Physics. — *The use of the effect of pressure on the electrical resistance of manganin as a method of measuring pressure.* By A. MICHELS and M. H. LENSSEN. (25th Communication of the "VAN DER WAALS-Fund".) (Communicated by Prof. J. D. VAN DER WAALS Jr.)

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Introduction.

As a result of work on the influence of pressure on the electrical resistance of gold and platinum [1]) it was decided to investigate the accuracy that could be obtained in measuring pressure by means of this effect. Following BRIDGMAN [2]), manganin was chosen because of its small temperature coefficient.

It was first necessary to investigate the treatment required by this material in order to ensure its constancy.

Apparatus.

As with the measurements with gold [1]), the actual resistance of the wire under pressure was not measured but a differential method was used. In this, the ratio of the resistances of the wire under pressure and of a similar wire at the same temperature but not under pressure was determined. No advantage could be gained by measuring the actual resistance of the wire owing to the uncertainty of the composition of manganin.

To obtain equality of temperature the method previously described [1]) was modified in that the wires were placed in two symmetrical holes drilled in the same steel block which was placed in a thermostat. Connection was made from one of these holes to the pressure apparatus. A diagram of the pressure vessel is shown in Figure 1.

As the temperature coefficients of the wires differed only very slightly, the effect of small fluctuations in temperature was eliminated and the accuracy of the measurements thereby increased. The absolute values of these coefficients are not obtained, but, on the other hand, the value of the difference between them is, and this latter alone can affect the accuracy of the method for purposes of pressure measurement.

The manner of suspending the wires was changed in order to be more certain that they were free from strain. They were not wound on glass

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[1]) 15th, 17th and 18th Communication of the VAN DER WAALS-Fund. These Proc. **29**, 1106, 1926; **30**, 47, 1927; **31**, 50, 1927.

[2]) P. W. BRIDGMAN, Proc. Am. Acc. Arts and Sc. **47**, 335, 1911.

but in rectangular grooves, 0.9 mm deep and 0.8 mm wide, cut on porcelain tubes in which the 0.2 mm wires could lie without strain. Thin glass tubes

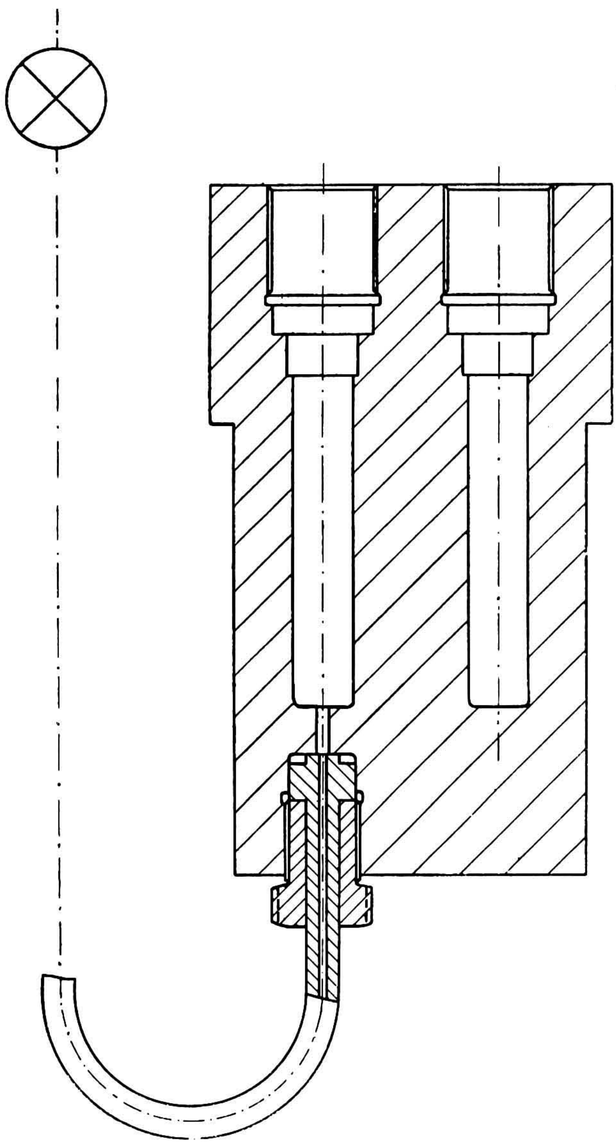

Fig. 1.

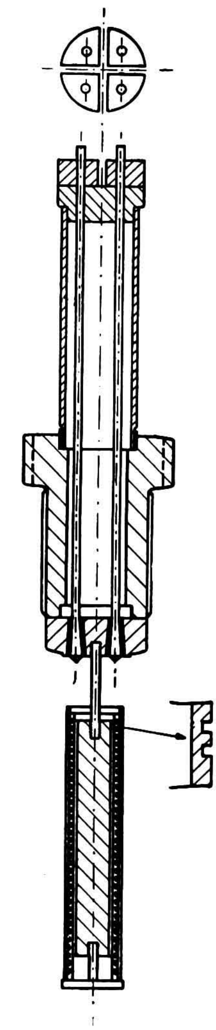

Fig. 2.

were slipped over the porcelain tubes to prevent the wires from slipping out of the grooves. The suspension of the wires is shown in Fig. 2.

"Orca" [1]) was used as the insulating material for the leads through the steel vessel.

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[1]) We are greatly indebted for this to the late Prof. MOIREU of Paris.

The electrical circuit used was the same as that described in Communication N^{0}. 18 (loc. cit.).

Method.

The wire to be subjected to pressure was of hard drawn manganin while the other was first heated at ca. 140° C. for one hour. The ratio of the resistance of the wires, and, therefore, the resistance of the first one, was found to decrease slowly with time, the rate of this decrease being greater at higher temperatures. In order to make correction for this effect the rate was determined before or after each set of measurements. (See Table I.)

TABLE I.
Change per hr. of Ratio of Resistance of wire under pressure to that of comparison wire $\times 10^7$.

	70° C.	51° C.	41° C.	31° C.	20° C.
					— 3^5
				— 17^5	— 2^5
			— 70^5	— 16^5	— 1^5
		— 445	— 47	— 10	— 1
	— 1592	— 84	— 31^5	— 7	— 1^5
After heating at 100° C.	— 51	— 6	— 4	— 1	—
After heating at 148° C.	— 5	—	+ 3	—	—

Measurements were first made at a temperature of ca. 20° C. and at pressures increasing by about 200 atms up to ± 1000 atms and then decreasing by the same amounts back to 1 atm.

The wires were then heated at ca. 30° C. for some time and measurements made at this temperature in a similar way. The measurements at 20° C. were then repeated and were found to give somewhat different results.

The following scheme of measurements was therefore carried out :

Wires heated to ca.	40°, Measurements made at ca.	40, 30, 20°
	50°	50, 40, 30, 20°
	70°	70, 50, 40, 30, 20°
	100°	70, 50, 40, 30, 20°
	148°	70, 50, 40, 30, 20°

(In the last case the wire to be put under pressure was removed and this alone was heated.)

Results and Conclusions.

Table II shows the values of the ratio at the various pressures obtained at 20° C. and at the highest temperatures after different heat treatments. It

TABLE II. Ratio of Resistance of wire under pressure to that of comparison wire.

Pressure in Kg/cm^2	Time h m	Pressure increasing	Time h m	Pressure decreasing	Time h m	Pressure increasing	Time h m	Pressure decreasing
						19°.9 C.		
1.0					0.00	0.979 9994	4.30	0.979 9988
189.1					0.45	0.980 4292	4.05	0.980 4281
419.6					1.15	0.980 9526	3.40	0.980 9520
650.3					1.35	0.981 4767	3.15	0.981 4765
881.1					2.00	0.982 0003	2.50	0.982 0003
1062.8					2.20	0.982 4126		
		31°.0 C.				19°.9 C.		
1.0	0.00	0.979 9179	3.15	0.979 9135	0.00	0.979 8833	3.20	0.979 8829
189.1	0.20	0.980 3468	2.55	0.980 3423	0.20	0.980 3114	2.55	0.980 3113
419.6	0.40	0.980 8701	2.35	0.980 8675	0.40	0.980 8353	2.35	0.980 8350
650.3	1.05	0.981 3951	2.20	0.981 3932	1.00	0.981 3591	2.15	0.981 3590
881.1	1.25	0.981 9189	2.00	0.981 9170	1.15	0.981 8828	1.55	0.981 8828
1062.8	1.40	0.982 3313			1.35	0.982 2950		
		40°.8 C.				19°.9 C.		
1.0	0.00	0.979 8223	3.50	0.979 7957	0.00	0.979 6917	3.15	0.979 6913
189.1	0.30	0.980 2476	3.25	0.980 2275	0.20	0.980 1192	2.55	0.980 1191
419.6	1.20	0.980 7667	3.05	0.980 7559	0.40	0.980 6431	2.35	0.980 6427
650.3	1.35	0.981 2913	2.45	0.981 2828	1.00	0.981 1664	2.15	0.981 1666
881.1	1.50	0.981 8141	2.25	0.981 8107	1.20	0.981 6904	1.55	0.981 6898
1062.8	2.05	0.982 2259			1.35	0.982 1020		
		51°.5 C.				19°.9 C.		
1.0	0.00	0.979 5121	3.19^5	0.979 4318	0.00	0.979 1610	4.15	0.979 1612
189.1	0.19	0.979 9319	2.58^5	0.979 8700	0.30	0.979 5881	3.50	0.979 5885
419.6	0.38	0.980 4500	2.38^5	0.980 4036	1.30	0.980 1116	3.30	0.980 1116
650.3	1.01	0.980 9664	2.21	0.980 9355	1.50	0.980 6349	3.10	0.980 6349
881.1	1.19	0.981 4849	1.58	0.981 4694	2.10	0.981 1582	2.50	0.981 1579
1062.8	1.38	0.981 8909			2.30	0.981 5695		

TABLE II (*Continued*).

Pressure in Kg/cm²	Time h m	Pressure increasing	Time h m	Pressure decreasing	Time h m	Pressure increasing	Time h m	Pressure decreasing
		70°.0 C.				**19°.9** C.		
1.0	0.00	0.978 9081	3.20^5	0.978 4045	0.00	0.977 8046	3.25	0.977 8048
189.1	0.20^5	0.979 2735	3.00^5	0.978 8783	0.30	0.978 2301	3.05	0.978 2307
419.6	0.46	0.979 7274	2.42	0.979 4467	0.50	0.978 7518	2.45	0.978 7520
650.3	0.59^5	0.980 2156	2.20^5	0.980 0218	1.05	0.979 2742	2.25	0.979 2734
881.1	1.21	0.980 6861	4.01^5	0.989 5918	1.25	0.979 7952	2.05	0.979 7951
1062.8	1.41	0.981 0523			1.45	0.980 2062		
		70°.0 C.				**19°.9** C.		
1.0	0.00	0.972 8144	3.01	0.972 8036	0.00	0.972 7522	3.20	0.972 7524
189.1	0.22	0.973 2369	2.41	0.973 2291	0.20	0.973 1740	3.00	0.973 1739
419.6	0.37	0.973 7573	2.22	0.973 7503	0.40	0.973 6908	2.40	0.973 6911
650.3	0.55	0.974 2764	2.04	0.974 2717	1.00	0.974 2075	2.20	0.974 2077
881.1	1.14	0.974 7957	1.48	0.974 7933	1.20	0.974 7243	2.00	0.974 7246
1062.8	1.31	0.975 2045			1.40	0.975 1316		
		70°.0 C.				**19°.9** C.		
1.0	0.00	0.965 3366	3.20	0.965 3355	0.00	0.965 3609	3.20	0.965 3608
189.1	0.20	0.965 7559	3.00	0.965 7548	0.20	0.965 7772	3.00	0.965 7777
419.6	0.50	0.966 2695	2.40	0.966 2688	0.40	0.966 2884	2.40	0.966 2883
650.3	1.05	0.966 7834	2.20	0.966 7830	1.00	0.966 7992	2.20	0.966 7992
881.1	1.25	0.967 2970	2.00	0.967 2971	1.20	0.967 3097	2.00	0.967 3098
1062.8	1.40	0.967 7016			1.40	0.967 7119		

can be seen from the figures that, after heat treatment, the variation of the resistance of manganin with pressure for lower temperatures was sufficiently reproducible to make it possible to use this effect to measure pressure. This may be more clearly seen when the figures are taken in conjunction with the values of the corresponding pressure coefficients for the different ranges of pressure. (Table III.) The accuracy of the method depends only on the constancy of the pressure coefficient over the whole pressure range and not on its actual value.

The greatest difference between the pressure coefficients, after the final heat treatment, is $^{3}/_{2300}$ which, over a pressure range of 200 atms.

TABLE III.
Pressure coefficient $\times 10^9$.

Pressure range in Kg/cm^2		19°.9 C.
1.0 — 189.1		2331
189.1 — 419.6		2318
419.6 — 650.3		2318
650.3 — 881.1		2316
881.1 — 1062.8		2315
	31°.0 C.	19°.9 C.
1.0 — 189.1	2327	2324
189.1 — 419.6	2321	2319
419.6 — 650.3	2323	2317
650.3 — 881.1	2316	2316
881.1 — 1062.8	2321	2315
	40°.8 C.	19°.9 C.
1.0 — 189.1	2327	2321
189.1 — 419.6	2326	2319
419.6 — 650.3	2324	2316
650.3 — 881.1	2322	2316
881.1 — 1062.8	2320	2313
	51°.5 C.	19°.9 C.
1.0 — 189.1	2324	2320
189.1 — 419.6	2327	2318
419.6 — 650.3	2328	2316

(*Continued*)

Pressure range in Kg/cm^2	51°.5 C.	19°.9 C.
650.3 — 881.1	2320	2315
881.1 — 1062.8	2322	2313
	70°.0 C.	19°.9 C.
1.0 — 189.1	2283	2315
189.1 — 419.6	2349	2314
419.6 — 650.3	2309	2313
650 3 — 881.1	2318	2310
881.1 — 1062.8	2321	2313
	70°.0 C.	19°.9 C.
1.0 — 189.1	2317	2305
189.1 — 419.6	2322	2305
419.6 — 650.3	2318	2302
650.3 — 881.1	2319	2303
881.1 — 1062.8	2318	2303
	70°.0 C.	19°.9 C.
1.0 — 189.1	2310	2295
189.1 — 419.6	2309	2295
419.6 — 650.3	2308	2294
650.3 — 881.1	2307	2292
881.1 — 1062.8	2306	2292

corresponds to an uncertainty of about $\pm$ 150 gms/cm^2. This difference is equivalent to a change of 5 in the last figure given for the ratio. One in the latter, however, is equivalent to $^1/_{10000}$ ohm in the resistance box which is of the order of the contact resistance at each plug, so that this last figure is uncertain. A greater accuracy for the measurement of pressure might be obtained by using a more sensitive electrical circuit.

Qualitative conclusions can also be drawn from the measurements that have been made.

As would be expected the resistance was lowered by the heat treatment (v. Table II).

It can be seen from Table III that the pressure coefficients increase with increasing temperature and therefore that the temperature coefficient is increased by increasing the pressure [1]).

Any pressure hysteresis that might have occurred was masked in the figures obtained by the change of the resistance with time. Table IV shows

TABLE IV.

70° C.			51° C.			41° C.			31° C.			20° C.		
Δ	C	Δ_{corr}	Δ	C	Δ_{corr}	Δ	C	Δ_{corr}	Δ	C	Δ_{corr}	Δ	C	Δ_{corr}
												6	16	10
									44	57	13	4	8	4
						266	270	4	28	51	23	3	5	2
			803	1480	677	135	171	36	19	37	18	− 2	4	6
5036	5319	283	280	285	5	113	104	− 9	− 8	23	31	− 2	5	7
108	154	46	17	20	3	16	12	− 4	6	3	− 3	− 2	0	2
11	17	6	3	0	− 3	− 13	− 12	1	0	0	0	+ 1	0	− 1

Δ = Difference between the observed ratios before and after application of pressure $\times 10^7$.
C = Correction for change of ratio with time $\times 10^7$.
Δ_{corr} = The corrected difference between the ratios $\times 10^7$.

the difference between the ratio at 1 atm before and after the application of pressure, the time correction, and the difference between the ratios corrected for time. From this it will be seen that in all cases, where the values of this final difference are greater than the experimental accuracy, they have the same sign. While this cannot be taken as a conclusive proof, it is an indication that hysteresis did occur before sufficient heat treatment had been given.

Finally from inspection of Table III and similar results obtained at the intermediate temperatures it seems possible that the pressure coefficient varied slightly with the pressure, but that this effect also disappeared after the heat treatment of the wire.

[1]) This follows from the fact that $\partial\beta/\partial T = \partial\alpha/\partial p$ where $\beta = \partial R/\partial p$ and $\alpha = \partial R/\partial T$.