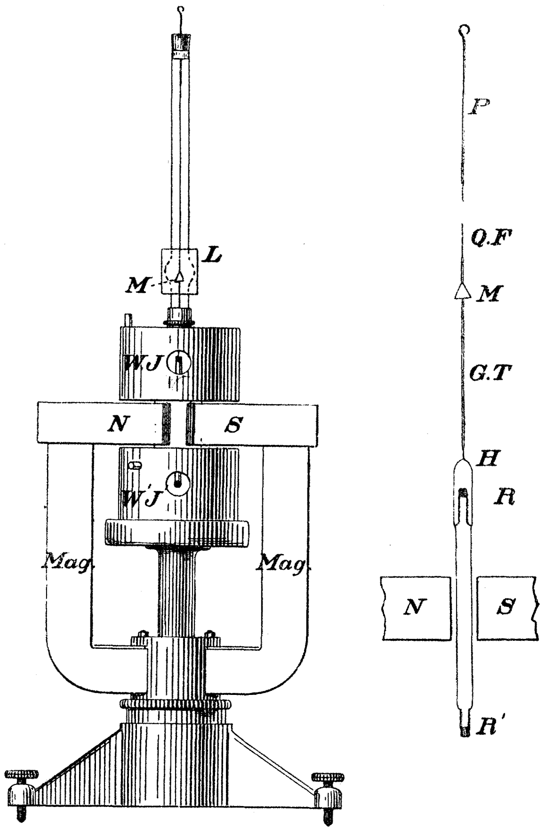
a well-known product of decomposition of chlorophyll. Another is a substance of well-marked properties, nearly resembling, but not identical with, phyllocyanin. It has not, so far as my experience goes, been hitherto observed as a result of any process of decomposition to which chlorophyll has been subjected outside the animal body. I consider it as a body *sui generis*, characterised by its fine purplish-blue colour and its brilliant metallic lustre. The existence of other products in addition to these two is possible. On one occasion, indeed, a definite crystalline substance was obtained, which seemed to be peculiar, but that it was in any way connected with chlorophyll could not with certainty be maintained.

"The Effective Temperature of the Sun." By W. E. Wilson, D.Sc., F.R.S. Received December 5,—Read December 12, 1901.

In March, 1894, Dr. G. Johnstone Stoney communicated to the Society a memoir by myself and Mr. P. L. Gray, entitled "Experimental Investigations on the Effective Temperature of the Sun," which was published in the 'Phil. Trans.,' A, vol. 185 (1894). In these investigations the method we adopted was as follows:—A beam of sunlight was sent horizontally into the laboratory by means of a Stoney single-mirror heliostat. The mirror was an optical plane of unsilvered glass, and the beam was directed into one aperture (A) of a differential Boys' radio-micrometer. The other aperture (B) received the radiation from a strip of platinum, which could be raised to any desired temperature by an electric current supplied by a battery of accumulators. The temperature of this strip was at any moment determined by its linear expansion, the instrument being previously calibrated by melting on it minute fragments of AgCl and of pure gold, as in Joly's meldometer. In front of the aperture (B) of the radio-micrometer was placed a stop with a circular hole of 5·57 mm., and the distance of this hole from the receiving surface of the thermo-couple was 60·2 mm. This gave for the angle subtended by a diameter of the aperture at the receiving surface 5°·301. Knowing then (i) the ratio which the angular diameter of this circular aperture bears to that of the sun, (ii) the temperature of the platinum strip at the moment that the radio-micrometer is balanced, (iii) the amount of the sun's radiation lost by reflection from the heliostat mirror and also by absorption in the earth's atmosphere, it is possible on any assumption with regard to the law connecting radiation with temperature, to determine the effective temperature of the sun. A series of very accordant observations were made in this way, the mean of which gave 6200° C. as the effective solar temperature.

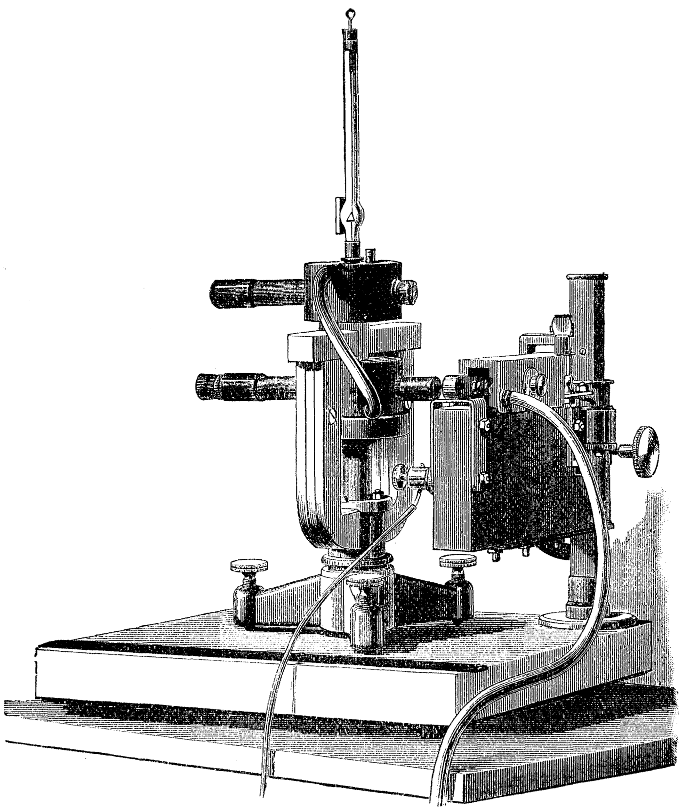
For the details of the apparatus and the complete method of reduction of the observations, the original memoir in the 'Phil. Trans.' may be referred to.



In order to protect the incandescent strip from draughts of air it was covered with a water-jacket of gilded brass. This was provided with a circular hole in one of its longer sides, through which its radiation could reach the aperture of the radio-micrometer. The internal walls of this water-jacket being highly polished, it has occurred to me, since the publication of the memoir referred to, that possibly some of the radiation from distant parts of the platinum strip may have been reflected backwards and forwards from the polished walls and the strip itself, ultimately escaping through the aperture and reaching the radio-micrometer, thus increasing the amount of radiation which should have reached it directly from the strip alone.

In order to test this surmise I first took a number of readings at known temperatures with the walls of the water-jacket polished as

before. I next smoked the surface of the walls well, and found that the amount of radiation coming from the aperture was then sensibly reduced. It is also possible that changes in the condition of the surface of the platinum strip may effect its emissivity, and in fact it is very doubtful whether it is possible to determine with any degree of accuracy what the emissivity of bright platinum is, relatively to lamp



black. In the original memoir we took Rosetti's estimate of 35 per cent. as the most probable value for this quantity, but as our former estimate of the solar temperature depends greatly on this factor, to which so much uncertainty attaches, I thought it would be a distinct advance to abolish entirely the platinum strip as a source of radiation, and to substitute in its place a uniformly heated enclosure which would radiate as an absolutely "black body."

In 1895 Mr. Lanchester pointed out to me that such an enclosure would be a theoretically perfect radiator; while Lummer, Paschen and others have shown that the law connecting temperature and

radiation from such an enclosure confirms in a remarkable manner Stefan's law of radiation, viz., $R = aT^4$.* Since therefore the results of several independent investigations corroborate this law, I have felt justified in applying it to the results of my observations.

On consideration it seemed that the most convenient form of radiator would be a long tube closed at one end, and uniformly heated in a gas furnace. Accordingly a porcelain tube, 2 feet in length and 1 inch internal diameter, was fitted into a Fletcher gas-tube furnace. This was afterwards changed for an iron tube, which was employed in the observations on September 30th, given below.

A plug of asbestos was inserted in the tube at about 10 inches from the end farthest from the radio-micrometer, and resting against this plug was the end of a Callendar platinum-resistance thermometer. This was connected with one of Professor Callendar's electric recorders, so that during an experiment the temperature of the tube was registered continuously on the paper wrapped round the drum of the instrument. In front of the open end of the tube, and between it and the radio-micrometer, was placed a large brass water-screen, through which a copious supply of water passed. In front of the aperture (B) of the radio-micrometer this screen was provided with a rectangular aperture. One side of this aperture was formed by a slide moved by a micrometer screw reading to 0·01 mm. By this means the area of this aperture at any time could be measured with precision. Its fixed sides were 5 mm. apart, and as the movable side had a range of 5 mm., the maximum area of the aperture was 25 sq. mm. The distance (d) of this aperture from the surface of the thermo couple was 66·3 mm.

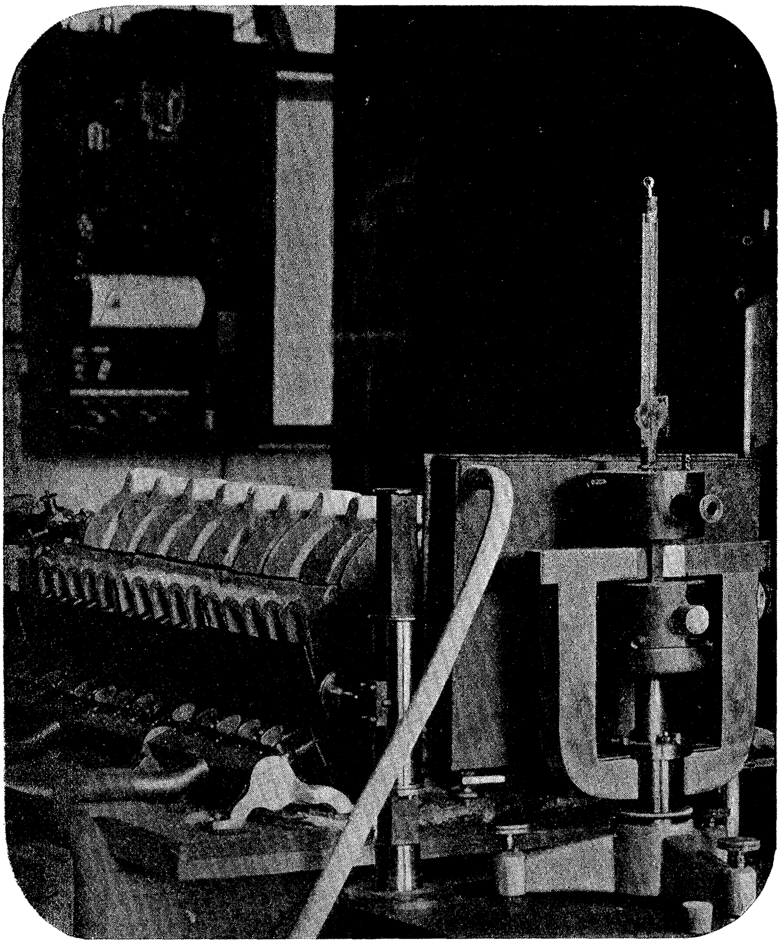
To make an observation the tube was heated to as high a temperature as the furnace was capable of, and when a steady temperature had been obtained, the amount of radiant heat coming from the interior of the hot tube and passing into the aperture (B) of the radio-micrometer was adjusted by the micrometer screw until a balance was obtained with the radiation coming from the Sun through the aperture (A).

If ρ is the angular semi-diameter of the sun, its radiation outside of our atmosphere is $K.\pi \sin^2 \rho$, where K is a constant depending on the sun's temperature.

Again, if α be the height of the slit through which the radiation from the hot tube reaches the radio-micrometer, and β its width, the radiation may with sufficient accuracy be expressed by $K\alpha\beta/d^2$. Assuming Stefan's law, the radiation of the sun outside our atmosphere is $a\theta^4\pi \sin^2 \rho$, θ being the effective temperature of the sun.

* Stefan, 'Sitzber. d. k. Akad. zu Wien,' vol. 79, 1879 (Abth. 2), p. 391; Boltzmann, 'Wied. Ann.,' vol. 22, 1884; M. Planck, 'Drude Ann.,' vol. 1, No. 1, 1900; Paschen, 'Wied. Ann.,' vols. 58, 60, 1896, 1897; Lummer and Pringsheim, 'Wied. Ann.,' vol. 63, 395, 1897.

The percentage transmitted is p, therefore the radiation before reflection from the heliostat is $\frac{ap\theta^4}{100} \pi \sin^2 \rho$.



At reflection q per cent. is transmitted, therefore the radiation received by the radio-micrometer is

$$a \cdot \frac{pq\theta^4}{(100)^2} \cdot \pi \sin^2 \rho \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ldots \quad (1).$$

Also the radiation received from the hot tube is

$$a' (T^4 - T_0^4) \cdot \frac{\alpha\beta}{d^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

We need not inquire what is the absorptive power of the thermo-junction, provided that we are justified in assuming that lamp-blacked surfaces absorb the radiation from the hot tube as freely as that from the sun, or that the constants in these expressions (1) and (2) for the radiation may be taken to be equal.

On balancing, these expressions must be equal, and therefore

$$\frac{pq\theta^4}{(100)^2} \cdot \pi \sin^2\rho = (\mathrm{T}^4 - \mathrm{T}_0{}^4)\frac{\alpha\beta}{d^2}$$

$$= \mathrm{T}^4\left(1 - \left(\frac{\mathrm{T}_0}{\mathrm{T}}\right)^4\right)\frac{\alpha\beta}{d^2} \quad \ldots\ldots\ldots\ldots\ldots (3).$$

But $\left(\frac{\mathrm{T}_0}{\mathrm{T}}\right)^4$ may be neglected, hence we have finally

$$\theta^4 = \frac{\alpha}{\pi d^2} \; \frac{\beta}{\sin^2\rho} \; \frac{100}{p} \; \frac{100}{q} \; \mathrm{T}^4$$

or

$$\theta = \sqrt[4]{\frac{10000\,\alpha}{\pi d^2}} \cdot \sqrt[4]{\frac{\beta}{pq\sin^2\rho}} \cdot \mathrm{T}$$

$$= \frac{0 \cdot 13806}{\sqrt{\sin\rho}} \cdot \sqrt[4]{\frac{\beta}{pq}} \cdot \mathrm{T}.$$

The mean value of $\frac{0{\cdot}13806}{\sqrt{\sin\rho}}$ is [1·30413].

Therefore $$\theta = 1 \cdot 30413 \,.\, \sqrt[4]{\frac{\beta}{pq}} \,.\, \mathrm{T} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4).$$

After a series of observations had been made, the furnace and tube were raised so that the radiation of the latter then passed into the aperture (A), on which the sunlight had previously fallen, while the beam of sunlight was now directed so as to be upon (B), and in this position a second series of observations was taken. The geometrical mean of the result of the two groups gives the Effective Temperature of the Sun, the effect of any difference in the sensitiveness of the thermo-junctions disappearing in the geometrical mean.

Observations were made in the manner described above on August 19th and September 30th, 1901, and reduced by means of equation (4), as exhibited in the following tables. In these the successive columns contain (1) the local mean time, (2) the value of β as read on the micrometer head, (3) the absolute temperature of the tube in the furnace, (4) the sun's altitude, (5) the percentage of the sun's radiation transmitted through the earth's atmosphere, (6) the angle of incidence on the heliostat mirror, (7) the percentage reflected from the surface of the mirror, (8) the corresponding value of θ deduced from equation (4). Of these (5) and (6) and (7) were determined as in Wilson and Gray's memoir referred to above.

Note, $\alpha = 7$ mm.

Local time.	Balance.		⊙ Altitude.	Per cent. trans.	Angle of incidence.	Per cent. reflected.	⊙ Temp. absolute.	Date, August 19, 1901. Blue sky.
	Reading.	Temp. absolute.						
h. m.		°	° ′		°		°	
11 0	1·68	1099	47 18	66	62	9	5586	First Position (B).
11 3	1·69	1098	47 36	66	62	9	5589	,,
11 7	1·70	1098	47 44	66	62	9	5598	,,
11 19	1·60	1100	48 24	66	62	9	5503	,,
11 22	1·55	1100	48 25	66	62	9	5459	,,
11 28	1·62	1101	48 41	66	63	11	5161	,,
11 30	1·70	1101	48 42	66	64	12	5223	,,
11 33	1·75	1101	48 50	66	64	12	5262	,,
11 36	1·77	1101	48 54	67	64	12	5278	,,
11 38	1·80	1101	49 0	67	64	12	5286	,,
						Mean........	5394	,,
12 48	3·99	1119	48 20	67	68	15	6192	Reversed Position (A).
12 51	4·00	1119	48 13	67	68	15	6184	,,
12 53	3·98	1119	48 6	67	68	15	6186	,,
12 56	3·96	1119	48 0	67	68	15	6190	,,
12 58	3·98	1119	47 49	66	68	15	6210	,,
1 3	3·94	1119	47 39	66	68	15	6193	,,
1 5	3·93	1119	47 36	66	68	15	6190	,,
1 7	3·93	1119	47 24	66	68	15	6190	,,
1 9	3·92	1119	47 18	66	68	15	6186	,,
1 11	3·96	1119	47 13	66	68	15	6202	,,
						Mean........	6192	,,

Geometrical mean of A and B $= \sqrt{5394 \times 6192} = 5779°$.

Note, $\alpha = 5$ mm.

Local time.	Balance.		☉ Altitude.	Per cent. trans.	Angle of incidence.	Per cent. reflective.	☉ Temp. absolute.	Date, Sept. 30, 1901. Weather, slight haze.
	Reading.	Temp. absolute.						
h. m.		°	° ′	°			°	
10 45	2·05	1107	31 30	59	64	11	5318	First Position (B).
10 52	2·16	1112	32 0	59	64	11	5379	,,
10 55	2·17	1113	32 0	60	64	11	5364	,,
11 25	2·55	1124	33 0	61	66	12	5446	,,
11 38	2·42	1124	33 0	61	67	13	5320	,,
						Mean......	5365	
11 51	5·20	1127	33 0	61	68	14	6302	Reversed Position (A).
11 55	6·05	1127	33 0	61	68	14	6585	,,
12 0	6·02	1126	33 0	61	68	14	6570	,,
12 8	5·39	1127	33 0	61	69	15	6290	,,
12 18	5·67	1128	32 30	60	70	17	6201	,,
12 25	5·18	1126	32 30	60	70	17	6053	,,
12 32	5·25	1127	32 15	60	71	18	5992	,,
12 36	5·18	1126	32 0	60	71	18	5968	,,
12 50	5·55	1122	32 0	60	71	18	6050	,,
12 58	5·25	1122	31 30	59	71	18	5992	,,
						Mean......	6201	

Geometrical mean of A and B = $\sqrt{5365 \times 6201} = 5768°$.

In the above tables Rosetti's determination of the amount of the terrestrial atmospheric absorption has been used. It may be well, however, to give the results obtained by using other estimates of this quantity. Taking Langley's transmission coefficient when the sun is in the zenith as 59 per cent., compared to Rosetti's 71 per cent., the temperature would be multiplied by $\sqrt[4]{(71/59)}$ and thus become $5773 \times 1 \cdot 054$, which is 6085° absolute. And, as in the previous memoir, to make the case general, if any later investigation shows the zenith transmission coefficient to be x per cent., the effective absolute temperature becomes

$$5773° \times \sqrt[4]{(71/x)}.$$

It may also be of interest to see what effect is produced if absorption in the atmosphere of the sun itself is taken into account. First, considering the falling off in radiation from the central to the peripheral parts of the sun's disc, we may deduce that, if the absorption were everywhere equal to that at the centre, the radiation would be multiplied by 4/3 and the temperature would become

$$5773° \times \sqrt[4]{(4/3)} = 5773 \times 1 \cdot 074 = 6201°.$$

Secondly, assuming Wilson and Rambaut's* result for the total loss due to absorption in the solar atmosphere as equal to one-third, our estimate of the temperature would have to be multiplied by $\sqrt[4]{(3/2)}$, and we get finally

$$6201° \times \sqrt[4]{(3/2)} = 6201° \times 1 \cdot 107 = 6863° \text{ absolute} = 6590° \text{ C.}$$

I wish to express my thanks to Dr. Rambaut for some valuable suggestions during the progress of the work.

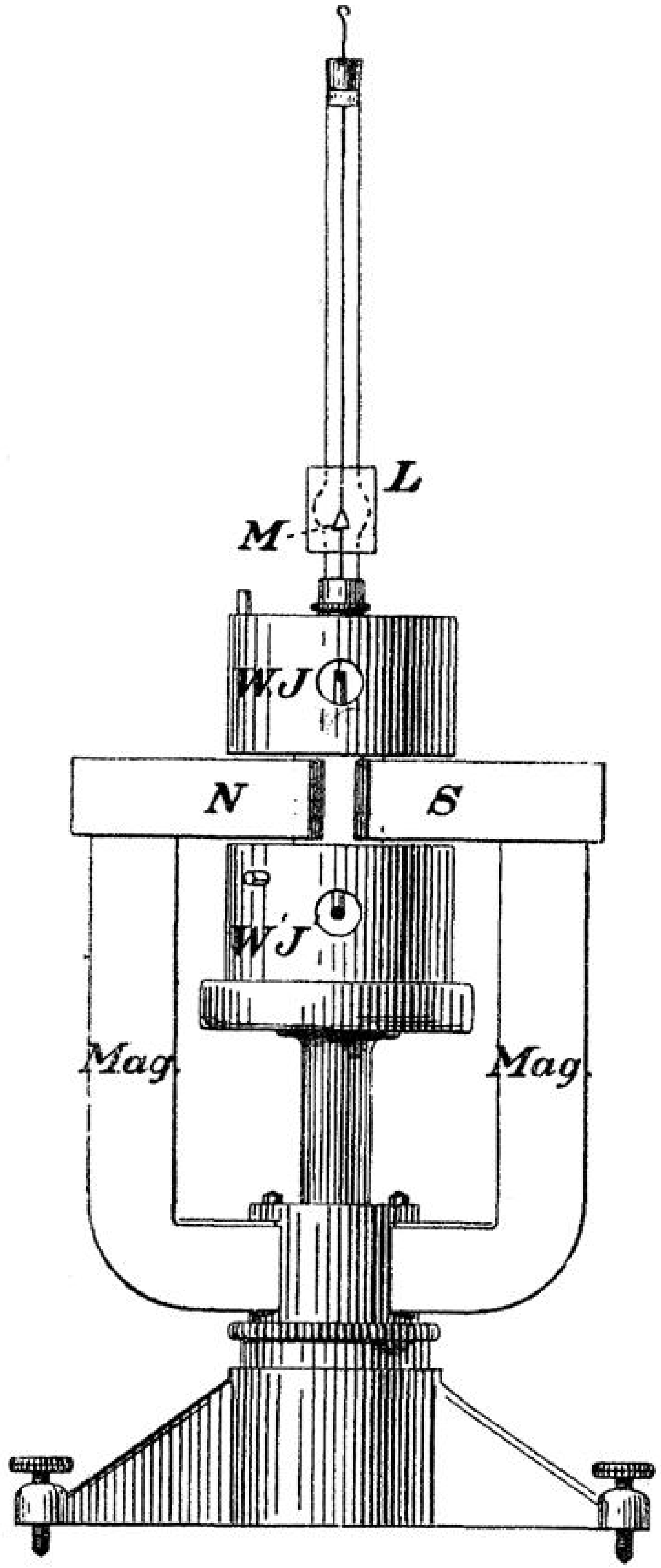
"On the Constitution of Copper-Tin Alloys." By C. T. Heycock, F.R.S., and F. H. Neville, F.R.S. Received December 9,—Read December 12, 1901.

In February, 1901,† we read a short paper on the results of chilling copper-tin alloys, and at the Glasgow meeting of the British Association, 1901, we gave an account of some of the conclusions that we had arrived at concerning the nature of the alloys rich in copper.‡ The present paper extends our conclusions to all alloys of copper and tin, and the accompanying diagram presents the result in a concise but very complete form.

* "The Absorption of Heat in the Solar Atmosphere," 'Proceedings Royal Irish Academy,' 1892, vol. 2, No. 2.

† 'Roy. Soc. Proc.,' vol. 68, p. 171.

‡ 'Report on Alloys,' Sec. B.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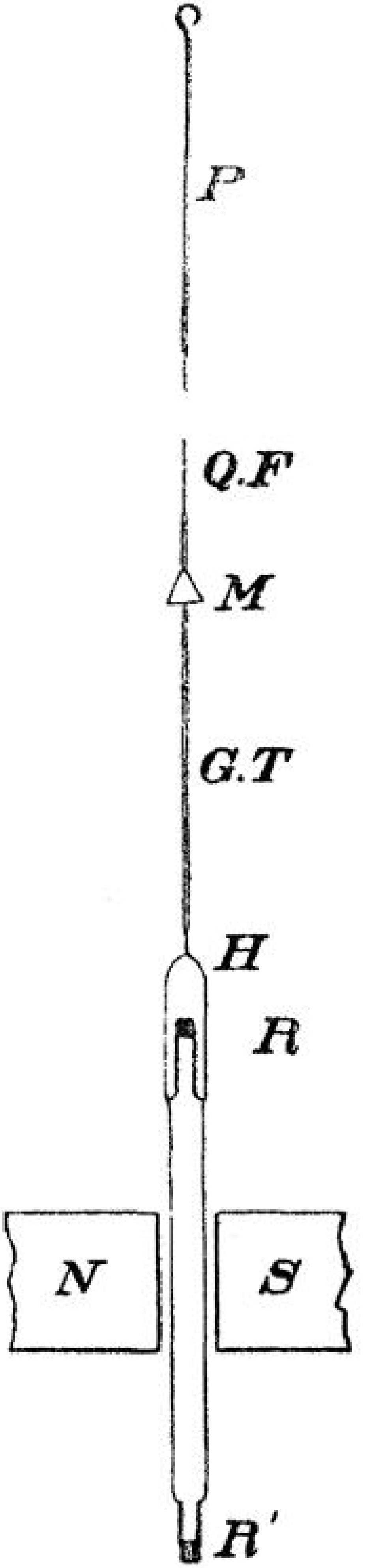
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