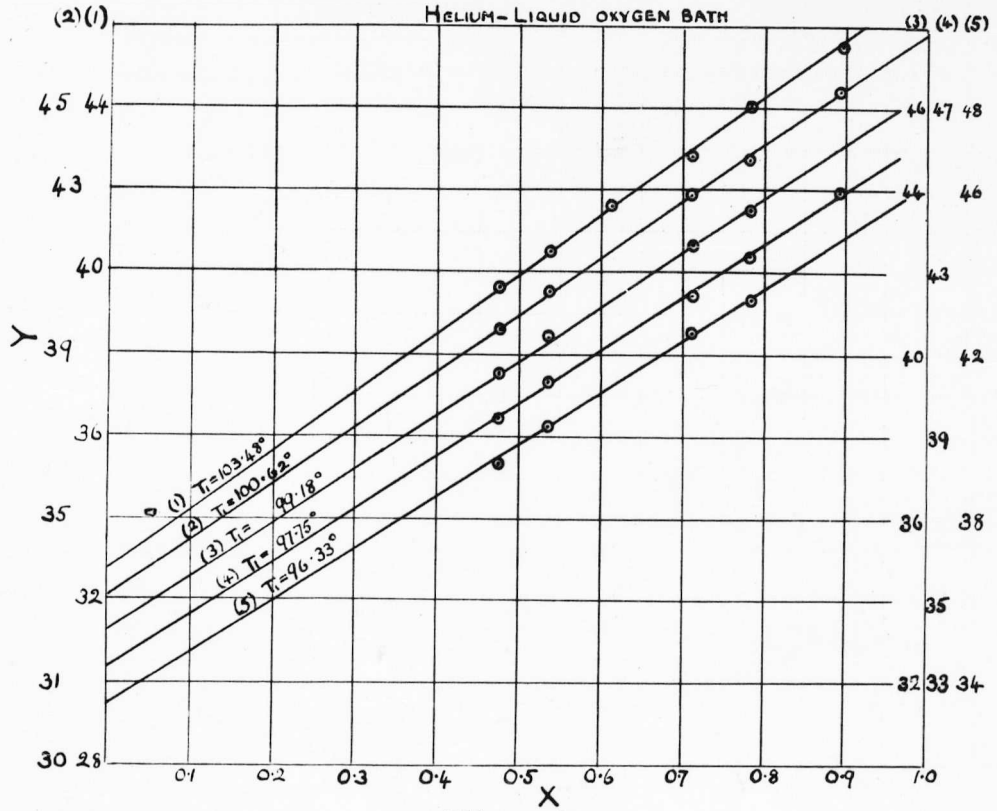

HELIUM – LIQUID OXYGEN BATH
(2) (1)
(3) (4) (5)
45 44
43
40
39
36
35
32
31
30 28
46 47 48
44 46
43
40 42
39
36 38
35
32 33 34
Y
X
0·1 0·2 0·3 0·4 0·5 0·6 0·7 0·8 0·9 1·0
(1) T₁=103·48°
(2) T₁=100·62°
(3) T₁= 99·18°
(4) T₁= 97·75°
(5) T₁=96·33°

Fig. 5

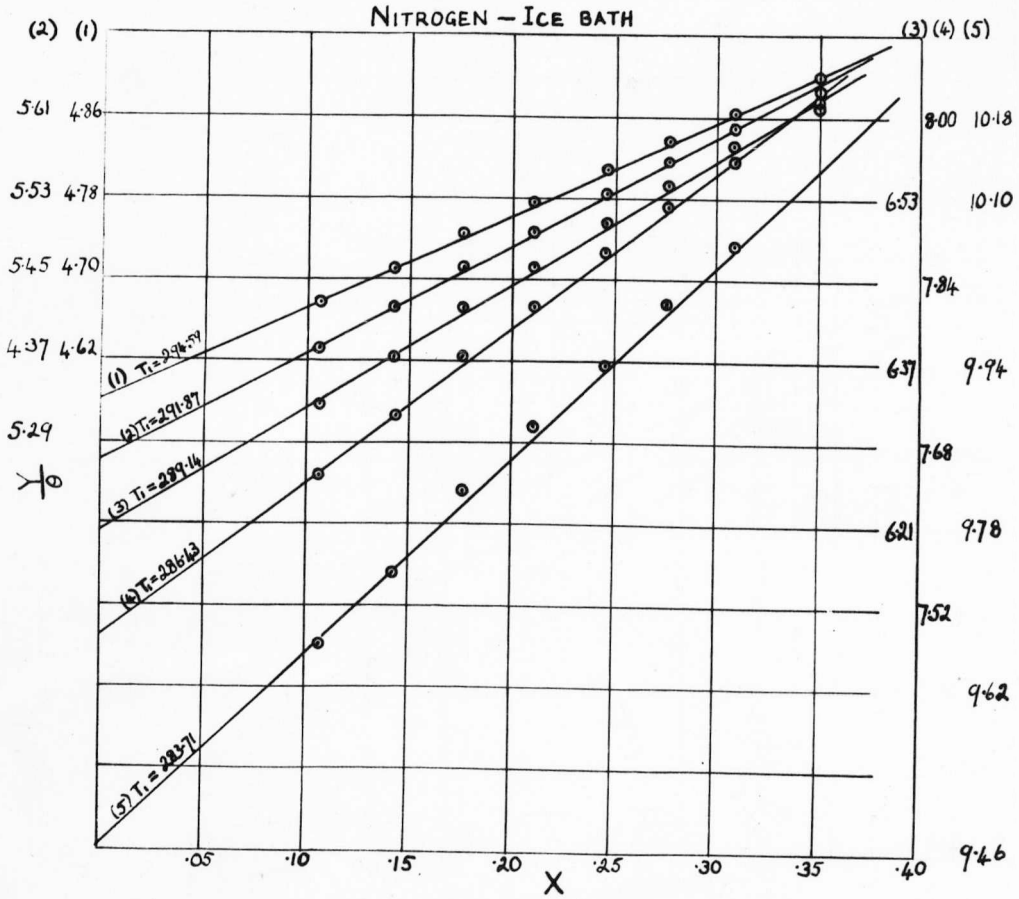

NITROGEN – ICE BATH
(2) (1)
(3) (4) (5)
5·61 4·86
5·53 4·78
5·45 4·70
4·37 4·62
5·29
8·00 10·18
6·53 10·10
7·84
6·37 9·94
7·68
6·21 9·78
7·52
9·62
9·46
θ
X
·05 ·10 ·15 ·20 ·25 ·30 ·35 ·40
(1) T₁=294·59
(2) T₁=291·87
(3) T₁=289·14
(4) T₁=286·43
(5) T₁=283·71

Fig. 6

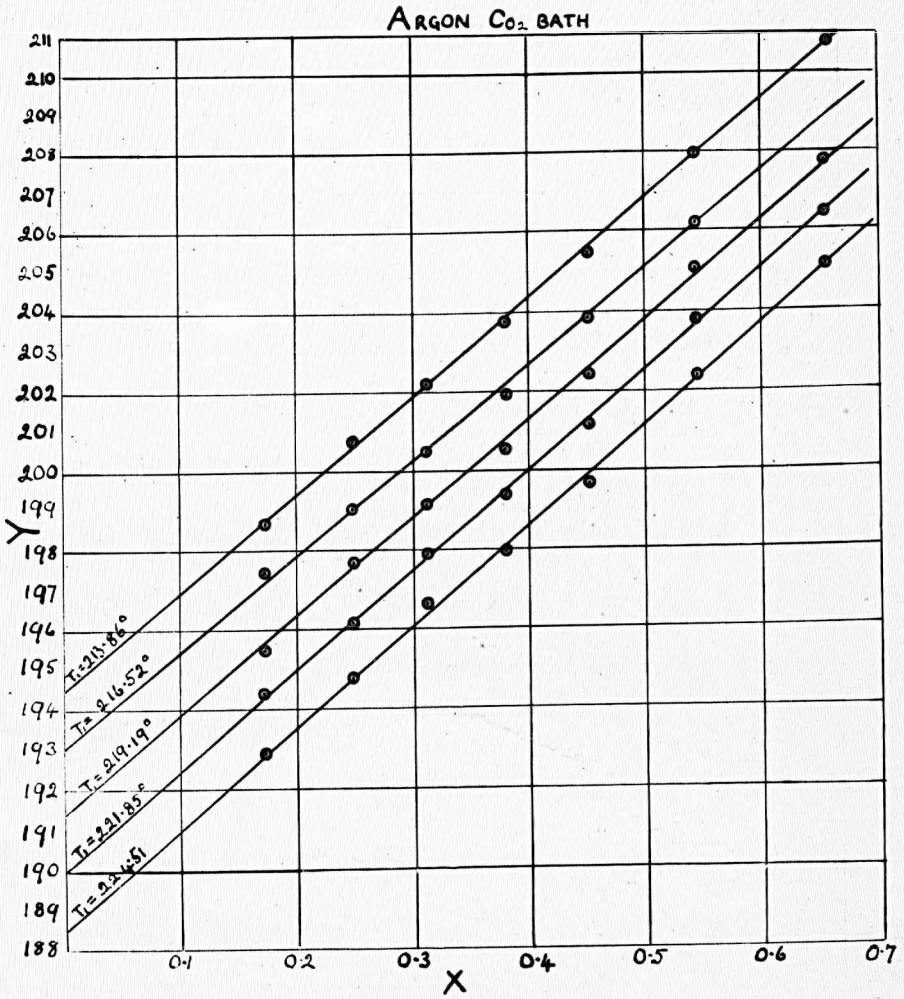

ARGON CO_2 BATH
Y
X
T=215·86°
T=216·52°
T=219·19°
T=221·85°
T=223·51

Fig. 7

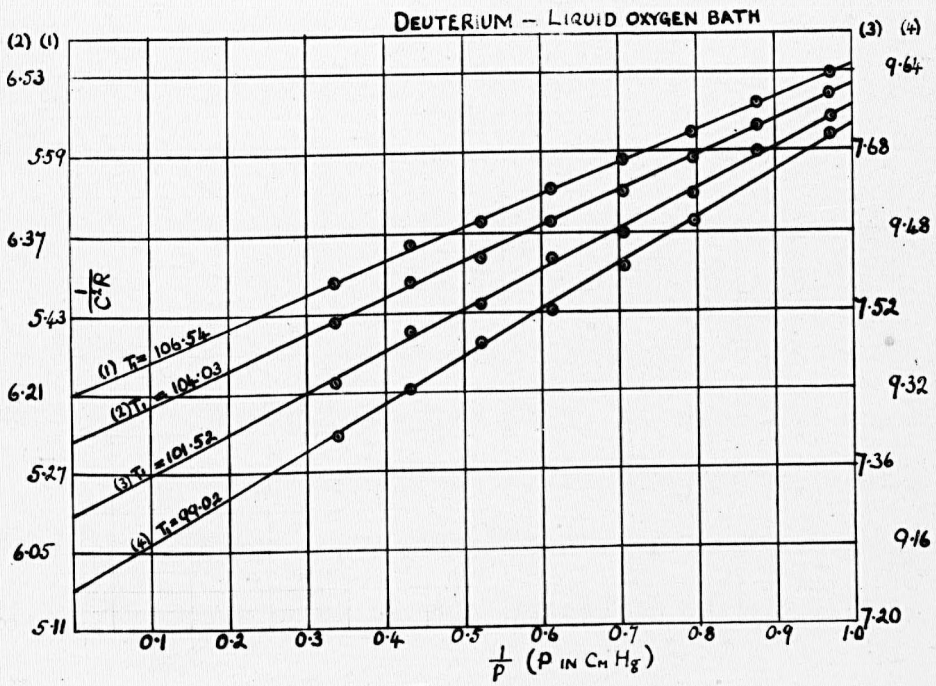

DEUTERIUM – LIQUID OXYGEN BATH
(2) (1)
(3) (4)
$\frac{1}{CR}$
$\frac{1}{P}$ (P IN CM H_g)
(1) T= 106·54
(2) T= 104·03
(3) T= 101·52
(4) T= 99·02

Fig. 8

In recent years, many attempts have been made to predict from theoretical considerations, the dependence on temperature of the Thermal Conductivity of Gases. In 1912 Professor Chapman[16] applied Maxwell's Kinetic Theory of Gases in a more generalized form to the solution of the problem and making use of the Hypothesis that forces of repulsion exist between molecules varying inversely as the nth power of the distance of seperation, was able to shew that for gases in the Monatomic state the Thermal Conductivity K was related to the Viscosity η and the Specific Heat at constant volume C_v in the manner expressed by the relation

$$K = f.C_v\eta \qquad (55)$$

where f is a numerical factor depending on the law of force operating in molecular collision and which for Monatomic Gases has the exact value 2.5 for n = 5

Since f and C_v for Monatomic Gases are constants and independent of temperature, the variation of K in respect of temperature will be parallel with that of η. These conclusions in relation to Monatomic Gases are strongly supported by the results of the present investigation in regard to Helium and Argon.

If Chapman's formula is applicable to Polyatomic Gases then apart from possible changes in f, it would be expected that K will vary more rapidly with the temperature than η on account of the influence of the Rotational and Vibrational Energies of the molecules on the Specific Heat C_v. This again

has received support from the present investigations and also from previous work on the subject by Gregory[5] and Archer.[17]

In general the above arguments in relation to the formula $K = f.C_v\eta$ suggest that the dependence of K on the temperature is the same as that of the product $C_v\eta$. For most Gases the effect of temperature on the Viscosity is satisfactorily represented by an equation of the form

$$\eta = g.T^{n} \qquad (56)$$

and if it is assumed that the quantity C_v is related in a similar manner to the temperature, then K may also be expressed in the form,

$$K = g' T^{n'} \qquad (57)$$

The truth of such reasoning may be tested in the present instance from the graphical interpretation of the experimental results for K in terms of the average gas temperature T_m.

In Fig (9) the results for all the gases tested are shewn to satisfy a linear relation between Log K and Log T in a very satisfactory manner and the corresponding values of g' and n' in relation to the gases are tabulated below.

Argon	$K = 1.97 \times 10^{-7} T^{.946}$	Cals	cm^{-1}	deg^{-1}	sec^{-1}
Deuterium	$K = 5.18 \times 10^{-6} T^{.735}$	"	"	"	"
Helium	$K = 8.94 \times 10^{-6} T^{.657}$	"	"	"	"
Nitrogen	$K = 2.58 \times 10^{-7} T^{.966}$	"	"	"	"

The author has also calculated the value of the factor f at various temperatures for each gas from the experimental results for K in conjunction with the most accurate experimental data available for η and C_v The results tabulated in Tables (15), (16), (17), and (17), substantiate the truth of Chapman's calculations in respect of the Monatomic Gases Helium and Argon and while the results shew deviations in relation to the constancy of f with temperature, it is pointed out that large errors are possible in the experimentally determined values of η and C_v and particulary so at the low temperatures employed in the present investigation. For all gases a marked change in the constancy of f might reasonably be expected to take place at temperatures in the neighbourhood of the condensing points of the gas and this conclusion would seem to have received some degree of substantiation from the experiments of Gregory and Dock[5] in relation to H_2 below 0.deg.C.

Calculations of the factor f for comparison with the above have also been made from relations of semi-empirical origin due to Eucken[2] and Jeans[18] viz

$$\text{Eucken} \qquad f = 2.5\,\frac{C_t}{C_v} + \frac{C_r}{C_v} \qquad (58)$$

$$\text{Jeans} \qquad f = \frac{9\gamma - 5}{4} \qquad (59)$$

In the above relations C_t and C_r represent the contribution of translational and rotational energies to the Specific Heat at constant volume and γ the ratio of the Specific heats of the gas.

Both equations give results which are in reasonable agreement with the results calculated from the relation $K = f(C_v)$ and are recorded in the Tables (15) to (17) for comparison.

Tables (15) Helium

Temp.Abs.	$\kappa \times 10^4$	μ	$\eta \times 10^7$	β	f	f Eucken	f Jeans
281.85	3.660		1921		2.53		
280.28	3.642		1913		2.53	2.50	2.48
278.71	3.627	.0030	1906	1.52	2.53		
277.15	3.605		1898		2.52		
273.18	3.566		1879		2.52		
232.61	3.177		1702		2.48		
231.07	3.171	.0012	1695	1.52	2.48		2.48
229.51	3.166		1688		2.49		
96.89	1.798		964		2.52		
95.45	1.782		955		2.52		
94.72	1.773	.0058	950	1.49	2.52		2.51
94.00	1.768		945		2.53		
93.29	1.761		941		2.53		

$$K = 8.94 \times 10^{-6} T^{.657}$$

Table (16) Nitrogen

Temp.Abs.	K x10^4	μ	η x10^7	β	f	f Euckem	f Jeans
283.40	.6020		1706	2.489	2.00		
282.54	.5995	.0030	1701		2.00		
281.17	.5970		1695		2.00	1.90	1.91
279.81	.5949		1689		2.00		
278.45	.5929		1682		2.00		
273.18	.5833		1657		2.00		
219.81	.4775		1389		1.95		
218.47	.4744		1382		1.95		
217.13	.4718	.0044	1375	2.489	1.95	1.90	1.91
215.78	.4668		1368		1.94		
214.44	.4662		1361		1.94		
100.22	.2231		682		1.88		
98.96	.2206	.0105	673	2.454	1.88	1.92	2.05
97.71	.2179		664		1.89		
96.45	.2152		655		1.89		

$$K = 2.58 \times 10^{-7} T^{.966}$$

Table (17) Argon

Temp.Abs.	K x10^4	μ	η x10^7	β	f	f Eucken	f Jeans
283.88	.4111		2171		2.52		
282.52	.4090		2169		2.51		
281.15	.4074	.0031	2154	1.513	2.51	2.50	2.51
279.80	.4057		2145		2.51		
278.44	.4044		2137		2.52		
273.18	.3976		2102		2.51		
212.63	.3131		1709		2.43		
211.27	.3107		1700		2.43		
209.94	.3084	.0059	1690	1.513	2.43		2.46
208.61	.3057		1680		2.42		
207.31	.3035		1669		2.42		
100.19	.1526		828		2.45		
98.94	.1508		817		2.45		
97.68	.1491	.0096	805	1.516	2.46		2.71
96.43	.1473		794		2.46		
95.17	.1460		783		2.47		

$$K = 1.97 \times 10^{-7} T^{.946}$$

Table (18) Deuterium

Temp.Abs.	K x 10^4	μ
284.00	3.303	
282.57	3.288	
281.20	3.278	
279.84	3.265	.0032
278.37	3.254	
273.18	3.196	
205.16	2.567	
203.82	2.547	
202.47	2.521	.0066
201.14	2.504	
98.36	1.516	
97.09	1.500	
95.83	1.485	.0086
94.37	1.468	

$$K = 5.18 \times 10^{-6} T^{.735}$$

The temperature coefficient of Thermal Conductivity

The results of the present investigation has confirmed in a very satisfactory manner that the variation with temperature of the Thermal Conductivity may be expressed between 0.deg.C and -183 deg.C by a relation of the form

$$K = g.T^{n'} \qquad (60)$$

The temperature coefficient of thermal conductivity, μ = dK/K.dT at any temperature between these limits may then be calculated from the Equation,

$$\mu = dK/K.dT = n'/T \qquad (61)$$

where the value of n' for each of the gases tested has been previously recorded in the paper.

A value of the temperature coefficient corresponding to each temperature of the thermostat may also be obtained more directly from the formula,

$$K = K_0(1 + \mu\theta) \qquad (62)$$

in which K represents the thermal conductivity of the gas at a mean temperature θ between that of the wire and the bath and in which the wire temperature is sufficiently close in magnitude to that of the bath to justify the linear form for K.

An example of this procedure in relation to Argon is graphically represented in Fig (10).

Since K satisfies a linear form with θ (the mean gas

temperature), the intercept K_o will represent the thermal conductivity of the gas corresponding to the temperature of the bath, and this aspect has been carried out at each of the fixed thermostat temperatures, 0.deg.C , -78.deg.C , and -183.deg.C respectively, and the results recorded in Table (19)

Table (19)

	He	N_2	Ar	D_2
$K_o \times 10^5$ Cal. cm^{-1} deg^{-1} sec^{-1}	35.66	5.833	3.976	31.96
$K_{-78} \times 10^5$ Cal. cm^{-1} deg^{-1} sec^{-1}	30.41	4.254	2.815	24.01
$K_{-183} \times 10^5$ Cal. cm^{-1} deg^{-1} sec^{-1}	17.29	2.016	1.388	14.14

Section 2

The Heat Conduction through Gases at low pressure

In the preceding section the author has discussed in detail the manner in which it has been found possible to calculate the coefficient of accommodation from aspects of the Heat transport through gases in terms of the Theory of the Temperature Drop effect recently developed by Dr Gregory.[6] At the same time the effect of temperature on both the Heat Conduction and the coefficient of accommodation has been investigated at temperatures between 0.deg.C and -183 deg.C. It remains to compare the results previously obtained in respect of the coefficient of accommodation α with those obtained from aspects of the Heat transport when the gases in the tubes are strongly rarefied. Such measurements in the present instance have been carried out with the same apparatus and under the same conditions of temperature as the experiments described in Section (1) of the paper.

The experimental procedure although similar in general detail to other workers on the subject at low pressure, differs in that the theoretical basis for the calculation of α in terms of the Molecular Heat transport requires careful modification in the present instance both from the point of view of the Equation deduced by Knudsen, and also in regard to other sources of error peculiar to the present investigation.

In the first place the form of the Hot Wire system used by the author to investigate the Temperature Drop effect

was designed primarily to fulfil in practice the criterion of a uniform heated wire, that such a criterion is possible was due to the magnitude of the ratio of the Heat losses through the gas to the corresponding heat losses by conduction through the ends of the wires. This ratio is very much less at low pressure and for this reason the distribution of temperature along the electrically heated wires is not the same as in the case when the gas is not rarefied.

For a uniformly heated wire of length L and temperature T_1(abs) the rate of Heat Transport Q through a rarefied gas may be represented (after Knudsen) by the relation,

$$Q = C^2.R = 2.\pi.r_1 L.p.\sqrt{\frac{R'}{2.\pi.M.T_2}}\,\alpha(\beta + 1/2)(T_1-T) \qquad (63)$$

where C denotes the current strength, T_2 the temperature (abs) of the internal surface of the tube, p the gas pressure, M the molecular weight, and $\beta R'$ the molecular heat of the gas at constant volume.

As applied to the present double system of wires and tubes, and for a condition of balance in the associated Bridge arrangement, R will correspond to the difference of Resistances between the long and short wires, C the balancing current and T_1 an average temperature calculated from the value of R.

Equation (63) was used by the author to interpret the experimentally determined Heat losses through rarefied gases in order to obtain values of α corresponding to various

temperatures but the results reexamined from a more rigid aspect in regard to the compensation of the double wire system were found to be incorrect to an amount varying between 5 and 8 percent, and for this reason an attempt was made to modify the theoretical basis on which the calculations of α depend.

The Equation expressing the thermal equilibrium of an element δx of either the long or short wires is given as in Section (1) by,

$$\frac{d^2\theta}{dx^2} - p.\left(\theta - \frac{S}{P}\right) = 0 \qquad (27)$$

where S has the same value as before and P now takes the form,

$$P = \frac{1}{K_m \pi . r_1^2 . J}\left(B + Z - \frac{C^2 . \rho_o\, a}{\pi . r_1^2}\right) \qquad (28)$$

$$\text{and } B = 2.\pi.r_1.p.\sqrt{\frac{R'}{2.\pi.M.T_2}}\,\alpha\left(\beta + 1/2\right) \qquad (25)$$

The solution of (27) is of the same form viz

$$\theta = \frac{S}{P}\left(1 - \frac{\cosh \sqrt{P}.\, x}{\cosh \sqrt{P}.L/2}\right) \qquad (31)$$

When the long and short wires are in series, consistent with a condition of Bridge balance, and if R_L and R_S denote their corresponding resistances, we have

$$R = R_L - R_S = \frac{\rho_o}{\pi . r_1^2}\left(1 + a.\frac{S}{P}\right)\left(L_1 - L_2\right)$$

$$+ \frac{2.\rho_o\, a.S.}{\pi . r_1^2\, P^{3/2}}\left\{\tanh \sqrt{P}.\, L_1/2 - \tanh \sqrt{P}.L_2/2\right\} \qquad (33)$$

Since $R_o = \frac{\rho_o L}{\pi . r_1^2}$, where R_o denotes the resistance of the wire of length $L = (L_1 - L_2)$ at the temperature of the surface of the tube, (33) can be written in the form,

$$R = R_o\left(1 + \frac{a.S.}{P}\right) - \frac{2.a.R_o.S}{L} F(P) \qquad (64)$$

where F (P) represents the term,

$$\frac{1}{P^{3/2}} \left(\tanh \sqrt{P}.L_1/2 - \tanh \sqrt{P}.L_2/2\right)$$

Writing D for $(R - R_o)$ and G for $R_o a = dR/dT$ we have from (64)

$$\frac{D}{G.S.} = \frac{1}{P} - \frac{2}{L} F(P) \qquad (65)$$

Substituting numerical values for r_1 and L in the expression for S , we obtain

$$\frac{1}{S} = \frac{K_m}{C^2.R_o} \times 10^{\bar{3}.44194}$$

and

$$\frac{2}{L} = .1348$$

Equation (65) now takes the form,

$$\frac{K_m}{C^2.R_o} \frac{D}{G} \times 10^{\bar{3}.44194} = \frac{1}{P} - .1348\, F(P) \qquad (66)$$

where P is now written in the form

$$P = \frac{B + Z}{\pi . r_1^2 . K_m J} \longrightarrow \phi \qquad (67)$$

and $\phi = \frac{C^2.\rho_o a}{(\pi . r_1^2)^2 K_m J} \Longrightarrow \frac{C^2 . G}{K_m} 10^{2.55806}$ (68)

Consider now the experimental procedure at low pressure, if observations are made of a series of values of the balancing current C for various pressures p in which the wire and bath temperatures T_1 and T_2 are maintained at a constant value, then D and $\mathfrak{G}$ will be constant for all related variations of C and p, and for each such values of C and p, a corresponding value of P may be found from (66) by the method of successive approximations.

$$\text{Since } P + \phi = \frac{B + Z}{\pi . r_1^2 . K_m J}$$

$$= \frac{B_1 p}{\pi . r_1^2 . K_m J} + \frac{Z}{\pi . r_1^2 . K_m J} \qquad (69)$$

therefore $(P + \phi)$ forms a linear relation with p from which a value of B_1 may be found and hence α since

$$B_1 = 2 . \pi . r_1 . \sqrt{\frac{R'}{2 . \pi . M T_2}}\, \alpha (\beta + 1/2) \qquad (70)$$

Equation (69) represents a form of the Knudsen Heat Transport Law modified in respect of Compensation.

The procedure outlined above in order to determine P is extremely laborious and to facilitate the process of calculation a set of tables are drawn up giving the corresponding values of 1/P and .1348 F(P) along with the related data for $R_0 G$ and a at various temperatures considered. Specimen Tables of such data for the purpose of illustrating these arguments are given below.

Table (20)

t.deg.C	R_0 Ohms	dR/dT	a
0	3.2552	.01293	.003971
-55	2.5379	.01316	.005185
-74	2.2866	.01326	.005798
-75	2.2736	.01325	.005832
-78	2.2340	.01328	.005943
-182.78	.8058	.01391	0.01726
-182.96	.8032	.01392	0.01733
-182.98	.8030	.01392	0.01733

Table 21

1/P	.1348 F(P)	1/P	.1348 F(P)
40340	40310	24.00	9.031
10090	10049	22.87	8.330
2522	4958	21.82	7.693
1121	1084.5	20.84	7.114
630.4	595.0	19.92	6.584
403.4	369.2	19.07	6.101
280.2	247.1	18.26	5.658
205.8	174.1	17.51	5.254
157.6	127.2	16.80	4.871
124.5	95.57	16.14	4.542
100.9	73.37	15.51	4.229
83.36	58.31	14.92	3.941
70.04	45.38	14.36	3.675
59.68	36.38	13.84	3.431
44.83	24.10	13.34	3.205
39.40	19.87	12.86	2.996
34.90	16.50	12.42	2.802
32.93	15.07	11.99	2.624
31.13	13.79	11.59	2.459
29.47	12.63	11.21	2.305
27.94	11.593	10.84	2.163
26.53	9.942	10.50	2.030
25.22	9.802	10.16	1.907

Table (21) continued

1/P	.1348 F(P)	1/P	.1348 F(P)
9.850	1.793	5.330	.4944
9.549	1.685	5.210	.4698
9.262	1.587	5.093	.4465
8.988	1.494	4.981	.4249
8.725	1.407	4.872	.4035
8.474	1.327	4.767	.3840
8.233	1.251	4.665	.3655
8.003	1.1804	4.566	.3478
7.783	1.1144	4.470	.3312
7.571	1.0525	4.378	.3154
7.368	.9945	4.288	.3005
7.172	.9402	4.200	.2864
6.985	.8892	4.116	.2729
6.805	.8413	4.034	.2602
6.631	.7964	3.955	.2482
6.464	.7542	3.878	.2367
6.304	.7136	3.803	.2256
6.149	.6771	3.730	.2156
6.000	.6420	3.659	.2058
5.856	.6093	3.591	.1965
5.718	.5777	3.524	.1877
5.584	.5483	3.459	.1792
5.455	.5206	3.396	.1712

Table (21) continued

1/P	.1348 F(P)	1/P	.1348 F(P)
3.334	.1637	2.4244	.07168
3.274	.1564	2.3873	.06876
3.216	.1495	2.3509	.06595
3.159	.1431	2.3155	.06328
3.104	.1369	2.2808	.06071
3.051	.1309	2.2469	.05826
2.998	.1253	2.2137	.05592
2.947	.11983	2.1812	.05368
2.8975	.11476	2.1495	.05154
2.8489	.10981	2.1185	.04948
2.8017	.10516	2.0881	.04752
2.7555	.10069	2.0584	.04564
2.7106	.096463		
2.6666	.09239		
2.6239	.08852		
2.5820	.08486		
2.5412	.08133		
2.5014	.07797		
2.4624	.07476		

Correction for the effect of Thermal Transpiration

The effect of thermal transpiration, due to the difference of temperature existing between the experimental tubes and the Mc Leod Gauge has important consequences in relation to the low temperatures and pressures employed in the experiments.

In the case, where the bath temperature is that corresponding to Liquid Oxygen, the tube connecting the Hot Wire system with the gauges will be associated with a large temperature gradient at the point of entry to the bath and for this reason a difference of pressure will be set up, which, according to Knudsen, when the gases are strongly rarefied, may be of the order of as much as 70 percent.

The formula connecting the pressure p_1 in the tube system with that indicated by the Mc Leod gauge p_2 is given by the relation,

$$p_1/p_2 = \sqrt{T_1}/\sqrt{T_2} \qquad (71)$$

where T_1 and T_2 are the temperatures of the bath and that of the gauge. The formula has been shewn to be true when the gases in the system are very strongly rarefied, and it was applied by the author to correct the pressures observed by the Mc Leod gauges, and found, as associated with the procedure for the calculation of α to give very unsatisfactory results, ie. ($\alpha > 1$).

A more general expression and one more strictly applicable to the present investigation was also deduced by Knudsen[19] for the case when the pressures in the tubes are such

that the ratio r/λ is not negligibly small, where r is the radius of the connecting tube, and λ the mean free path.

If p is the pressure of the gas at a point in the connecting tube and if T and λ are the related temperature and mean free path, then we have from Knudsen,

$$\frac{d.p}{p} = \frac{dT}{2.T} \cdot \frac{1}{1 + \frac{2.i\,r}{\lambda}} \qquad (72)$$

where i is a constant theoretically equal to unity, but experimentally has been found to depend on the nature of the gas and of a magnitude greater than 1. For H_2 Knudsen[20] found $i = 2.46$.

$$\text{Since } \lambda \propto \frac{\eta}{v.\rho} \propto \frac{\eta\sqrt{T}}{p}$$

where η represents the viscosity of the gas at a temperature T, v the mean velocity of agitation, and ρ the density at a pressure p.

Since also, it is known that η may be expressed in the form $\eta = \beta T^{n}$, where n is a constant for a particular gas, therefore $\lambda p = \beta_1 T^{(n + 1/2)} = \beta_1 T^{y}$ say. (73)

Eliminating T by means of (72) and (73) we have

$$\frac{dp}{p} = \frac{d\lambda}{2.y\,2i\,r + \lambda(2y-1)} \qquad (74)$$

Intergrating (74) between p_1 and p_2 for p and between λ_1 and λ_2 for λ we obtain finally

$$2.y \text{ Log } \frac{p_2}{p_1} = \text{Log } \frac{(2.y - 1)\lambda_2 p_2 + 4.y.i.r.p_2}{(2.y - 1)\lambda_1 p_1 + 4.y.i.r.p_1} \quad (75)$$

If p_2 represents the pressure as determined from the Mc Leod gauge, then p_1 the pressure of the gas in the experimental system is calculated from (75).

For definite temperatures of the bath and the surroundings, the values of the terms $\lambda_1 p_1$ and $\lambda_2 p_2$ are constant and may be calculated from (48). A difficulty however arises in regard to the value of i and the author has adopted the procedure of calculating p_2 from (75) in terms of three different values of i in turn, viz i = 1, 2, 3

In this manner substituting r = 0.24 cms in (75) we have for Helium,

(1) Liquid Oxygen Bath

$$2.294 \text{ Log } \frac{p_2}{p_1} = \text{Log } \frac{.001879 + 1.1011 \text{ i. } p_2}{.0004858 + 1.1011 \text{ i. } p_1} \quad (76)$$

(2) $C.O_2$ Bath.

$$2.294 \text{ Log } \frac{p_2}{p_1} = \text{Log } \frac{.001894 + 1.1011 \text{ i.} p_2}{.001205 + 1.1011 \text{ i.} p_1} \quad (77)$$

and a similar procedure was followed in relation to the gases Nitrogen and Argon.

For Deuterium since the variation of η with temperature is not known over the range considered, the author has made use of the data contained in the present investigation in regard to the dependence on temperature of the Thermal

Conductivity of Deuterium between 0.deg.C and -183 deg.C. According to Chapman such procedure is permissible in that the value of n' in the relation $K = \gamma' T^{n'}$ would be the same as for the variation of the Viscosity over the same temperature range. For example Omnes and Weber[21] found n = .647 in relation to the Viscosity of Helium as compared with the Authors result $n' = .657$ for the Thermal Conductivity.

Experimental Procedure at Low Pressure

The experimental procedure relevant to the investigations at low pressure are in the main identical with the procedure at higher pressure. The adjustments necessary in order to maintain the temperature of the element of wire at a constant value for each of a series of pressures, requires a much longer period of time in order to attain thermal equilibrium of the system, and the measurement of the corresponding pressures effected by the Mc Leod gauges demands much more care and skill than in the Temperature Drop investigation. Great care is also needed in order to eliminate the effect of residual traces of vapours which would have a marked influence at low pressure, and the use of Liquid Oxygen traps in order to prevent the diffusion of Mercury Vapour into the experimental system of tubes. In the earlier period of the research the author found that a large amount of Mercury had distilled over into the experimental tubes and caused the Fundamental Interval of the centrally disposed platinum wires to change from time to time, eventually the use of a U tube filled with tin ribbon and immersed in Liquid Oxygen obviated the effect.

In all experiments it was found necessary to promote as much turbulence as possible in the thermostatic fluid, since otherwise the wall of the tube would be heated to a higher temperature than the fluid, an effect which is shewn up

by the very sensitive bridge system associated with the centrally disposed wires. It has been found possible in the present instance to detect changes in temperature of the tube wall to something like 1/1000 deg.C.

The experimental results at low pressure are contained in the Tables (22) to (33). In columm (4) values of p_2, measured by the Mc Leod gauges are recorded and the corresponding values of the current required to balance the bridge system at these pressures are shewn in Columm (1) . Columms (5), (6) and (7) refer to the pressures p_1' , p_1'' and p_1''' which represent the values of p_2 corrected for the effect of Thermal Transpiration in terms of Equation (72) in which the constant i takes the value 1 , 2, and 3 successively.

Values of the quantities P and $(P + \phi)$ as calculated from Equation (66) are tabulated in Columms (2) and (3).

The numerical values of the terms R_0 and $D/G = \frac{(R - R_0)}{a.R_0}$ are shewn at the head of each Table, the latter quantity representing a measure of the average temperature of the wire corresponding to each temperature of the bath.

In Figs (11) to (16) the quantity $(P + \phi)$ has been plotted against each of the related terms p_2 , p_1' , p_1'', and p_1''' in turn and the values of α calculated from the slopes of such lines are also shewn in the Tables.

In the particular case of the $C.O_2$ bath in which the temperature was found to vary during the course of the experiments the values of D instead of P are shewn in Columm (2)

Table 22

Helium ---------- Ice bath Low Pressure

R_o= 3.2561 D = .2218 D/G = 17.17

C x 100 Amps	P	P + φ	p_2 x1000 Cm Hg	p'x1000 Cm Hg	p''x1000 Cm Hg	p'''x1000 Cm Hg
2.5238	.2443	.2621	2.683	2.630	2.648	2.653
2.3963	.2184	.2345	2.372	2.324	2.340	2.347
2.2804	.1939	.2084	2.109	2.064	2.077	2.084
2.1498	.1698	.1827	1.805	1.764	1.775	1.783
2.0185	.1465	.1579	1.544	1.508	1.517	1.523
1.8858	.1243	.1342	1.291	1.259	1.266	1.271
1.8325	.1158	.1252	1.207	1.176	1.183	1.188
1.7161	.09813	.1064	0.999	0.9722	0.9777	0.9812
1.6221	.08467	.09203	0.8384	0.8108	0.8161	0.8177
		α	0.409	0.418	0.416	0.413

$\alpha\left(p_2\sqrt{\frac{T_2}{T_n}}\right) = .424$

Table 23

Helium ---------- CO_2 bath Low Pressure

R = 2.4603 Ohms

C X 100 Amps	D	P + φ	p_2 x1000 Cm Hg	p' x 1000 Cm Hg	p''x 1000 Cm Hg	p'''x1000 Cm Hg
2.6840	.1752	.2731	2.771	2.521	2.605	2.648
2.5456	.1748	.2436	2.451	2.216	2.292	2.331
2.3797	.1767	.2069	2.072	1.858	1.922	1.958
2.2107	.1748	.1771	1.746	1.557	1.611	1.642
2.0794	.1735	.1549	1.522	1.344	1.391	1.418
1.9843	.1796	.1329	1.275	1.116	1.154	1.178
1.9149	.1778	.1233	1.135	.990	1.023	1.045
1.8080	.1750	.1091	.958	.829	.855	.873
1.17150	.1782	.09310	.825	.710	.732	.746
		α	.351	.374	.363	.361

$\alpha\left(p_2\sqrt{\frac{T_2}{T_n}}\right) = .428$

Table 24

Helium -------- Liquid Oxygen bath --Low Pressure

R_0 = .8059 Ohms D = .2409 D/G = 17.09

C x100 Amps	P	P + ϕ	p_2 x1000 Cm Hg	p_1' x1000 Cm Hg	p_1'' x1000 Cm Hg	p_1''' x1000 Cm Hg
4.8705	.2037	.2701	2.567	2.018	2.213	2.306
4.5945	.1782	.2372	2.302	1.780	1.959	2.048
4.3129	.1537	.2058	2.006	1.518	1.678	1.759
4.0068	.1289	.1738	1.744	1.292	1.433	1.507
3.7646	.1105	.1502	1.532	1.112	1.237	1.304
3.4576	.08887	.1223	1.288	0.9109	1.013	1.072
3.3872	.08412	.11624	1.188	0.8295	0.9228	0.9816
3.1428	.06847	.09612	1.024	0.7000	0.7775	0.8260
2.8889	.05354	.07690	.08453	0.5629	0.6231	0.6630
		α	.317	.375	.343	.332

$\alpha\left(p_2\sqrt{\frac{T_2}{T_1}}\right) = .572$

Table 25

Nitrogen --------- Ice bath --- Low Pressure

R_0 = 3.2552 Ohms D = .2759 D/G = 21.34

Cx 100 Amps	P	P + ϕ	p_2 x1000 Cm Hg	p_1' x1000 Cm Hg	p_1'' x1000 Cm Hg	p_1''' x1000 Cm Hg
2.9173	.2645	.2883	2.438	2.413	2.424	2.428
2.8058	.2427	.2647	2.239	2.216	2.226	2.230
2.7227	.2270	.2477	2.079	2.057	2.066	2.069
2.6198	.2082	.2274	1.884	1.862	1.871	1.875
2.5404	.1940	.2121	1.747	1.726	1.734	1.738
2.4513	.1789	.1957	1.580	1.559	1.568	1.571
2.3583	.1635	.1791	1.399	1.379	1.387	1.391
2.2563	.1474	.1616	1.224	1.205	1.212	1.215
2.1369	.1293	.1421	1.044	1.027	1.033	1.036
		α	.812	.825	.823	.820

$\alpha\left(p_2\sqrt{\frac{T_2}{T_1}}\right) = .844$

Table 26

Nitrogen ------ CO_2 BATH --- Low Pressure

R = 2.7932 Ohms

C x100 Amps	D	P + ϕ	p_2 x1000 Cm Hg	p_1' x1000 Cm Hg	p_1'' x1000 Cm Hg	p_1''' x1000 Cm Hg
3.3470	.2584	.3293	2.707	2.621	2.658	2.673
3.1922	.2553	.3012	2.493	2.408	2.445	2.459
3.0702	.2541	.2782	2.300	2.218	2.252	2.266
2.9673	.2558	.2562	2.114	2.033	2.067	2.081
2.8441	.2550	.2340	1.934	1.856	1.888	1.901
2.7324	.2549	.2140	1.757	1.681	1.713	1.724
2.6192	.2572	.1924	1.561	1.488	1.517	1.529
		α	.850	.855	.854	.854

$\alpha\left(p_2\sqrt{\frac{T_2}{T_1}}\right) = .989$

Table 27

Nitrogen --------- Liquid Oxygen bath -Low Pressure

R_o = .8058 Ohms D = .1713 D/G = 12.32

C x100 Amps	P	P + ϕ	p_2 x1000 Cm Hg	p_1' x1000 Cm Hg	p_1'' x1000 Cm Hg	p_1''' x 1000 Cm Hg
5.0550	.3172	.3878	2.587	2.363	2.462	2.500
4.8768	.2934	.3591	2.421	2.197	2.297	2.334
4.7340	.2750	.3369	2.283	2.062	2.159	2.197
4.5755	.2552	.3130	2.136	1.918	2.016	2.051
4.3995	.2340	.2875	1.978	1.764	1.857	1.893
4.2204	.2132	.2624	1.844	1.634	1.724	1.760
4.0056	.1894	.2337	1.651	1.447	1.533	1.561
3.7679	.1644	.2036	1.459	1.262	1.343	1.377
3.4516	.1335	.1664	1.235	1.048	1.122	1.155
		α	.829	.854	.837	.834

$\alpha\left(p_2\sqrt{\frac{T_2}{T_1}}\right) = 1.50$

Table 28

Argon -------- Ice bath -- Low Pressure

R_0 = 3.2552 Ohms D = .2758 Ohm D/G = 21.33

C x100 Amps	P	P +ϕ	p_2 x1000 Cm Hg	p_1' x1000 Cm Hg	p_1'' x1000 Cm Hg	p_1''' x1000 Cm Hg
2.5098	.1889	.2065	2.703	2.678	2.688	2.693
2.4198	.1737	.1901	2.429	2.405	2.416	2.419
2.3668	.1650	.1807	2.302	2.278	2.288	2.292
2.2915	.1529	.1676	2.096	2.073	2.082	2.086
2.2264	.1428	.1567	1.947	1.924	1.933	1.937
2.1604	.1329	.1460	1.734	1.712	1.721	1.724
2.0879	.1223	.1345	1.536	1.515	1.523	1.526
2.0003	.1099	.1211	1.338	1.318	1.325	1.329
1.8920	.09542	.1054	1.098	1.080	1.085	1.089
		α	.887	.899	.891	.882

$\alpha\left(p_2\sqrt{\frac{T_2}{T_1}}\right) = .920$

Table 29

Argon ----------CO_2 bath --- Low Pressure

R = 2.5911 Ohms

C x100 Amp	D	P + ϕ	p_2 x1000 Cm Hg	p_1' x1000 Cm Hg	p_1'' x1000 Cm Hg	p_1''' x1000 Cm Hg
3.0183	.3066	.2012	2.732	2.615	2.665	2.685
2.9099	.3085	.1838	2.478	2.364	2.412	2.432
2.8298	.3098	.1716	2.309	2.197	2.244	2.263
2.7433	.3138	.1511	2.131	2.022	2.067	2.086
2.6300	.3115	.1435	1.943	1.837	1.880	1.898
2.4982	.3069	.1290	1.737	1.631	1.675	1.693
2.3937	.3091	.1151	1.549	1.451	1.489	1.505
2.2726	.3117	.09989	1.358	1.265	1.299	1.316
2.1177	.3098	.08372	1.135	1.048	1.079	1.094
		α	.879	.898	.895	.890

$\alpha\left(p_2\sqrt{\frac{T_2}{T_1}}\right) = 1.07$

Table 30

Argon --------- Liquid Oxygen bath Low Pressure

R = .8032 Ohm D = .2779 Ohm D/G = 19.96

C x100 Amp	P	P + ϕ	p_2 x1000 Cm Hg	p_1' x1000 Cm Hg	p_1'' x1000 Cm Hg	p_1''' x1000 Cm Hg
5.1602	.1938	.2674	3.130	2.875	2.990	3.035
4.9792	.1786	.2471	2.924	2.672	2.785	2.828
4.8256	.1661	.2305	2.749	2.499	2.611	2.654
4.6687	.1537	.2140	2.554	2.308	2.415	2.459
4.5169	.1421	.1985	2.361	2.119	2.225	2.267
4.3089	.1268	.1781	2.171	1.933	2.036	2.077
4.1014	.1123	.1588	1.961	1.729	1.824	1.867
3.8539	.09586	.1369	1.719	1.461	1.589	1.628
3.6570	.08350	.1205	1.516	1.300	1.391	1.426
		α	.800	.814	.809	.808

$\alpha\left(p_2\sqrt{\frac{T_2}{T_1}}\right) = 1.45$

Table 31

Deuterium -------- Ice bath -- Low Pressure

R_0 = 3.2552 Ohms D = 0.2756 Ohm D/G = 21.32

C x100 Amp	P	P + ϕ	p_2 x1000 Cm Hg	p_1' x1000 Cm Hg	p_1'' x1000 Cm Hg	p_1''' x1000 Cm Hg
2.9581	.2730	.2975	2.147	2.110	2.123	2.129
2.8506	.2516	.2743	1.963	1.928	1.940	1.946
2.7763	.2373	.2589	1.844	1.809	1.821	1.826
2.6793	.2193	.2394	1.690	1.657	1.668	1.673
2.5989	.2047	.2236	1.584	1.552	1.562	1.567
2.5122	.1895	.2072	1.451	1.421	1.430	1.435
2.4110	.1724	.1887	1.303	1.273	1.284	1.287
2.2917	.1531	.1678	1.141	1.115	1.122	1.126
2.1438	.1305	.1434	0.948	0.9246	0.9305	0.9340
		α	.380	.387	.385	.385

$\alpha\left(p_2\sqrt{\frac{T_2}{T_1}}\right) = .394$

Table 32

Deuterium ---------- CO_2 bath -- Low Pressure

R = 2.4809 Ohms

C x100 Amps	D	P + ϕ	p_2 x1000 Cm Hg	p_1' x1000 Cm Hg	p_1'' x1000 Cm Hg	p_1''' x1000 Cm Hg
3.5155	.2495	.3378	2.280	2.162	2.205	2.225
3.3876	.2494	.3119	2.061	1.948	1.988	2.007
3.2975	.2496	.2940	1.939	1.829	1.867	1.886
3.1851	.2501	.2719	1.809	1.702	1.739	1.757
3.0694	.2498	.2510	1.672	1.570	1.603	1.621
2.9542	.2507	.2296	1.542	1.444	1.475	1.492
2.8152	.2498	.2069	1.378	1.286	1.314	1.329
2.6560	.2500	.1810	1.213	1.127	1.152	1.166
2.4640	.2512	.1510	1.010	0.9334	0.9538	0.9658
		α	.387	.400	.393	.389

$\alpha\left(p_2\sqrt{\frac{T_2}{T_1}}\right) = .476$

Table 33

Deuterium ---------- Liquid Oxygen bath --Low Pressure

R_o = .8030 Ohm D = .2781 Ohm D/G = 19.98

C x100 Amp	P	P + ϕ	p_2 x1000 Cm Hg	p_1' x1000 Cm Hg	p_1'' x1000 Cm Hg	p_1''' x1000 Cm Hg
7.6603	.4568	.6190	2.620	2.344	2.451	2.499
7.3380	.4175	.5664	2.399	2.132	2.234	2.280
7.0980	.3891	.5284	2.296	2.033	2.132	2.178
6.8431	.3600	.4895	2.144	1.888	1.985	2.026
6.5611	.3289	.4479	1.989	1.741	1.831	1.874
6.2858	.2999	.4091	1.847	1.607	1.693	1.734
5.9616	.2672	.3655	1.666	1.437	1.516	1.550
5.5656	.2296	.3152	1.471	1.260	1.327	1.363
5.0706	.1860	.2571	1.248	1.051	1.112	1.145
		α	.441	.479	.462	.456

$\alpha\left(p_2\sqrt{\frac{T_2}{T_1}}\right) = .798$

In order to distinguish between the lines corresponding to $p'_{,}, p''_{,}, p'''_{,}$, it has been found necessary, with the exception of Fig. (11), to move the origin of the pressure scale for $p''_{,}$ and $p'''_{,}$ to the right by amounts equivalent to ·0001 and ·0002 Cm. Hg. respectively.

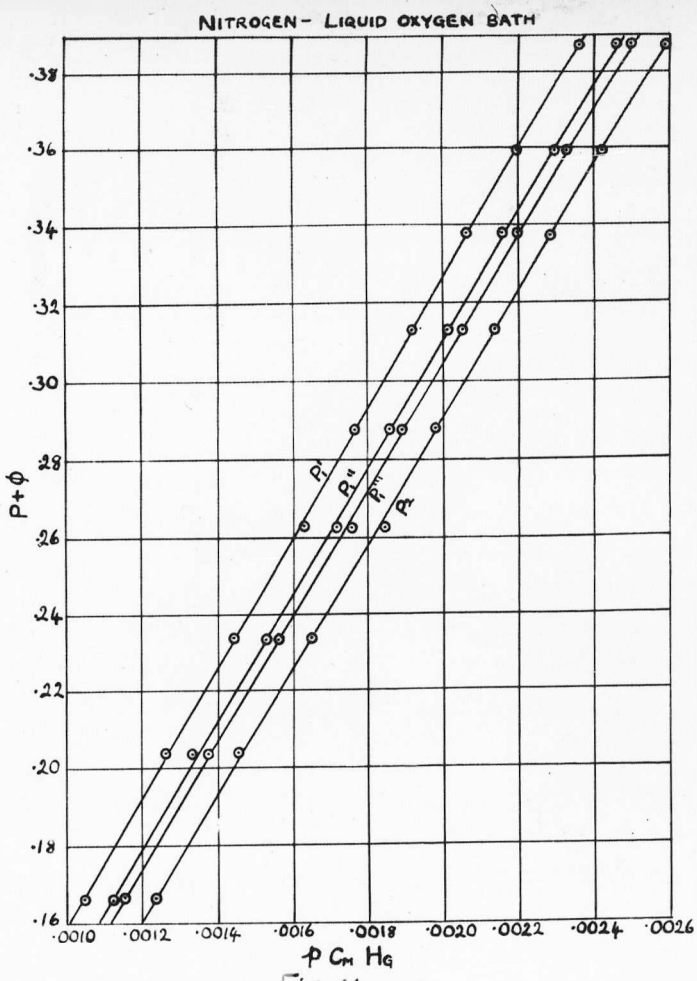

NITROGEN – LIQUID OXYGEN BATH
P+φ
·38
·36
·34
·32
·30
·28
·26
·24
·22
·20
·18
·16
P'
P''
P'''
P''''
·0010
·0012
·0014
·0016
·0018
·0020
·0022
·0024
·0026
p Cm Hg

Fig 11

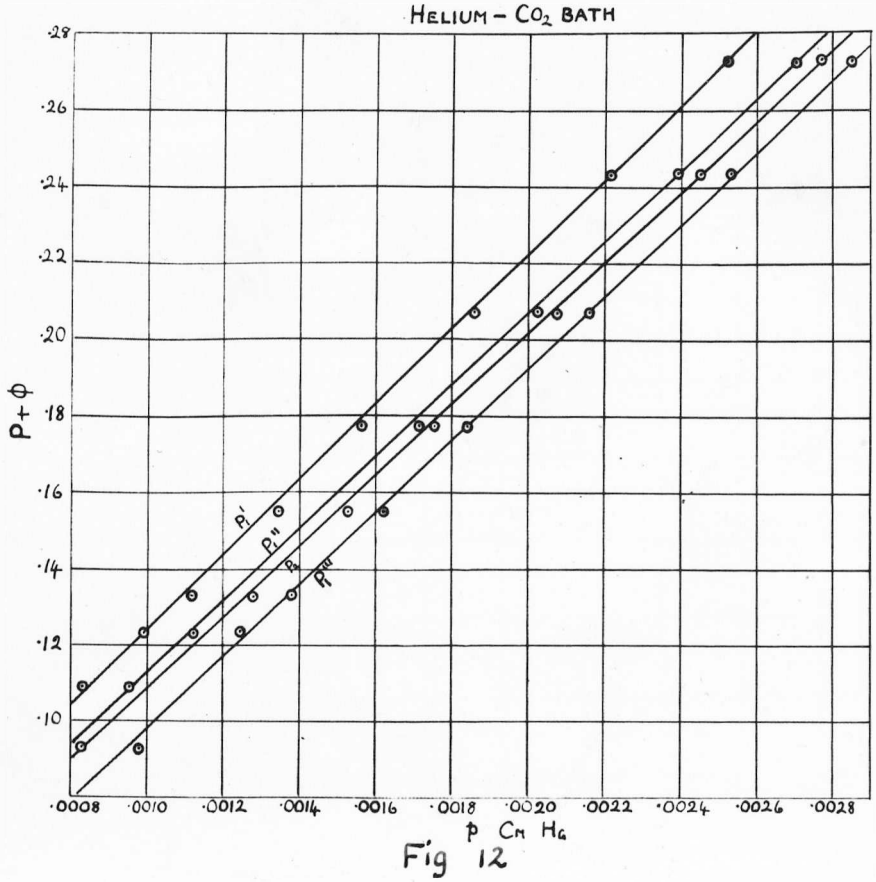

HELIUM – CO_2 BATH
P+φ
·28
·26
·24
·22
·20
·18
·16
·14
·12
·10
P'
P''
P'''
P''''
·0008
·0010
·0012
·0014
·0016
·0018
·0020
·0022
·0024
·0026
·0028
p Cm Hg

Fig 12

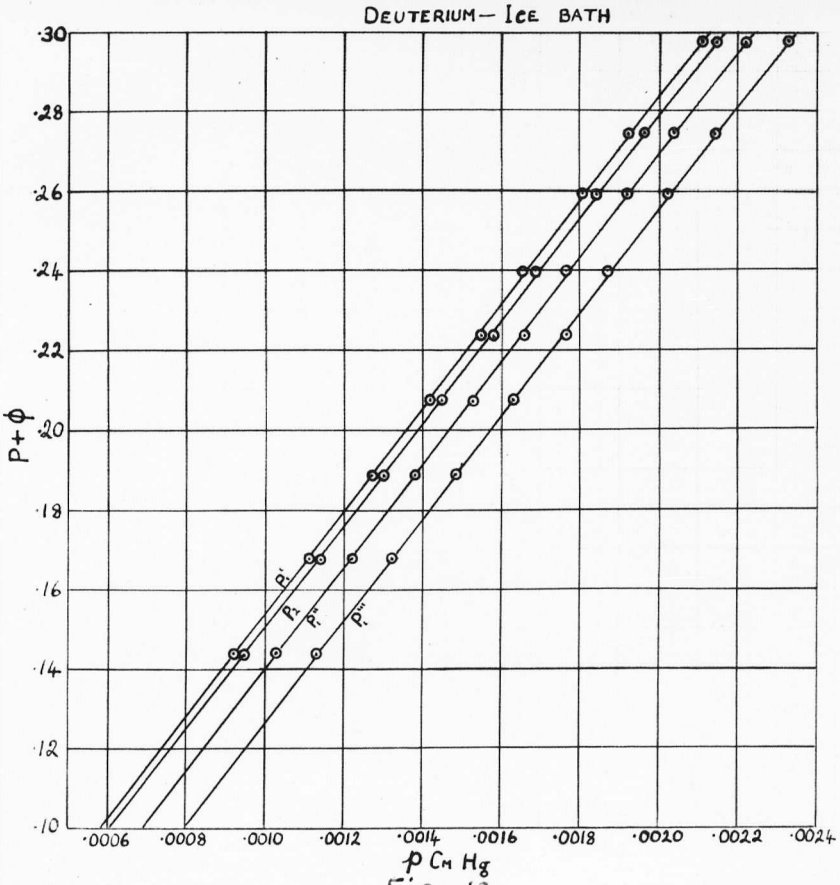

DEUTERIUM — ICE BATH
·30
·28
·26
·24
·22
·20
·18
·16
·14
·12
·10
P + φ
P'
P₂
P''
P'''
·0006
·0008
·0010
·0012
·0014
·0016
·0018
·0020
·0022
·0024
p Cm Hg

Fig. 13

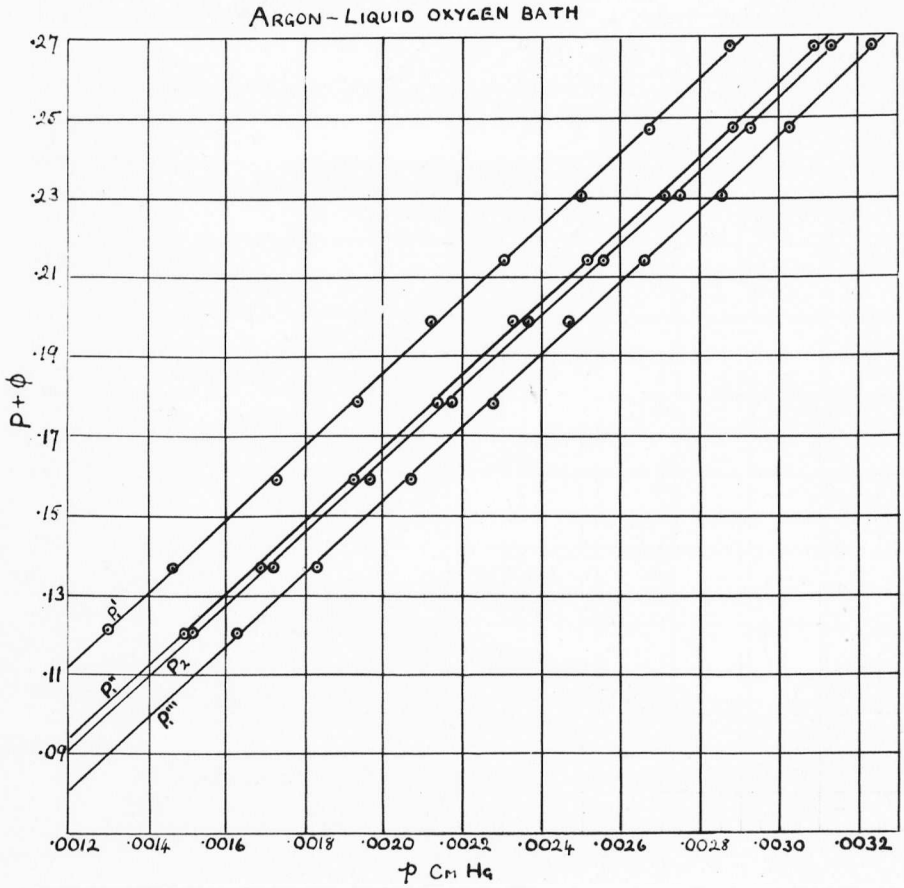

ARGON — LIQUID OXYGEN BATH
·27
·25
·23
·21
·19
·17
·15
·13
·11
·09
P + φ
P'
P''
P₂
P'''
·0012
·0014
·0016
·0018
·0020
·0022
·0024
·0026
·0028
·0030
·0032
p Cm Hg

Fig. 14

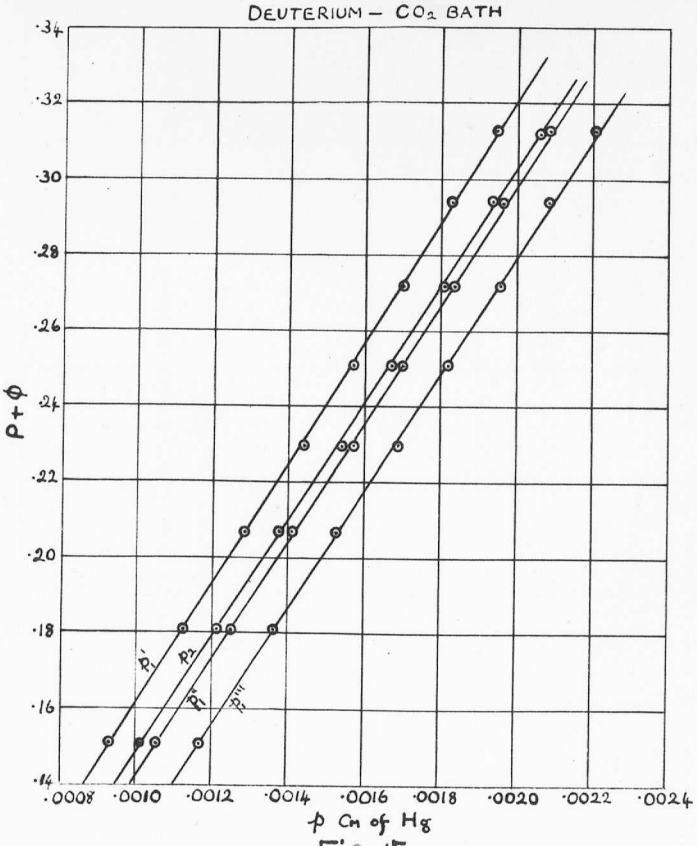

DEUTERIUM – CO_2 BATH
P + φ
·34
·32
·30
·28
·26
·24
·22
·20
·18
·16
·14
·0008
·0010
·0012
·0014
·0016
·0018
·0020
·0022
·0024
p Cm of Hg
P_1'
P_2
P_1''
P_2''

Fig. 15

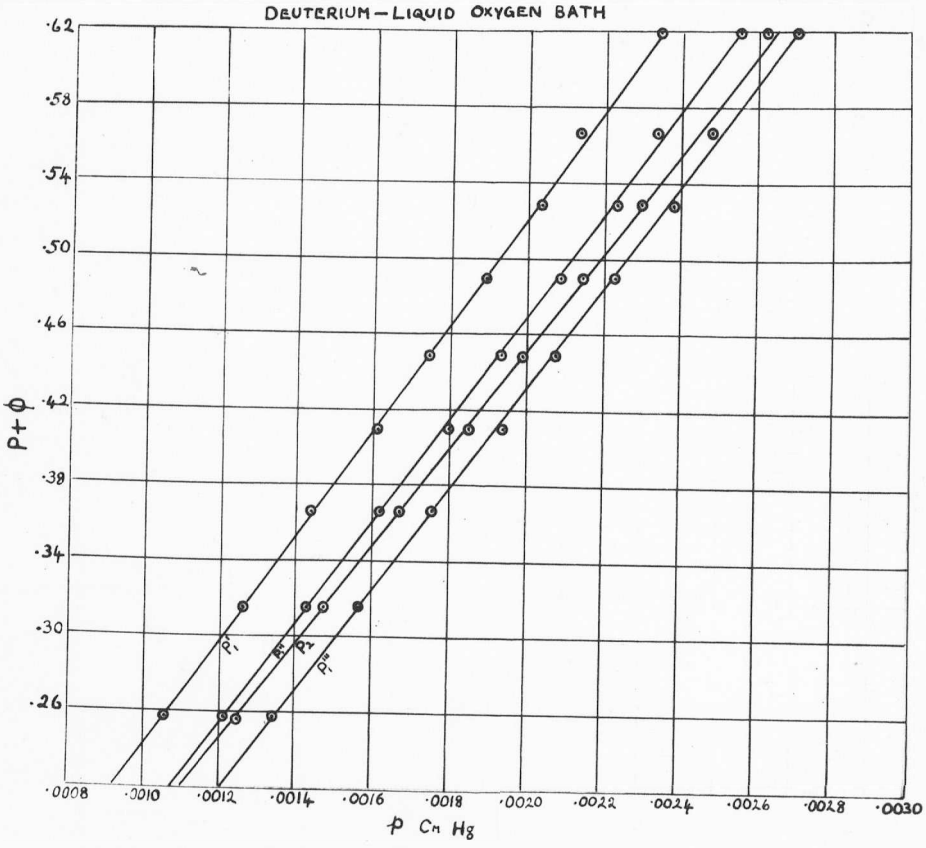
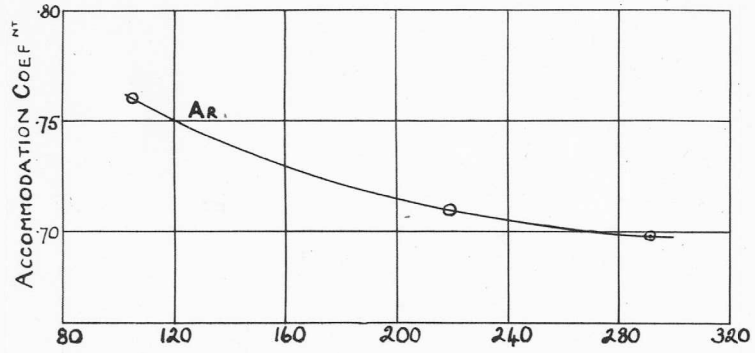

DEUTERIUM – LIQUID OXYGEN BATH
P + φ
·62
·58
·54
·50
·46
·42
·38
·34
·30
·26
·0008
·0010
·0012
·0014
·0016
·0018
·0020
·0022
·0024
·0026
·0028
·0030
p Cm Hg
P_1'
P_2'
P_1''
P_2''

Fig. 16



Argon

Fig. 17

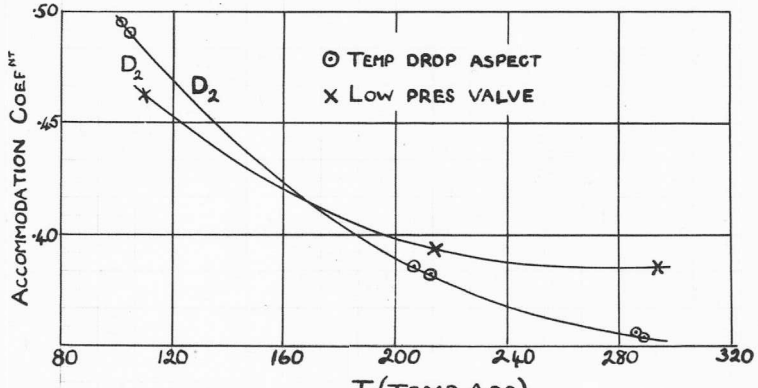


Fig. 18

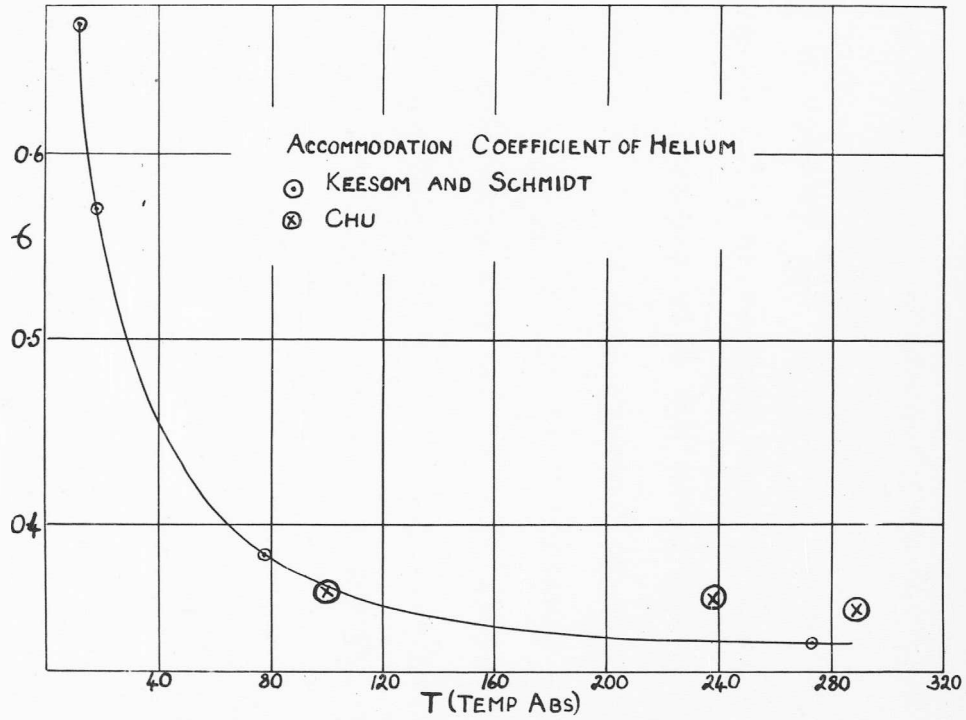


Fig. 19

The Coefficient of Accommodation

It remains to compare the values of the coefficient of accommodation calculated at various temperatures in terms of the Temperature Drop theory with the corresponding values deduced from aspects of the Heat Conduction through the gas when strongly rarefied. In the present instance the values obtained from both methods are not in such close agreement as might be expected and the reason for such divergence cannot be completely explained in terms of possible errors associated with the experimental procedure.

In relation to the investigations carried out at low pressure it is emphasised that some uncertainty exists in the procedure for calculating the corrections associated with the existence of the effect of Thermal Transpiration together with the difficulty of assigning a precise value to the constant i in the Knudsen Transpiration formula. In addition the application of the Heat Transport law modified by the author in respect of faulty compensation is both troublesome and extremely laborious.

The question too of measuring accurately pressures of the order of 10^{-3} mms Hg by the Mc Leod gauge is debateable in spite of every consideration in details of design which have been employed in the construction of the gauges used in the present investigations.

For these reasons and others, Dr Gregory has put forward the argument that the Temperature Drop method in comparison with that at low pressure is not only capable of greater accuracy at low temperature but has definite advantages in relation to the larger current densities employed along with the accuracy associated with the higher pressure range.

Theoretically we have for the Heat Transport at low pressure the relation

$$Q = 2.\pi.r_1 L.p.\sqrt{\frac{R'}{2.\pi.M.T_2}}\,(\beta + 1/2).\alpha\,(T_1 - T_2) \quad (63)$$

where T_1 and T_2 are the temperatures of the wire and tube, and for the Heat Transport in the region of the Temperature Drop we have similarly the relation,

$$Q' = 2.\pi.r_1 L.p.\sqrt{\frac{R'}{2.\pi.M.T_1''}}\,(\beta + 1/2).\alpha\,(T_1 - T_1'') \quad (78)$$

The above two Equations are exactly the same except that the temperature of the vessel T_2 is replaced by T'', the temperature of the molecules before colliding with the wire.

Now in (63) Q depends directly on the pressure p, while in (78) Q' for the same value of T_1 and T_2 depends on the product $p.(T_1 - T_1'')$. Since $(T - T'')$ is of the order of one tenth of the value of $(T_1 - T_2)$, and since also the pressure ratio in the two cases is from several hundreds to several thousands, the ratio of the Heat Transport may well be of a magnitude between 50 and 100 times.

These considerations bring out the importance of correctly defining the temperature drop $\delta\theta$ which is related to the value of T" in the way defined by Knudsen, viz.

$$\delta\theta = T_1 - 1/2\ (T_1' + T_1'')\ .$$

In general the Temperature Drop method has supplied rather lower values of α in comparison with the low pressure investigations at the same temperatures.

In the special case of Helium, the observations of Keesom and Schmidt are in close agreement at the temperature of Liquid Oxygen with the values obtained by the author in terms of the Temperature Drop method, Fig (19), while the findings of the author in respect of the gas Deuterium over a similar range of temperature are very satisfactory and compare very favorably with the results obtained at low pressure for the same gas, Fig (18)

It is possible that the higher values of α associated with the results at low pressure might be reconciled from the point of view of the effect of impurities and minute traces of vapours which would have more serious consequences at the lower pressures.

For Argon the variation of α with temperature has been represented graphically Fig (17) in terms of the average values of the results obtained in the neighbourhood of each of the bath temperatures and are less accurate than the corresponding values of α for D_2, due to the small magnitude of the temperature

drop associated with the former gas.

The results for all the gases tested reveal a marked and rapid increase as the temperature decreases and in this respect agree with the results obtained by Gregory and Dock for Hydrogen and also with those of Keeson and Schmidt.

In regard to Nitrogen, the value for α at 0° C. calculated from the tmeasurements at low pressure agrees very closely with the results obtained by Keesom and Schmidt, but does not agree with the value found from the temperature drop aspect. The value of α corresponding to the temperature of the CO_2 bath calculated from the temperature drop aspect is not at all satisfactory and the author suggests that since all calculated values of α in the present instance are based on an assumed value of β at the appropriate temperature and since also there is a surprising dearth of reliable experimental data in respect of β for Nitrogen at low temperature, the discrepancy might reasonably due to inaccuracies in the experimentally determined value of β at this temperature.

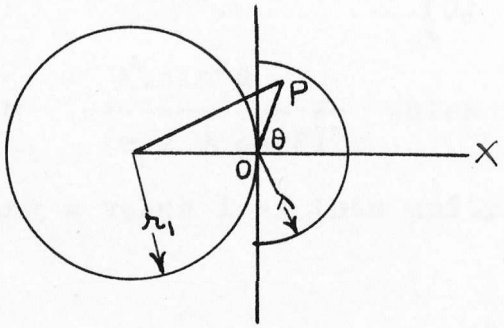
No comparison with the present results for Deuterium is possible, since these represent the only data at present available over the temperature range 0° C. to -183° C., with one exception, that found by Archer at 0° C. (·376), which is not corrected for the effect of the mean free path, and if such correction is made, the value is found to be ·351, which is in close agreement with author's value at the same temperature.

It is considered by the author that the experimental data for α recorded in the present paper might well be applied to test any theoretical contribution for a mechanism of the effect of accommodation, up to the present no such theoretical explanation has been found possible. In the present investigations the condition of the wire surface approximates to a state in which the surface is partially or almost completely covered by a monomolecular layer of gas and the problem should not be beyond a satisfactory solution.

A theory for the mechanism of accommodation in gases has been advanced by Gregory in terms of the Hypothesis of the Surface Energy of the Gas-Solid phase and although this theory predicts the existence of a temperature discontinuity at the gas solid interface, it is not possible to calculate the value of α owing to the dearth of experimental data in respect of the corresponding Heats of Adsorption for the gases tested.

Appendix

Calculation of the average value of the Mean Free Path at the surface of the wire



Let the circle of radius r_1 represent a cross section of the wire by the plane of the paper. Now the molecules colliding with the surface of the wire at a point O start from a number of points like P on the surface of the Hemisphere whose centre is O

Take a system of spherical polar coordinates with O as centre and OX as polar axis, where θ is the angle between the radius vector OP and the Polar axis OX and φ the angle made by the plane containing the lines OP and OX and the plane of the paper.

If d is the distance of the point P from the axis of the wire, then

$$d = \sqrt{(r_1 + \lambda \cos.\theta)^2 + \lambda^2 \sin^2.\theta.\cos^2\varphi}$$

If $\bar{d}$ denotes the average value of d for all molecules coming from the hemi-spherical surface then we have

$$\bar{d} = \frac{\int_0^{\frac{\pi}{2}}\int_0^{\frac{\pi}{2}} \sqrt{(r_1 + \lambda\cos.\theta)^2 + \lambda^2\sin^2\theta.\cos^2\varphi}\ \cos\theta.\sin\theta\ d\theta d\varphi}{\int_0^{\frac{\pi}{2}}\int_0^{\frac{\pi}{2}} \cos\theta.\ \sin\theta\ d\theta\ d\varphi}$$

The denominator of the above equation has the value $\pi/4$.

Hence the above equation for $\bar{d}$ becomes

$$\bar{d} = \frac{4}{\pi} \int_0^{\frac{\pi}{2}} (r_1 + \lambda \cos^2\theta)\cos\theta . \sin\theta \left[\int_0^{\frac{\pi}{2}} \sqrt{1 + A^2 . \cos^2\varphi}\ d\varphi \right] d\theta$$

where $A^2 = \dfrac{\lambda^2 . \sin^2\theta}{(r_1 + \lambda \cos\theta)^2}$ which is a dimensionless quantity having a value less than unity, provided λ is less than r_1

Now $$\int_0^{\pi/2} \sqrt{1 + A^2\cos^2\varphi}\ d\varphi = \frac{\pi}{2}\left(1 + \frac{A^2}{4} - \frac{3.A^4}{64} + \frac{5.A^6}{256} + \cdots \right)$$

and $\bar{d}$ becomes

$$\bar{d} = 2 \int_0^{\pi/2} (r_1 + \lambda\cos\theta)\ \cos\theta\ \sin\theta\ \left(1 + \frac{A^2}{4} - 3.A^4/64 + \cdots\right) d\theta$$

$$2\ (\ 1_0 + 1_1 - 1_2 + \cdots\ )$$

where $1_0 = \int_0^{\pi/2} (r_1 + \lambda\cos\theta)\ \cos\theta .\ \sin\theta\ d\theta = r_1/2 + \lambda/3$

$$1_1 = \frac{1}{4} \int_0^{\pi/2} \frac{\lambda^2 \sin^3\theta\ \cos\theta}{r_1 + \lambda\cos\theta}\ d\theta$$

$$= \frac{\lambda}{16}\left(\frac{\lambda}{r_1}\right) + \frac{\lambda}{30}\left(\frac{\lambda}{r_1}\right)^2 + \frac{\lambda}{48}\left(\frac{\lambda}{r_1}\right)^3 + \cdots$$

$$1_2 = \frac{3}{64} \int_0^{\frac{\pi}{2}} \frac{\lambda^4 \sin^5\theta\ \cos\theta}{(r_1 + \lambda\cos\theta)^3}\ d\theta = \frac{\lambda}{128}\left(\frac{\lambda}{r_1}\right)^3 + \cdots$$

hence

$$\bar{d} = r_1 + \frac{2.\lambda}{3} + \frac{\lambda^2}{8.r_1} - \frac{\lambda^3}{15.r_1^2} + \frac{5\lambda^4}{192.r_1^3} + \cdots$$

The average distance from the surface of the cylinder is therefore

$$\frac{2.\lambda}{3}\left\{1 + \frac{3.\lambda}{32.r_1} - \frac{1}{20}\left(\frac{\lambda}{r}\right)^2 + \frac{5}{1280}\left(\frac{\lambda}{r_1}\right)^3 + \cdots\right\}$$

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