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Physics. — *"Isotherms of diatomic gases and their binary mixtures. VIII. The breaking stress of glass and the use of glass tubes in measurements under high pressure at ordinary and low temperatures".* By Dr. H. KAMERLINGH ONNES and Dr. C. BRAAK. (Communication n°. 106 from the Physical Laboratory at Leiden by Dr. H. KAMERLINGH ONNES).

(Communicated in the meeting of April 24, 1908).

§ 1. *Introduction.* With former determinations of isotherms (Comms. n^{os}. 78 April 1902, 97^a March 1907, 99^a Sept. 1907, 100^a and 100^b Dec. 1907, 102^a Dec. 1907 and 102^b Febr. 1908) we could not raise the pressure above 60 atm. For in order to reach the required accuracy of about $^1/_{2000}$ we want a manometer which is reliable to the same degree. And till now we could only reach this degree of accuracy by means of a calibration with the open manometer described in Comm. n°. 44 (Nov. 1898) which reads to 60 atm. only. Already long ago we intended to include the higher pressures in our investigation. As a first step in that direction we have raised the upper limit of the pressure to 120 atmospheres. For while keeping the same arrangement we could easily complete the existing open manometer to one of the same accuracy reading to 120 atmospheres by merely adding a number of new manometer tubes of greater resisting power than those we had.

The new manometer and also the other apparatus intended for pressures to 120 atmospheres are nearly completed and will soon enable us to determine the isotherms to 120 atm. Afterwards we hope that these will be followed by measurements at still higher pressures. It seems even possible to reach 500 atmospheres with almost the same accuracy.

For all these investigations it is a great advantage when the piezometer- and barometer tubes can be made of glass. Therefore we have investigated in how far this would be possible with regard to the breaking stress of glass.

The breaking stress of glass has been investigated most at ordinary temperature, because it is in the first place desirable that the reservoirs of the manometer tubes of the open manometer and the divided stems of the piezometer tubes should be made of glass.

To these measurements we have added a series of determinations at lower temperatures in order to judge to what extent glass piezometer reservoirs could be used for the higher pressures at these temperatures.

Investigations on the maximum strain of glass have been made by GALITZIN [1]) and by WINKELMANN and SCHOTT [2]). The former has determined the inner pressure which cylindrical glass tubes can resist, the latter two have determined the maximum strain of glass rods. GALITZIN's determinations, however, were made only at relatively small pressures, those of WINKELMANN and SCHOTT only at ordinary temperature.

In our investigation we partly follow the method of GALITZIN. From the theory of elasticity we can derive in connection with the dimensions of the apparatus the maximum tension in the glass from the maximum pressure which the glass tube resists. The results obtained in this way were compared with the direct data obtained in a second series of measurements, where the maximum strain of glass rods was determined. If we take into consideration the material investigated, it is not astonishing that the results of the two series show irregular differences. These differences however are of no influence upon some general conclusions that may be drawn from the measurements.

§ 2. *Determinations at ordinary temperature.*

Survey of the observations and arrangement of the measuring apparatus.

1. *Determination of the maximum inner pressure.*

The experiments were made with ordinary Thüringer glass. A cylindrical reservoir of the glass to be investigated was fused on to a thick walled glass capillary. The capillary was provided at its end with a steel nut with a hexagonal part by means of which it could be screwed on to a steel capillary which is connected to a pressure pump with a metal manometer. For measurements to 200 atms. it was fixed on the glass by means of sealing wax, for higher pressures it was soldered to the glass (comp. Comm. N°. 99^a § 15, October 1907). If carefully made this connection proved able to resist the highest pressures (1200 atms.) The tubes were previously annealed carefully.

According to their dimensions they can be divided into three kinds:

a. thick-walled tubes with large inner bore.

b. thick-walled capillaries.

c. thin-walled tubes with large inner bore.

It will appear that these three kinds of tubes give results different for each group.

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[1]) Bull. de l'Acad. Imp. des Sciences de St. Pétersbourg, V^e Serie, B. XVI N^o. 1.

[2]) Wied. Ann. 51.

The accuracy of the manometer is about 2 $^0/_0$, which is quite sufficient for our purpose.

2. *Direct measurement of the maximum strain* T_m *by the determination of the breaking stress.*

In order to prevent as much as possible unequal strain during the suspension we have used here glass threads of at the most 0.6 mm. thickness [1]).

In order to reduce the tensions to minimum the glassrod was bent to a hook at either end. It was then suspended by the upper hook and the rod was drawn out in the middle to a thread by applying a certain force to the lower hook in about the same way as in the actual experiment. The weight used was a beaker into which water flowed.

§ 3. *Results.*

1. *Determinations with cylindrical tubes and internal pressure.*

In order to facilitate a comparison with Galitzin's results we take the same value $\frac{1}{4}$ for the coefficient of contraction. Let P_m be the maximum internal pressure, $2R$ the external diameter, $2R'$ the inner diameter (this is further on expressed in mm), and let $n = \frac{R}{R'}$, then we can represent the maximum tension T_m in the glass, (in this case that of the internal portions of the glass in a direction perpendicular to the axis of the cylinder) by:

$$T_m = \frac{1}{4}\left\{5P_m + 7\left(\frac{P_m - 1}{n^2 - 1} - 1\right)\right\}.$$

If, as is the case in the following tables, P_m is expressed in atmospheres, we find T_m expressed in KG/mm^2 (as it is given in the following tables) by multiplying the value found above by 0.01033.

For the three series mentioned in § 2 sub *a*, *b* and *c* the results have been combined in the table below. The meaning of the columns will be clear after what has just been said. Where several results are given under one number we have after the tube had partly burst (for instance so that only the end had broken off, or the tube had broken near the steel piece) used the same tube again for the following experiment.

The results for T_m are lowest for series *a* and highest for series *b*. In the last series this is especially the case for the tubes with a very

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[1]) In the experiments of Winkelmann and Schott where thicker rods of 10—20 mM². section were used this required great care.

TABLE I. Maximum internal pressure and tension of cylindrical glass tubes.

No.	$2R$	$2R'$	n	P_m	T_m
Series *a*					
1	9.3	3 5	2.66	340	5 38
2	8.8	4.0	2.20	280	4.91
3	8 7	4 2	2 07	230	4.21
4	9.4	3.2	2 94	270	4 10
5	9 2	3 0	3 07	380	5 70
6	9.7	4.2	2.31	370	6 30
7	10 4	4 0	2.60	240	3.83
8	12 8	5.8	2.21	260	4.54
9	17.6	5.0	3 52	290	4 19
Series *b*					
10	7.4	1.00	7 40	510	6.74
11	6 8	1.00	6.80	420	5 57
12	7.5	0.27	27 78	460	5 93
13	6.5	0 35	18.57	500	6 46
14	6 7	0 24	27.92	540	6.97
				800	10.33
				1100	14.21
15	6 7	1.08	6.20	530	7.08
16	5.9	0.70	8.43	680	8.94
17	5 8	0.46	12.61	1200	15.61
18	5 9	0.62	9.52	820	10.74
19	5.3	0.46	11 52	920	11.99
20	5 5	0 46	11.96	1060	13.80
21	6 6	1.00	6.60	660	8.78
22	7.2	1.40	5.14	520	7.07
23	6.4	1.35	4.74	520	7 13
Series *c*					
24	3.8	2.42	1 57	283	7 12
25	5.6	4.00	1 40	193	6.09
26	6.4	4.78	1.34	221	7 84
27	6.9	3.91	1 76	329	7.06
28	7.4	5.11	1.45	179	5 21
29	7.9	5.46	1.45	157	4 57
30	3 5	2 26	1.54	261	6.78
31	6.8	5.13	1.32	203	7.52
32	7 4	5.19	1 43	201	6.04
33	6 8	5.78	1.18	66	3.83
34	3 8	2.42	1 57	377	9.49
35	3.8	2.50	1.52	277	7.36
36	6.0	4 37	1.37	179	5.96
37	6 8	5.17	1.31	159	6.02
38	6.8	4.85	1.40	169	5 33
39	7.3	5 62	1.30	109	4.22
40	7 8	7.31	1 067	54	7.60

small inner bore if we except nos. 12 and 13 where the soldering was ineffective. Helped by the experience made we have treated the following tubes more carefully. With the tubes which have burst under a too low pressure the existence of irregular tensions appears clearly from the way of bursting, where the break has a transverse or irregular direction and not, as theory requires, parallel to the axis.

2. *Maximum strain of glass threads.*

The diameter of the threads lies between 0.1 and 0.6 mm. The results are combined in the two following tables. The bore was determined by a measurement of the diameter in two directions at right angles. The mean of these two measurements is given in the tables. The first table contains the results obtained with glass threads which have undergone only the operation mentioned sub § 2. To investigate the influence of irregularities which thus may remain in the structure of the glass we have made a series of measurements by means of threads which had beforehand been heated to incandescence and then cooled very slowly. The results of this series are combined in table III.

TABLE II. Maximum strain of uncooled glass threads.

Stress in grams	Diameter in mm	T_m in KG/mm^2	Stress in grams	Diameter in mm.	T_m in KG/mm^2
257.6	0.119	23 1	2615	0.424	18.4
496.5	0 192	17.5	2785	0.446	17.8
457.8	0.159	22.9	1425	0.351	14.7
2325	0 384	19.8	1635	0.370	17.5
1175	0.257	22.7	1325	0.325	16.0
1475	0.325	17.6	1555	0.298	22.4
1695	0.311	22.4	2335	0.370	21.5
4105	0.487	22.1			

Except the thread for which T_m is lowest viz. 14.7 all the threads of table II show where broken a sharply ridged structure while we find at the edge a small semicircular smooth spot as was found by Winkelmann and Schott[1]).

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[1]) p. 718 loc. cit.

TABLE III. Maximum strain of cooled glass threads.

Stress in grams	Diameter in m.m.	T_m in $KG./mm^2$	Stress in grams	Diameter in m.m.	T_m in $KG./mm^2$
2920	0.438	19.4	1910	0.325	23.4
3530	0.597	12.6	1760	0.322	21.6
2120	0.532	9.5	2850	0.445	18.3

With regard to the series of table III we may remark the following. In order to prevent changes of form of the threads suspended in the furnace and softened by the heat under the influence of gravitation, which afterwards during the measurements might give rise to irregular tensions, we have shaped the extremities (cf. § 2) not into hooks as in the former series but to closed rings in such a way that the whole becomes as symmetrical as possible with regard to a plane through the longitudinal axis. A comparison of the tables II and III shows that the two methods lead to the same results.

Of the glass thread with the lowest T_m (cf. table III) the section was little ridged but smooth, to the next value of T_m ($= 12.6$) belonged a relatively large smooth semicircular spot, while for the highest T_m ($= 23.4$) no spot was to be seen, but the whole section showed a very sharply ridged structure. All these facts agree with what has been found by Winkelmann and Schott [2]).

On the plate we show the structure of the sections of a couple of threads at the place where the thread has broken. They both clearly show the smooth parts and the structure radiating thence. The smallest diameter of the sections is 0.530 and 0.555 mm. respectively.

§ 4. *Conclusions.*

Table I shows that as to the series *a* and *c* our results agree tolerably well with those of Galitzin [1]).

Those of the series *b*, however, show that the result derived by him for the maximum internal pressure, viz. 623 atms. is too low, because the highest pressure observed by us is 1200 atms. For the tubes of the series *b* T_m appears to lie higher than would be expected from the observations in the two other series. Probably this must be explained as follows. From a comparison between the 3 series

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[1]) loc. cit.

[2]) Table I p. 12 and 13, loc. cit.

it appears that series *a* gives the lowest results for T_m, series *b* the highest. The fact that the values for *a* are lower than for *c*, must probably be ascribed to the circumstance that with almost equal internal bores the wall is thickest for the first series and hence the chance of abnormal stresses is greater. For series *b* the wall is thicker than for *c*, but the inner bore is much smaller, and hence the existence of inequalities and scratches on the surface which unfavourably influence the breaking stress [1]) are reduced to a minimum. For the tubes for which $2R' = 1$ mm. it seems that the two factors neutralize each other, for those with the smaller inner bore the favourable influence of the surface being smaller preponderates.

In order to investigate in detail in how far the above mentioned two unfavourable factors influence T_m we have applied the direct determination with thin glass threads of which the surface is as smooth as possible and where owing to the small bore abnormal tensions are necessarily small. The results which are much higher than those of WINKELMANN and SCHOTT, agree with those found by means of the first method and seem to justify the supposition made above about the unfavourable influence of a not perfectly smooth surface and inner abnormal stresses. They point to an upper limit for $P_m = 1700$ atms.

§ 5. *Determinations at low temperatures.*

The determinations in liquid air were made in the same way as those at ordinary temperature. The lower hook of the glass thread was fastened to a wooden bearer, placed beside the thread in a vacuum glass with liquid air. The first determinations gave results which differed much from the later ones. Their mutual agreement is very bad and they are characterized by very high values for the maximum strain, which vary from 44 to 73 KG. per mm.^{2} while for the ordinary temperature the highest strain was 23 KG. per mm.^{2}. Also the structure of the section was totally different, being scarcely ridged but smooth. The smooth spot on the section was as a rule missing. In these measurements the threads were pulled asunder almost immediately after they had been placed in liquid air. Before the following measurements they were left at least 20 minutes in the bath of low temperatures. The latter gave lower results with a better mutual agreement. The structure of the section is similar to that at ordinary temperature, generally a little less distinct. The results are combined in the following table.

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[1]) Cf. WINKELMANN and SCHOTT, loc. cit.

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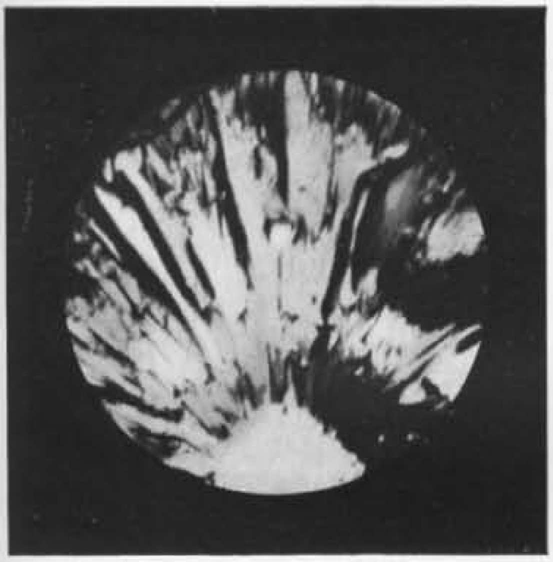

Fig. 1.

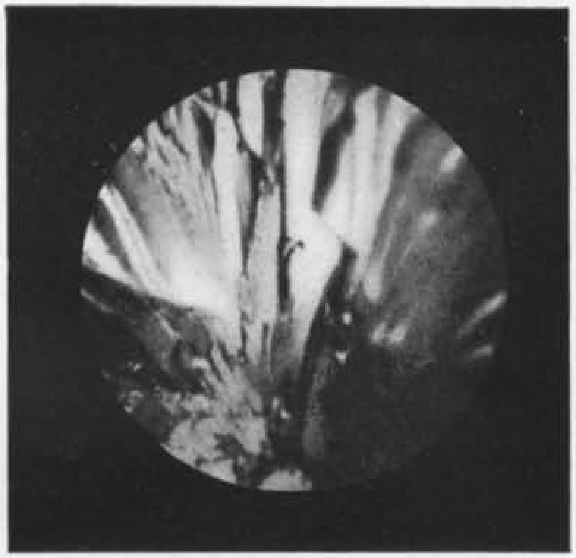

Fig. 2.

TABLE IV. Maximum strain of glass threads at the temperature of liquid air.

Stress in grams.	Diameter in mm.	T_m in KG/mm^2	Stress in grams.	Diameter in mm	T_m in KG/mm^2
1993	0.280	32.4	2498	0.297	35.9
2653	0.372	24.3	2055	0.286	31.9
2523	0.290	38.2	3550	0.359	35.1
1293	0.236	29.5	3865	0.396	31.3

The results are still much higher than for the ordinary temperature, a very favourable result for measurements at low temperature.

Lastly a single determination in liquid hydrogen was made. Fifteen minutes after the thread had adopted the temperature of the bath it was pulled asunder. The total weight was 3013 grams, the diameter 0.271 m.m., hence the maximum strain in $^{KG}/_{mm^2} = 52.1$ again much higher than at the temperature of liquid air. The structure of the section was striated, unridged and no smooth part occurred.

Zoology. — *"Poterion a Boring Sponge."* By Prof. G. C. J. Vosmaer.

(Communicated in the meeting of May 30, 1908).

In 1822 Hardwicke published [1]) a short notice on a remarkable "Zoophyte, commonly found about the Coasts of Singapore Island." The author stated that it belonged to the Sponges, and called it *Spongia patera*. Evidently not acquainted with this publication Schlegel 1858 [2]) proposed the name *Poterion neptuni* for a sponge, which universally is considered to be identical with Hardwicke's sponge. According to the rules of nomenclature the object has, consequently, to be called *Poterion patera* (Hardw.), as first pointed out by Sollas [3]).

Both Hardwicke and Schlegel state that the sponge is fairly common. No wonder that this object, which presents itself as a gigantic cup, with a height of more than 1 M. and an aperture of 30 cm. or more, drew the attention of sailors. It is also found in many museums, especially in Holland. The Leyden Museum of Natural History, the Museum of the Utrecht University and the Museum of the Amsterdam Zoological Gardens ("Artis") possess beautiful specimens, together more than 30. This rich material induced Harting

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[1]) Asiatic Researches XIV, p. 180.

[2]) Handleid. Dierkunde II, p. 542.

[3]) Ann. en Mag. Nat. Hist. (5) VI, p. 441 (1880).