# ON THE MAGNETIC SUSCEPTIBILITY AND TEMPERATURE COEFFICIENTS OF $Cu_4SO$ AND $MgSO_4$ SOLUTIONS.

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I HAVE made some relative determinations on the solutions of the above named salts by the balance method as used by Professor Stearns in his determination of the magnetic susceptibility of water,[1] and with practically the same apparatus used by him.

The apparatus consists of a very sensitive non-magnetic balance of a special type designed by Helmholtz. This was, of course, enclosed in a glass case and the whole surrounded on all but one side by a zinc box to shield it from such external agencies as light, etc. The open side of the zinc box is provided with a black curtain, which is drawn over the opening when an observation is to be made. A glass tube passes up through a hole in the bottom of the balance case and connects it with the wooden box, *K*, into which the pole pieces, *PP*, of the large electro-magnet, *M*, project. This being almost airtight the apparatus is very effectively protected from external air currents. To the bottom of the balance-pan, *N*, is attached a silk cord which is practically inelastic for small weights so that the bottom of the tube, *T*, is at a constant height when the balance is in equilibrium. This cord passes down through the tube, *Q*, and terminates in a hook made of copper wire, which is inserted into the eyelet in the upper end of the thermometer, *H*. The tube, *T*, which contains the solution is fitted with a rubber cork, *C*, which is perforated so as to allow the thermometer to be passed through it and into the solution. By this means the tube, *T*, is suspended between the pole-pieces, *PP*. The pole-pieces are held apart a distance of 1.6 cm. by a brass block, *V*, which is hollowed out in the center so as to allow the tube, *T*, to pass below the center of the magnet pole. The box, *K*, is fitted with a slide door, *L* (which has a glass

[1] H. D. Stearns, PHYS. REV., Vol. XVI., No. 1, January, 1902.

window, *W*), which enables one to read the thermometer without opening the box. The electro-magnet rests on a solid bench, *X*, while the balance is supported by a solid plank whose ends, *AA*, rest on masonry piers. At the center of the balance-beam is a mirror

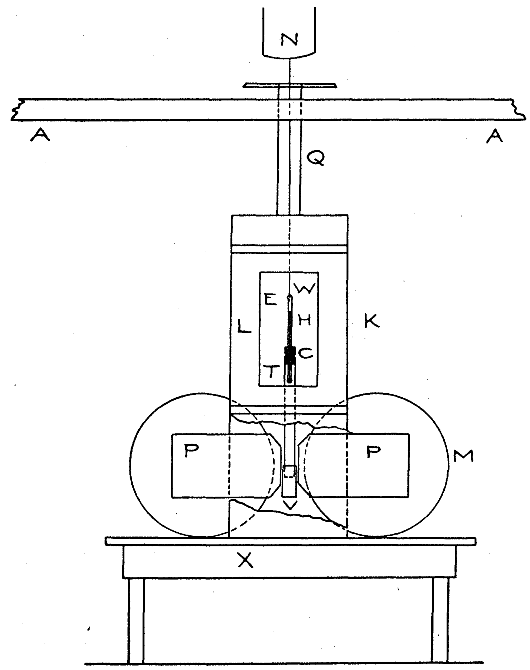


Fig. 1.

which reflects a scale into a reading telescope. The scale and telescope are at a distance of 1.5 meters. By this means it is possible to weigh accurately to $\frac{1}{100}$ of a milligram with a 20 milligram rider.

The magnetic susceptibility ($K$) is given by the following formula which may be easily derived so it is not deemed necessary to give the theory at this time :

$$K = (2gp / H^2 q).$$

Where ($g$) is the acceleration of gravity, ($p$) the attractive force in grams exerted by the magnet upon the cylinder in the direction of its axis (repulsion being denoted by a (—) sign before the quantity), ($q$) is the cross-section of the liquid cylinder, and ($H$) is the horizontal component of the magnetic field.

Since only a relative determination is desired we have only to measure the attraction ($p$) with a given tube and constant current. The other quantities remain the same.

I have used the susceptibility of water as $-.73.10^6$ which is the value obtained by Professor Stearns. The reason for my selection is not only because it was determined under the same conditions as those under which I have been working but also because since this is the mean value of the determinations made by the different investigators as shown by the following table I consider it the best determination yet made on water.

TABLE I.

| Observer. | $K.10^6$. | Observer. | $K.10^6$. |
|---|---|---|---|
| Quincke.[1] | −.84 | DuBois.[1] | −.86 |
| Henrichsen.[2] | −.75 | Curie.[3] | −.79 |
| Townsend.[4] | −.77 | Königsberger.[5] | −.80 |
| Jäger and Meyer.[6] | −.66 | Faraday.[7] | −.69 |
| Becquerel.[7] | −.63 | Wahner.[7] | −.536 |
| BuBois.[7] | −.837 | Stearns.[8] | −.73 |
| | | | Mean value −.741 |

The salts used in these determinations were tested for iron but as no perceptible trace of it was found it is safe to say that the per cent. of iron, if there be any present, is so small as to be inappreciable.

The null point was taken both before and after the reading for the excited magnet, and if the variation of these two null points from the mean value is over one per cent. the reading is rejected. The residual magnetism was so slight that it may be easily neglected.

A single rider whose mass was about 20 mg. was used. As only a comparative determination is to be made it is not necessary to know its mass accurately.

[1] Wied. Ann., Vol. XXXV., p. 137, 1888.
[2] Wied. Ann., Vol. 45, p. 38, 1892.
[3] Journal de Physique, p. 206, 1895.
[4] Proc. Roy. Soc. London, LX., p, 186, 1896–7.
[5] Wied. Ann., Vol. 66, p. 698, 1898; Drude's Ann., Vol. VI., p. 506, 1901.
[6] Wied. Ann., Vol. LXVII., p. 712, 1899; Drude's Ann., Vol. VI., p. 870, 1901.
[7] Pogg. Ann., Vol. XXXV.
[8] PHYS. REV., Vol. XVI., No. 1, January, 1903.

The water used in making the solution was distilled from rain water caught in a glass bottle after copious showers had cleansed the tiled roof.

Readings were taken only every half hour so as to be sure that the solution was in a stable condition.

I have given one set of data in full so as to give some idea of the various features of the work. In this I have used the following notation:

*C*, the current in the electromagnet.

*Rm*, the number of scale divisions the rider has been moved along the balance arm from the position with zero current in the electromagnet to the position with (*C*) amperes current in the magnet coil.

*No*, null point with zero current in the magnet.

*Nt*, null point with current in the magnet.

*Ni*, null point after the current has been turned off.

*T*, the temperature registered by the thermometer (*H*). (See Fig. 1.)

*p*, the attraction exerted by the magnet on the tube (*T*) and contents.

4.53 *Per Cent.* $CuSO_4$ *Solution.*

| *C* | *Rm* | *No* | *Nt* | *Ni* | *T* | *p* |
|---|---|---|---|---|---|---|
| 10 | 2.5 | 26.7 | 29.8 | 26.6 | 16.7 | −.01044 |
| 10 | 2.5 | 26.4 | 31.3 | 26.9 | 17.0 | −.01065 |
| 10 | 2.5 | 26.2 | 31.3 | 26.8 | 17.3 | −.01065 |
| 10 | 2.5 | 27.7 | 31.6 | 27.7 | 18.0 | −.01051 |
| 10 | 2.5 | 31.5 | 36.8 | 31.8 | 19.0 | −.01065 |
| 10 | 2.5 | 31.2 | 36.4 | 31.2 | 19.6 | −.01057 |
| 10 | 2.5 | 32.6 | 39.4 | 32.8 | 19.9 | −.01086 |
| 10 | 2.8 | 32.0 | 34.0 | 32.1 | 20.5 | −.01082 |
| 10 | 2.8 | 31.9 | 34.1 | 32.2 | 20.5 | −.01084 |

From the curves for empty tubes (I.) and (II.), Fig. 2, it will be seen that glass has a very high temperature coefficient. This causes a difference in the value of (*p*), for the tube, of .0004 per degree centigrade. Since the limit of possible error does not exceed 2.5 per cent. the variations in the above curves could not be due to this cause.

The curves for the 4.53, 7.16 and the 8.94 per cent. $CuSO_4$ solutions, Fig. 3, lie so near the origin that a small error in taking the data would make a great variation in the final result. In the 7.16

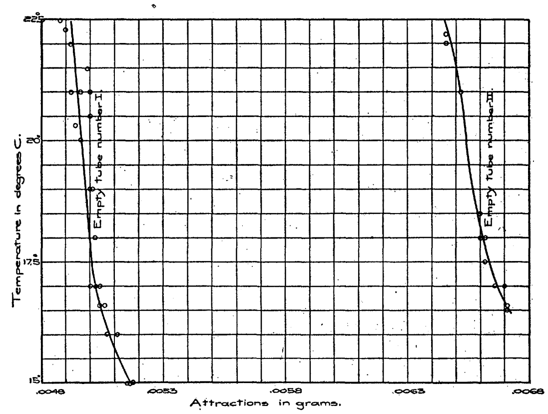


Fig. 2.

per cent. solution the greatest variation is 5 per cent. and in the 8.94 per cent. solution it is slightly over 3 per cent. but these are easily within the limit of experimental error. Hence I conclude that,

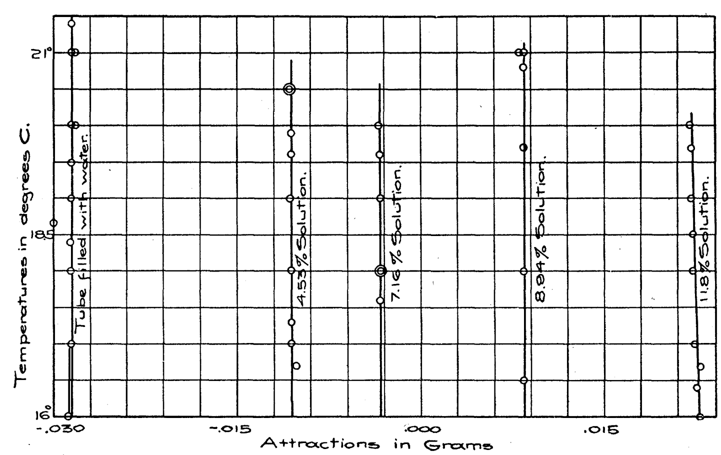


Fig. 3. $CuSO_4$ solutions.

between the limits of 16° and 21° C. there is no temperature coefficient in $CuSO_4$ solutions. Whether this is true or not for a wider range of temperatures remains to be seen.

Assuming $K \cdot 10^6$ to be $-.73$ for water, I have calculated the values of this quantity for each of the solutions used.

TABLE II.

| Per Cent. Solution. | Specific Gravity. | $K \cdot 10^6$ (Measured). | $K'$ (Calculated). | $K \cdot 10^6$ (Calculated). |
|---|---|---|---|---|
| 7.16 | 1,071 | −.084 | .002 | .002 |
| 11.8 | 1,117 | .537 | .476 | .532 |
| 8.94 | 1,082 | .212 | .184 | .199 |
| 4.53 | 1,032 | −.270 | −.266 | −.275 |

The specific magnetism ($K'$) of $CuSO_4$ is given by the formula[1]:

$$K' = (10.4)(P/100) - .80(1 - (P/100)).^{2}$$

Where $P$, is the per cent. of water-free salt in the solution, and $K' = K/s$ where $K$, is the magnetic susceptibility and $s$, the specific gravity of the solution.

The above computations show a very good agreement except in the case of the 7.16 per cent. solution.

## $MgSO_4$ Solutions.

From the curves for the $MgSO_4$ solutions, Fig. 4, it can be easily seen that the greatest possible variation is much less than 2.5 per cent. (the probable error). Hence I conclude that, $MgSO_4$ solutions have no temperature coefficient for a range of temperatures from 16° to 21°C.

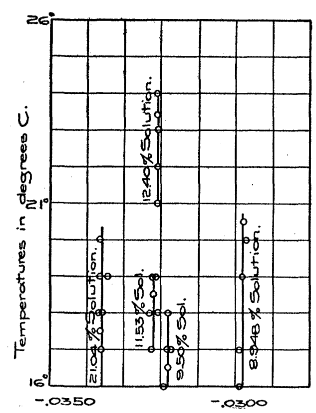

Fig. 4. $MgSO_4$ solutions.

The specific magnetism of $MgSO_4$ is given by the formula:

$$K' = -.46(P/100) - .73(1 - (P/100)).$$

[1] Wied. Ann., Vol. LXVI., p. 698, 1898.

[2] Where $K \cdot 10^6$ is taken as $-.73$ the formula becomes:

$$K' = 9.49(P/100) - .73(1 - (P/100)).$$

TABLE III.

*$MgSO_4$ Solutions.*

| Per Cent. Solution. | Specific Gravity. | $K \cdot 10^6$ (Measured). | $K'$ (Calculated). | $K \cdot 10^6$ (Calculated). |
|---|---|---|---|---|
| 9.48 | 1,089 | −.698 | −.704 | −.767 |
| 21.04 | 1,200 | −.823 | −.672 | −.806 |
| 12.40 | 1,118 | −.786 | −.696 | −.778 |
| 11.53 | 1,109 | −.789 | −.698 | −.774 |
| 8.95 | 1,084 | −.780 | −.706 | −.765 |
| 4.73 | 1,038 | −.765 | −.717 | −.744 |

The results show a very good agreement of experimental and calculated values except for the 9.48 per cent. solution. This is no doubt due to experimental error.

In reducing from the mirror scale to the balance arm scale I have used the relation, 1.5 divisions on the mirror scale equal .1 scale division on the balance arm scale.

What value there may be in this paper is due very largely to the aid and suggestions of Professors Sanford and Stearns, of the Physics Department.

STANFORD UNIVERSITY, 1905.