

A METHOD OF MEASURING THE THERMAL CONDUCTIVITY OF LIQUIDS

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Summary

We described the development of an apparatus for the determination of the thermal conductivity of liquids. The apparatus is suitable for all kinds of liquids, including the strongest acids. From a given time we pass an electric current through a thin straight wire, placed in a homogeneous material of which the thermal conductivity is to be measured.

The constant heat production in the wire causes a cylindrical temperature field in the material. The rise of temperature depends on the thermal properties of the material. The apparatus used is sketched in figure 1.

The drawback of the old methods, viz the convection current of the liquid is evaded, because the time in which the measurement is done, is so short that the density differences can not develop a disturbing convection current within this time. The results of the measurements are given in table II.

For water we found the same dependence of the thermal conductivity on temperature as F. Schmidt and W. Sellschopp (see figure 9)

Introduction. The usual methods of measuring the thermal conductivity of a material are based on the solution of the differential equation of Fourier at stationary circumstances and for the case, that the temperature depends only on one coordinate.

Let: θ = the temperature, centigrade

x = the thickness, cm.

f = the area of surface, cm².

Q = the quantity of heat transmitted, cal/sec.

Then:
$$dQ = -\lambda \frac{d\theta}{dx} df dt.$$

where λ is the thermal conductivity in cal/cm sec°C.

If the material is a liquid with this method the convection cur-

rents cause trouble, whereas with a very thin layer of the liquid used to suppress convection currents the measurement of the temperature and the thickness of the layer become very difficult. To avoid this difficulties we have used a nonstationnary method with a very short time of measurement.

The principle of the non stationnary method. From a given time we pass an electric current through a thin straight wire, placed in the homogeneous material of which the thermal conductivity is to be measured. The constant heat production in the wire causes a cylindrical temperature field in the material. The rise of temperature in the material is dependent on the thermal properties of this material. The possibility of measuring the thermal conductivity λ based on this principle has been indicated first by Stålhane and Pyk¹⁾. For the difference θ of the temperature of the wire and its initial temperature they found:

$$\theta = A \frac{q}{\lambda} \ln \left(\frac{r_0^2}{t} + B \right)$$

where: q = the heat production in Watt/cm.

$2r_0$ = the diameter of the wire in cm.

A and B are two definite constants. By comparison with known liquids they determined that $A = 0,0445$.

Thus a simple method of measuring the thermal conductivity was found, but when we tried to repeat the experiments we encountered all sorts of troubles.

Mathematical introduction. The empirical formula of Stålhane and Pyk was mathematically deduced in 1932²⁾.

In order to find a simple solution of the differential equation of Fourier, suiting our case we assume the following boundary conditions:

$$\left. \begin{array}{l} r = \infty \\ t \neq \infty \end{array} \right\} = 0; \quad \left. \begin{array}{l} r \neq 0 \\ t = 0 \end{array} \right\} = 0; \quad \left. \begin{array}{l} r \rightarrow 0 \\ t < 0 \end{array} \right\} - 2\pi r \lambda \frac{\partial \theta}{\partial r} = q = \text{constant}$$

The third boundary condition is a simplifying assumption.

The solution of this mathematical problem is:

$$\theta = \frac{q}{4\pi\lambda} \left\{ -Ei \left(-\frac{4at}{r^2} \right) \right\} \quad (1)$$

where $-Ei(-x) =$

$$= \int_x^{\infty} \frac{1}{x} \exp(-x) dx = -C - \ln x + \frac{x}{1.1!} - \frac{x^2}{2.2!} + \dots C = 0,5772 \dots$$

being the constant of Euler and a the thermal diffusivity.

If $r^2/4at$ is very small, $-Ei(-x)$ can be described by the terms $-C - \ln x$ only.

Then the temperature at the surface of the wire is given by:

$$\theta = \frac{q}{4\pi t} \left(\ln \frac{4at}{r_0^2} - 0,5772 \dots \right) \tag{2}$$

Comparison with the empirical formula of Stålhane and Pyk gives $A = 0,2389/4\pi \log.e. = 0,04377$, which is indeed a constant and in good agreement with the experimental determination. However B is not a general constant, B being $-0,5772 \dots \log e + \log 4a$. This difficulty can be avoided by taking the difference in temperature at two times. Then we obtain:

$$\theta_2 - \theta_1 = \frac{q}{4\pi\lambda} \ln \frac{t_2}{t_1}. \tag{3}$$

This relation is the base of the non stationary method of measuring the thermal conductivity of liquids. By recording the temperature at the surface of the wire half-away along its length, and plotting against $\ln t$, we find $q/4\pi\lambda$ as the slope of the straight line in this plot.

The Apparatus. The measurement of the temperature can be done in two ways, i.e. with a thermocouple or with the variation of the electrical resistance of the wire. We rejected the latter way for many reasons. If we want to measure the temperature with a resistance thermometer, the resistance of the wire should change greatly with temperature, but this means that the heatproduction is not constant during the period of heating. Moreover this method needs a complicated apparatus.

A thermocouple has the advantage of measuring the temperature at a fixed point of the wire and so initially our measurements are not disturbed by the three-dimensional heat flow at the ends of the wire. We choose Manganine (diameter 0,3 mm) as the material for the heating wire, which has a change of resistance with temperature of 0,002%/°C. Not only the chemical activity of some liquids but also

phenomena like polarisation and electrophoresis made it impossible to use the bare wire in the liquid. The object of our research-work was to find a method suitable for all kinds of liquids, including the most aggressive acids. Therefore it is not enough to lacquer the wire. We put the lacquered wire and the thermocouple together in a narrow glass capillary tube. Further on we will call the tube with its contents the heater. Later on we shall see to what extent our experimental results deviate from formula (3).

Both ends of the capillary tube are fused into the wall of a glass vessel.

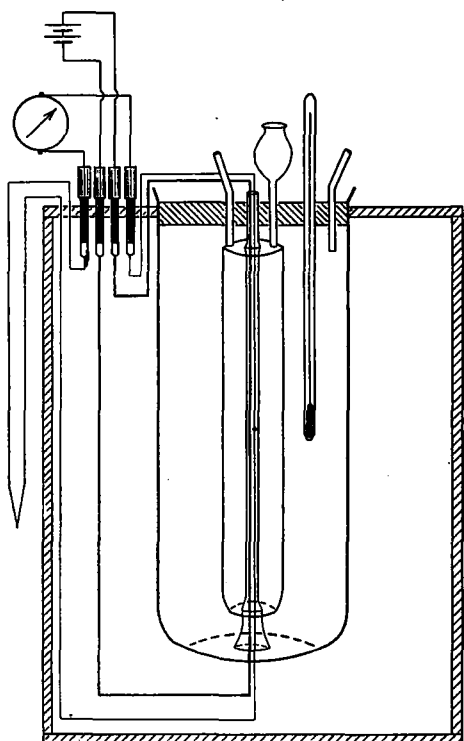


Fig. 1. Apparatus for the determination of the thermal conductivity in liquids.

The cylindrical space between the tube and the wall contains the liquid to be investigated. The vessel is placed in a Dewar flask filled with water, so that a constant temperature of the surroundings is assured (Figure 1). The thermocouple is composed of constantan and copper (0,1 mm diameter). The two copper terminals are connected with a Mollgalvanometer. The light spot is registered photographically, while at the same time with lightflashes at regular intervals a timebase is marked on the film.

To be independent, as much as possible, of the shrinking of the photographic paper during development, we use a Gevaert photographic paper with lines at distances of two mm parallel to the time axis, especially produced for the electrocardiography.

The influence of the thickness of the heater. For the validity of formula (3) we had to assume that this thickness was zero. We will try by using simple corrections to adjust the result of the experiment

to this formula. In deriving (3) we neglected the terms

$$\frac{r_0^2}{4at} - \frac{r_0^2}{64a^2t^2} + \dots$$

This is allowed for large r_0 after a rather long time (at $t = 2,5 r_0^2/a$ the error is about 5%). We can reduce this error by subtracting from t a constant time $t_0 = -r_0^2/4a$. This can be shown by putting $\tau + t_0$ in stead of t_0 in (1):

$$\theta = \frac{q}{4\pi\lambda} \left\{ -E_i \left(\frac{r_0^2}{4a(\tau + t_0)} \right) \right\} = \frac{q}{4\pi\lambda} \left\{ -C - \ln \frac{r_0^2}{4a\tau} + \ln \left(1 + \frac{t_0}{\tau} \right) + \frac{r_0^2}{4a\tau} \left(\frac{1}{1 + t_0/\tau} \right) - \frac{1}{4} \left(\frac{r_0^2}{4a\tau} \right)^2 \left(\frac{1}{1 + t_0/\tau} \right)^2 + \frac{1}{18} \left(\frac{r_0^2}{4a\tau} \right)^3 \left(\frac{1}{1 + t_0/\tau} \right)^3 \dots \right\}$$

Inserting $t_0 = -r_0^2/4a$ gives:

$$\theta = \frac{q}{4\pi\lambda} \left\{ -C - \ln \frac{r_0^2}{4a\tau} + \frac{1}{4} \left(\frac{r_0^2}{4a\tau} \right)^2 + \frac{2}{9} \left(\frac{r_0^2}{4a\tau} \right)^3 + \dots \right\}$$

As there is no term in this series with the first power of $r_0^2/4a\tau$ the error coming from suppression of the power series will be lower than in the original series (at $\tau = 0,81 r_0^2/a$ the error is about 5%).

Put $r_0^2/4a\tau = x$ then $r_0^2/4a(\tau + t_0) = x/(1 - x)$.

The calculation shows that

$$\left| \frac{-C - \ln x}{-E_i(-x/(1-x))} \right|$$

for e.g. CCl_4 after 5 seconds lies between 0,99 and 1,00, while without correction this value can not be reached during the time of measurement.

Besides this mathematical correction we have to correct too for the deviation of the rise of temperature in the heater with regard to its ideal rise given by the formula for $r = r_0$. This heat flow is $q_0 = -2\pi r_0 \lambda (\partial\theta/\partial r)_{r=r_0} = q \cdot \exp(r_0^2/4at)$. Because of the thickness of the heater we need an extra heat production to warm it up, viz:

$$q_1 = \pi r_0^2 C_1 \rho_1 \left(\frac{\partial\theta}{\partial t} \right)_{r=r_0} = q \frac{C_1 \rho_1}{C \rho} \cdot \frac{r_0^2}{4at} \exp \left(-\frac{r_0^2}{4at} \right).$$

where it is supposed that the temperature rise is the same for all points across a cross section of the heater. This is allowed after a short time depending on the value of r_0 . In reality after some se-

conds a situation develops in the heater in which there is a constant temperature difference between the thermocouple and the surface of the heater. This causes only a displacement of the straight line without a change of the slope. So formula (3) describes a temperature field which in the real case is caused by a heat production:

$$q_{tot} = q_0 + q_1 = q \left(1 + \frac{C_1 \varrho_1}{C \varrho} \cdot \frac{r_0^2}{4at} \right) \exp \left(-\frac{r_0^2}{4at} \right)$$

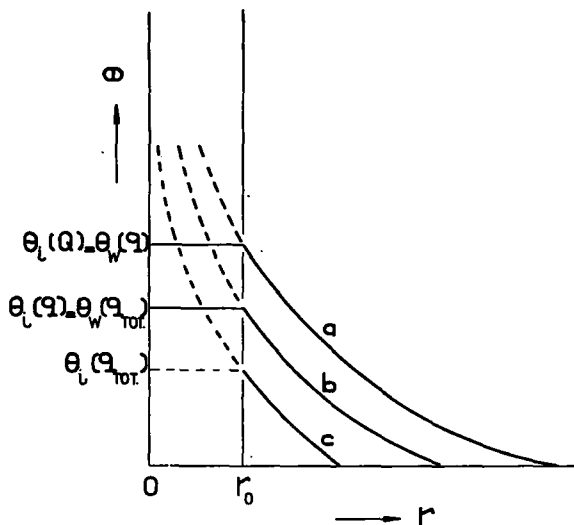


Fig. 2. Influence of the thickness of the heater on the temperature distribution.

In figure 2 the temperature is shown beyond $r = r_0$ at a given time. Curve *a* gives the temperature in accordance with formula (3) and the temperature in the real case if we use a heat production q_{tot} . In the ideal case a heat production q_{tot} gives a $\theta_i(q_{tot})$ given by curve *c* and described by

$$\theta_i(q_{tot}) = \frac{q}{4\pi\lambda} \int_0^t \left\{ \left(1 + \frac{C_1 \varrho_1}{C \varrho} \frac{r_0^2}{4at'} \right) \exp \left(-\frac{r_0^2}{4at'} \right) \right\} \cdot \left\{ \frac{1}{t-t'} \exp \left(-\frac{r_0^2}{4a(t-t')} \right) \right\} dt'$$

However we need the variation of the temperature in the real case with a heat production q (curve *a*). We get curve *c* from curve *b* by

correction of the heat production in formula (3) with $q = q_{tot}$. Therefore if we want to get curve a from curve b we have to take a heat production $Q = q + (q - q_{tot})$ in formula (3) and so we can describe curve a , i.e. the real temperature in the liquid by:

$$\begin{aligned} \theta_i(q_{tot}) = \theta_i(Q) &= \frac{q}{4\pi\lambda} \int_0^t \left[2 - \left(1 + \frac{C_1 \rho_1}{C \rho} \cdot \frac{r_0^2}{4at'} \right) \exp\left(-\frac{r_0^2}{4at'}\right) \right] \cdot \\ &\cdot \frac{1}{t-t'} \exp\left(\frac{4a(t-t')}{r_0^2}\right) dt' = \frac{q}{4\pi\lambda} \left[-Ei\left(-\frac{r_0^2}{4at}\right) \right] + \\ &+ \left\{ \frac{q}{4\pi\lambda} \left[-Ei\left(-\frac{r_0^2}{4at}\right) \right] - \frac{q}{4\pi\lambda} \int_0^t \left[\left(1 + \frac{C_1 \rho_1}{C \rho} \cdot \frac{r_0^2}{4at''} \right) \cdot \right. \right. \\ &\left. \left. \exp\left(-\frac{r_0^2}{4at''}\right) \right] \left[\frac{1}{t-t'} \exp\left(\frac{-r_0^2}{4a(t-t')}\right) \right] dt' \right\}. \end{aligned}$$

In figure 3 we found $\theta_w(q)$ for CCl_4 by the construction as given by this formula, while $\theta_i(q_{tot})$ is obtained by graphical integration. The same is done for water (not given here). Both figures show that from a certain time $\theta_w(q)$ and $\theta_i(q)$ have a constant difference in time. Therefore we may conclude that we can use formula (3) if we correct it with this constant difference in time.

These two corrections of the time and the uncertainty in fixing the time of the beginning of the experiment can be contained in a total correction t_0 . It is possible to determine t_0 experimentally. Formula (3) becomes:

$$\theta_2 - \theta_1 = \frac{q}{4\pi\lambda} \ln \frac{t_2 + t_0}{t_1 + t_0}.$$

The reciprocal of the derivative with respect to t is:

$$\frac{\partial t}{\partial \theta} = \frac{4\pi\lambda}{q} (t + t_0)$$

If we plot $\partial t / \partial \theta$ against t , again we find a straight line with a slope $q/4\pi\lambda$.

The axis $\partial t / \partial \theta = 0$ cuts this straight line at $-t_0$. We do not use this line to determine λ as by graphical differentiation we get an inadmissible spread of the points. We use it only to determine t_0 and correct the undifferentiated curve with it. For CCl_4 we found experimentally $t_0 = 0,6$ seconds, while theoretically we found from

figure 5 and $-\frac{r_0^2}{4a}$: $t_0 = 1,9 - 1,2 = 0,7$ seconds; for water experimentally, 3,2 and by calculation 3,1.

The influence of the length of the heater.

The finite length of the heater has two effects on formula (3), viz the deviation of the two-dimensional field of the temperature, and the heat transport along the wire to the ends of the heater.

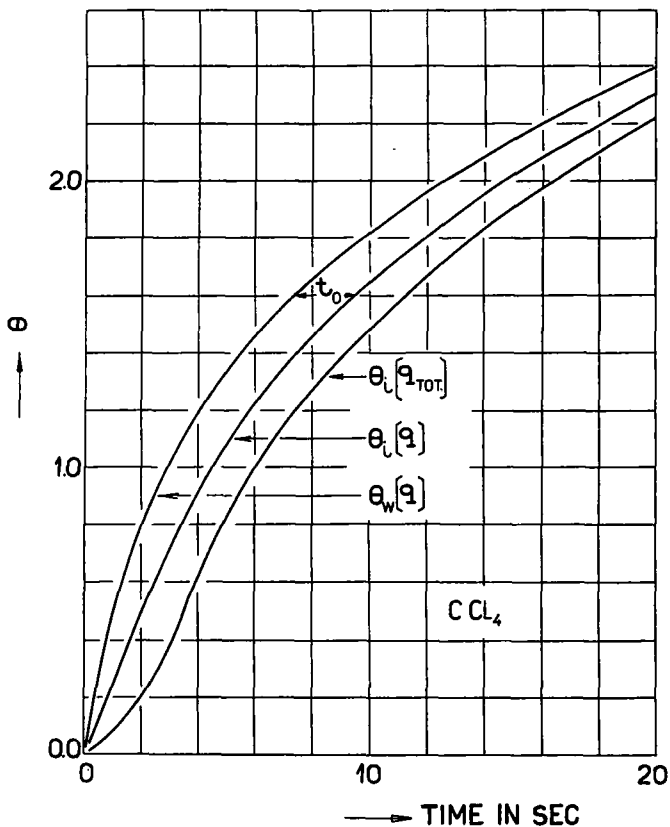


Fig. 3. The deviation of the measured temperature from formula (2).

If we call the length of the heater l and the distance along the heater from the centre y , we may consider the heater as a collection of pointsources of strength $qdy \cdot dt'$. Each source causes a field of temperature given by:

$$\theta = \frac{2dydt'}{C_p(4\pi at)^{3/2}} \exp\left(-\frac{R^2}{4at}\right) \quad \text{where } R = \sqrt{r^2 + y^2}.$$

Integration over y gives:

$$\frac{\partial \theta}{\partial t} = \int_{-\frac{1}{2}l-y}^{\frac{1}{2}l-y} \frac{q}{C\rho(4\pi at)^{3/2}} \exp\left(-\frac{r^2 + y^2}{4at}\right) dy$$

Putting: $y^2/4at = z^2$, we obtain:

$$\frac{\partial \theta}{\partial t} = \left\{ \frac{q}{4\pi\lambda t} \exp\left(-\frac{r^2}{4at}\right) \right\} \frac{1}{2} \left\{ \Phi\left(\frac{\frac{1}{2}l-y}{\sqrt{4at}}\right) + \Phi\left(\frac{\frac{1}{2}l+y}{\sqrt{4at}}\right) \right\}$$

where
$$\Phi(z) = \frac{2}{\sqrt{\pi}} \int_0^z \exp(-z^2) dz$$

We remark that
$$\frac{1}{2} \left\{ \Phi\left(\frac{\frac{1}{2}l-y}{\sqrt{4at}}\right) + \Phi\left(\frac{\frac{1}{2}l+y}{\sqrt{4at}}\right) \right\}$$

gives the deviation from formula (3). Calculation shows that for CCl_4 this deviation is more than 5% only if $t > 4800$ seconds, so that we can neglect this error completely.

The heat transport to the ends of the heating wire needs an additional heat production q' and if we suppose that q' is produced equally throughout the wire (this overestimates the error) the differential equation is:

$$\pi r_0^2 \lambda \frac{\partial^2 \theta}{\partial y^2} + q' = 0 \quad \text{or} \quad \theta' = -\frac{q}{2\pi r_0 \lambda} y^2 + By + C.$$

Suppose that at $y = 0$ and $y = l$ $\theta = 0$ (also an overestimation) then $C = 0$, and at $x = \frac{1}{2}l$

$$\frac{\partial \theta}{\partial x} = 0, \quad B = \frac{q}{2\pi r_0^2 \lambda} l.$$

Then the loss of the heat at the ends of the wire is given by: $q'l$. In the centre of the heater the temperature is given by:

$$\theta_m = \frac{q'l^2}{8\pi r_0^2 \lambda}.$$

Therefore:
$$q' = \frac{8\pi r_0^2 \lambda \theta_m}{l}.$$

If we compare this q' with the produced heat q we find the error and it appears that this error is less than 0,5% during the measurements.

The influence of the diameter of the tube filled with the liquid. Formula (3) is only valid if the rise of temperature near the thermocouple is not influenced by disturbances coming from outside the tube. As the tube is placed in a Dewar-flask, at the beginning the whole apparatus has a constant temperature. Therefore only the wall of the vessel can give rise to disturbances at the wire by reflection of the temperature rise. We exaggerate the disturbance when we suppose that no heat can pass to the outside.

In reality the heat passing through the wall is dependent on the b -value of the two dividing materials ($b = \sqrt{\lambda c \rho}$).

P f r i e m ³⁾ calculated that the coefficient of reflection can be written as $r = (b_1 - b_2)/(b_1 + b_2)$, where index 1 refers to the liquid and 2 to the glass.

For a dividing wall which causes a reflection, we can describe the phenomenon with an imaginary source at a distance $2R$ from the wire and with a strength twice that of the heatsource itself.

The increase of temperature at the position of the thermocouple due to the imaginary source is given by:

$$\theta_s = \frac{2q}{4\pi\lambda} \left\{ -Ei \left(-\frac{4R^2}{4at} \right) \right\}!$$

We must compare θ_s and θ during the measurement. It appears that the influence of θ_s can be neglected completely during our time of measurement.

The inertia of the galvanometer. The last correction which we have to consider is the inertia of the galvanometer. The differential equation of an aperiodic galvanometer is:

$$\frac{1}{\beta^2} \frac{\partial^2 x}{\partial t^2} + \frac{2}{\beta} \frac{\partial x}{\partial t} + x = \zeta$$

where x = deflexion, ζ = the deflexion if there is no inertia, $\beta = 2\pi/T$ with T the deflexiontime. The deflexion of a galvanometer changes for a constant current as:

$$a = a_0 \{1 - (1 + \beta t) \exp(-\beta t)\}$$

where a_0 is the final deflexion. For $a/a_0 = \frac{1}{2}$: $\beta t = 1,6784$. Measurements give $t = 0,18$ seconds. So we find $\beta = 9,3$ and $T = 0,67$ seconds. If we differentiate the recorded curve twice we can calculate ζ at every time. As the correction is very small it is sufficient

to correct by differentiating graphically. After 10 seconds the error is less than the error in the observation, while the first usable point occurs after 3 to 4 seconds.

The time of measurements. The first usable point is fixed by the time after which the temperature is sufficiently approximated by formula (3), after correction with t_0 .

This time follows from the figures 5 and 7. The last point is fixed by the convection in the liquid resulting from differences in density. If both surfaces of a cylindrical space are kept constantly each at its own temperature we can calculate an apparent thermal conductivity λ_i from the measured heat transfer. This λ_i is greater than λ , because λ_i contains an extra contribution from the convection. Therefore $\lambda_i/\lambda = \zeta$ is a measure for the convection.

For gravity convection Nusselt ⁵⁾ has proved that

$$\zeta = f\left(Gr, Pr, \frac{D_i}{D_u}\right)$$

where:
$$Gr = \frac{g\beta\theta D_i^3}{\nu^2} \text{ and } Pr = \frac{\nu}{a}$$

with g the gravity, β the coefficient of expansion, ν the viscosity, D_i the diameter of the inner cylinder and D_u of the exterior cylinder.

Van der Held ⁶⁾ has remarked that $\zeta = f(Gr, Pr)$ if in Gr we take $\delta = (D_u - D_i)/2$ instead of D_i . All measurements of ξ done within the region

$$7 < Pr < 4000$$

$$0,1 < Gr < 10^8$$

$$0,25 \cdot 10^{-3} < \delta < 0,285$$

are given in figure 4 where $\log(\xi)$ is plotted against $\log(Gr \cdot Pr)$ with $Gr = g\beta\theta\delta^3/\nu^2$. We remark that for $Gr \cdot Pr = 1000$ to 1200 the convection becomes important. If

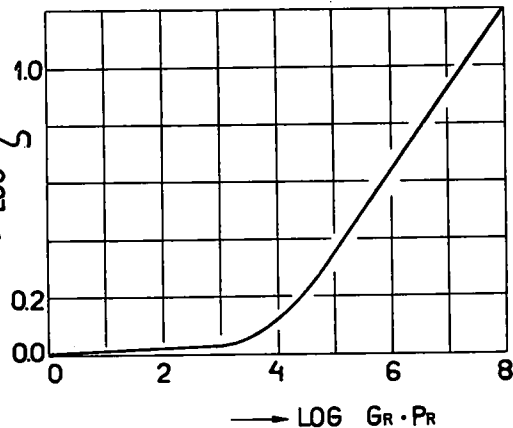


Fig. 4. The increasement of the conductivity by convection.

we want to use this result, we have to remember that all these

measurements are done with a constant field of temperature, while we have a non stationary field of temperature. In our case we can consider the exterior cylinder as an expanding cylinder at the place where the temperature begins to rise. It makes no difference to the convection whether there is liquid or a wall outside this coaxial cylinder.

The temperature difference of the two cylinders in our case is given by:

$$\theta_r - \theta_{r_0} = \frac{q}{2\pi\lambda} (\ln r - \ln r_0) \quad \delta = r_0 \left\{ \exp \left(\frac{2\pi\lambda\theta}{q} \right) - 1 \right\}$$

$$q = \frac{4\pi\lambda\theta}{\ln (4at/r_0) - 0,5772}$$

$$\delta = r_0 \left\{ \exp \frac{1}{2} \left(\ln \frac{4at}{r_0^2} - 0,5772 \dots \right) - 1 \right\}$$

So we obtain

$$Gr.Pr = \frac{g\beta\theta}{\nu.a} r_0^3 \left\{ \exp \frac{1}{2} \left(\ln \frac{4at}{r_0^2} - 0,5772 \dots \right) - 1 \right\}^3$$

We have determined *Gr.Pr* at the time after which a deviation of the straight line starts for 8 liquids of which *a*, ν and β are wellknown.

We found a mean value of *Gr.Pr* = 1070. As this value is in very good agreement with the critical point of the convection as found by Kraussold⁷⁾ we can conclude that the last point of the measurements is fixed by *Gr.Pr* = 1070.

With this critical value we find for our apparatus as the final time of the measurement:

$$t_e = \frac{2}{3} \left\{ \left(\frac{\nu}{\beta\theta\sqrt{a}} \right)^{1/3} + \frac{0,03}{\sqrt{a}} \right\}^2 \text{ seconds.}$$

In table I the calculated t_e and the t_e found by measurement are given for eight liquids.

TABLE I

Liquid	<i>q</i>	Gr.Pr.	θ	t_e measured	t_e calculated
Water	2,830	1365	2,40	16	16,4
Pentanol	0,835	812	3,25	50	55,3
Methanol	0,835	1145	2,22	20	19,6
Aniline	0,835	785	2,86	50	59,9
Carbon Tetrachloride	0,835	1100	2,72	18	17,6
Benzene	0,835	1100	2,59	18	18,2
Acetone	0,835	1310	2,33	16	15,0
Chloroform	0,678	935	1,78	16	17,2

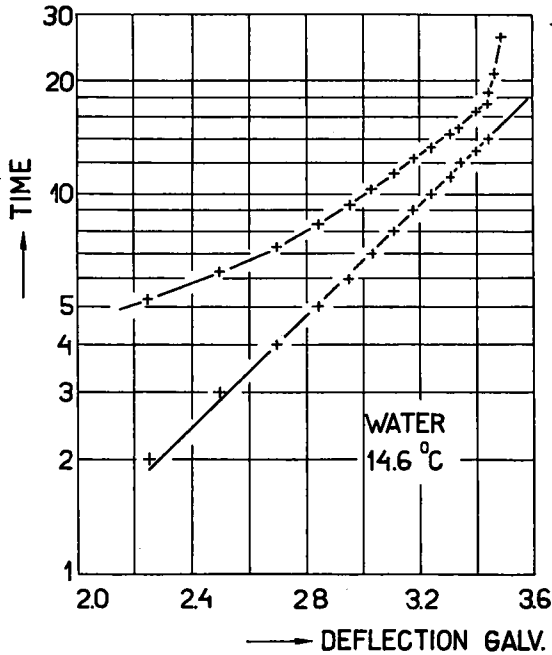


Fig. 5. Plot of log time versus deflection of the galvanometer without and with t_0 correction for water.

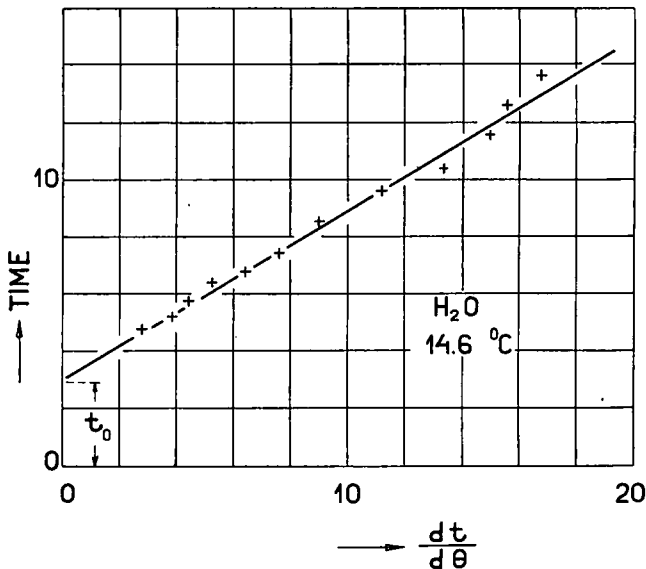
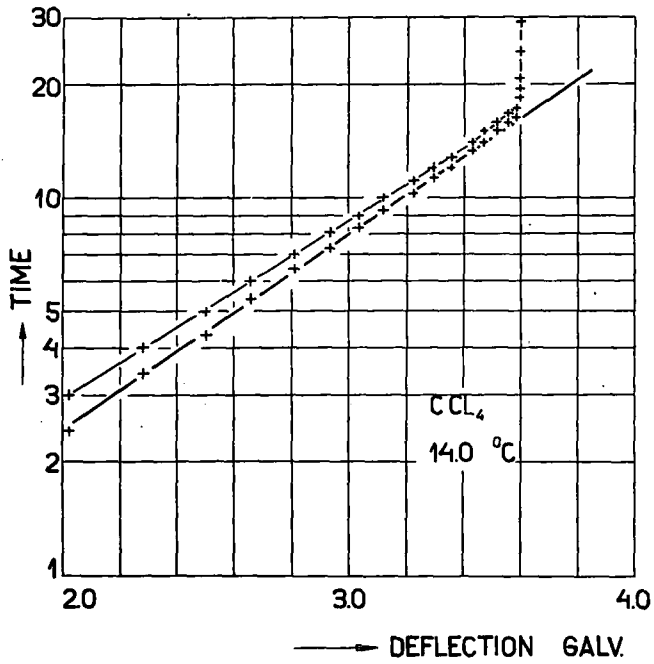
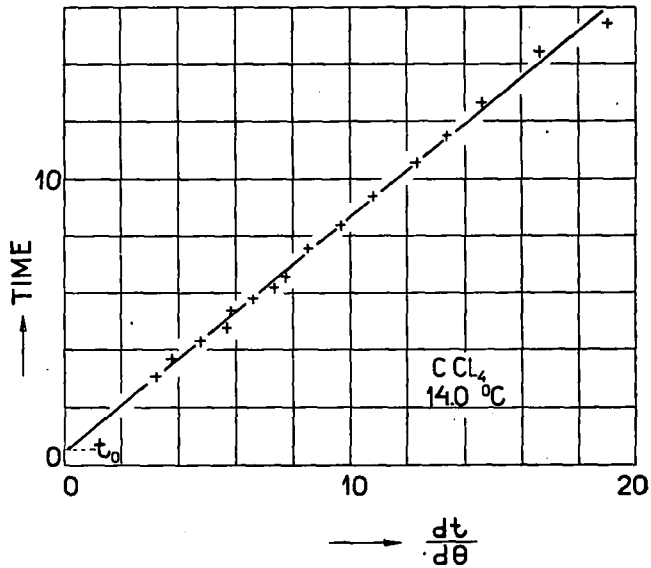


Fig. 6. Determination of the t_0 correction.

The results of the measurements. As the thermal conductivity of water had been measured by many experimenters, we also began our experiments with water. In figure 5 for one of our measurements

Fig. 7. As fig. 5 for CCl₄.Fig. 8. As fig. 6 for CCl₄.

In t is plotted against θ . In figure 6 t is plotted against $\partial t/\partial \theta$ and this gives t_0 . After correction with t_0 in figure 5 we find the straight line with the slope $q/4\pi\lambda$. This straight line is fixed by the points between $t = 4$ seconds and $t = 16$ seconds (table I). The same has been done for CCl_4 in figures 7 and 8. For water we measured the

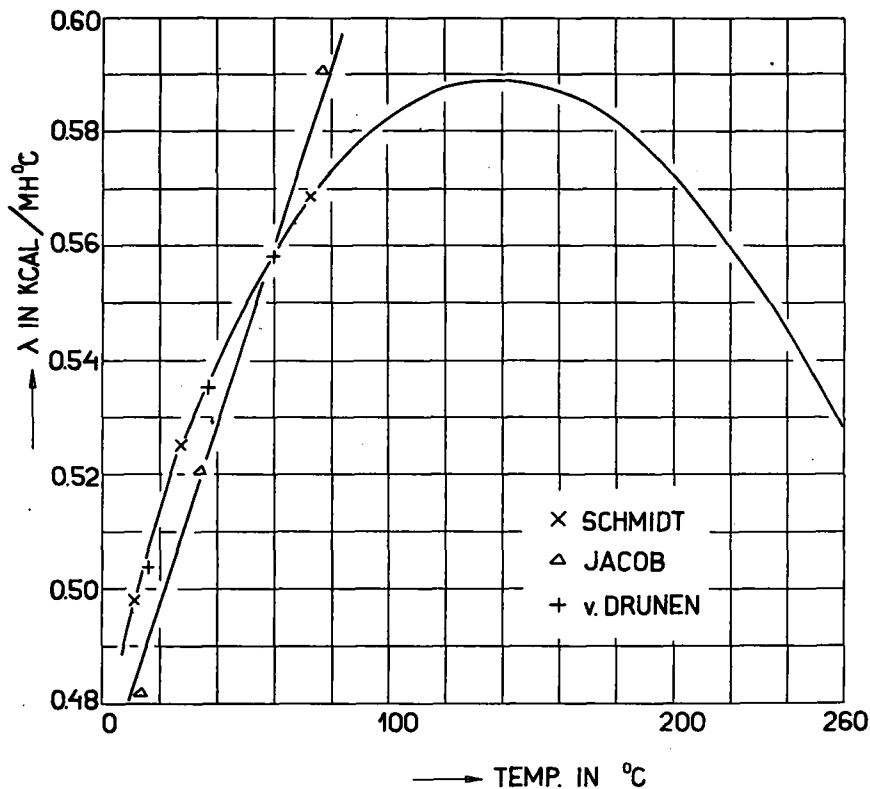


Fig. 9. Measurements of the conductivity of water at different temperatures by Schmidt, Jacob and Van Drunen.

thermal conductivity at different temperatures and the result is given in figure 9. Besides many organic liquids we measured some inorganic acids of which the results are given in table II.

TABLE II

Liquid	η	mean temperature °C	t_0 sec	t_2 sec	λ kcal/mh°C	$\lambda \cdot 10^4$ cal/cm sec °C
Pentanol	0,835	17,5	1,0	50	0,121	3,36
Methanol	0,835	15,1	1,3	20	0,171	4,75
Aniline	0,835	16,4	1,5	50	0,157	4,35
Carbon tetrachloride	0,835	14,0	0,6	18	0,092	2,56
Bromobenzene	0,835	16,4	0,9	20	0,095	2,64
Amylbromide	0,835	18,0	0,4	18	0,0845	2,35
Benzene	0,835	22,5	1,2	18	0,136	3,78
Acetone	0,835	16,1	1,6	16	0,163	4,53
Aceticacid Amylester	0,835	20,0	1,2	20	0,111	3,08
Chloroform	0,678	15,9	0,9	16	0,104	2,89
Aceticacid Ethylester	0,678	16,0	0,8	19	0,128	3,56
Hydrogen Bromide (48%)	1,932	17,7	1,8	21	0,377	10,5
Hydrogen Chloride (38,1%)	2,830	21,8	3,4	22	0,498	13,8
„ „ (18,2%)	2,830	21,3	3,4	21	0,505	14,0
„ „ (9,1%)	2,830	21,2	3,2	20	0,515	14,3
Nitric acid (50%)	2,643	17,0	1,9	35	0,355	9,86
„ (30%)	2,643	17,1	2,4	28	0,418	11,6
„ (20%)	2,643	17,1	2,6	24	0,457	12,7
„ (10%)	2,643	17,3	2,9	22	0,475	13,2
Phosphoric acid (86%)	2,830	19,4	1,6	35	0,401	11,15
„ (64,5%)	2,830	19,6	1,8	30	0,428	11,9
„ (32,3%)	2,830	19,6	1,9	28	0,468	13,0
Perchloric acid (66%)	1,932	24,8	2,2	26	0,147	4,09
Acetic acid (97%)	1,932	22,6	1,2	20	0,334	9,28

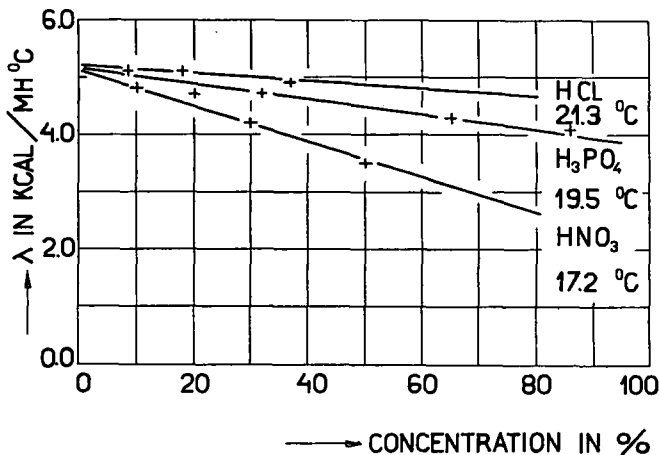


Fig. 10. The influence of the concentration on the conductivity for HCl, H_3PO_4 and HNO_3 in water.

For some inorganic acids we measured the variation of the thermal conductivity with concentration. We always found a linear dependence as given in figure 10. All given values of the thermal conductivity, are means of four or more measurements. The total error of the measurements is less than 2%. The results are in good agreement with the known thermal conductivities of some liquids. The dependence of the thermal conductivity on temperature as found with a very complicated apparatus by E. Schmidt and W. Sellschopp⁸⁾ is confirmed by our rapid method up to 60°C (figure 9). With this we have found a method which fulfils our aim.

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