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phases of a heart period that has been registered by derivation I, for instance, and of another period by derivation II or III.

Moreover, one heart contraction is not exactly like another At a superficial glance the E.K.G. of the same series, appear so similar to one another, that one would take one period for the reproduction of another, but, when measured, numerous small differences appear which impede the accurate calculation of the direction and the manifest value of the potential difference. All these difficulties disappear when the E.K.G. is registered by the three derivations simultaneously.

The method is of service not only physiologically, but also clinically. For the object of practical cardiography is not to ascertain the potential difference that exists between one hand and another, or a hand and a foot, but to obtain an insight into the working of the heart itself [1]).

Physics. — *"The magnetic susceptibility and the number of magnetons of nickel in solutions of nickelsalts."* By P. Weiss and Miss E. D. Bruins. (Communicated by Prof. H. A. Lorentz.)

§ 1. The purpose of this research was to investigate, how in connection with the magnetontheory the magnetic susceptibility of nickel in solutions of nickelsalts depends on the concentration of nickel in the solution. The research was made after Quincke's method improved by Piccard [2]).

Before and after every series of measurements water was measured of which the specific susceptibility or coefficient of magnetisation has of late years been determined with great accuracy after different methods.

For this coefficient Séve gives : $-0.725.10^{-6}$ at 22° C. [3])
Piccard : $-0.7193.10^{-6}$ „ 20° C. [2])
de Haas and Drapier : $-0.721.10^{-6}$ „ 21° C. [4])

In the following calculations has been used the value given by Piccard $\chi_{water\ 20^\circ C.} = -0.7193.10^{-6}$.

The coefficient of magnetisation χ_L of the solution is calculated with the formula:

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[1]) The complete account of the above investigation will appear elsewhere.

[2]) Die Magnetisierungskoeffizienten des Wassers und des Sauerstoffs. Promotionsarbeit von A. Piccard. Arch. de Genève 1913.

[3]) Sève. Paris 1912. Thêse. Ann. Chim phys. (8) 27 p. 189–244. 1912.

[4]) De Haas und Drapier. Annalen der Physik. Band 42. p. 673—684. 1913.

$$\chi_L = \frac{k_1}{\gamma_1} + \frac{h_1}{h}\left(\chi_{water} - \frac{k}{\gamma}\right) \quad . \; . \; . \; . \; . \; . \; . \quad (I)$$

where: h_1 = the measured ascension of the solution.

k_1 = the susceptibility of the air which is above the meniscus of the solution. At 20° C. and a pressure of 760 m m. $k = 0.0294 \, . \, 10^{-6}$.

Therefore $k_1 = 0.0294 . 10^{-6} \frac{p_1}{760}\left(\frac{293}{T}\right)^2$,

where p_1 indicates the atmospheric pressure decreased with the moisture of the air

γ_1 = the density of the solution.

h = the measured ascension of the water.

k = the susceptibility of the air which is above the meniscus of the water.

γ = the density of the water.

If the solution contains $x^0/_0$ of the nickelsalt, we have according to **Wiedemann**'s law:

$$\chi_L = \frac{(100 - x)\,\chi_{water} + x\chi_{Ni\,salt}}{100} \quad . \; . \; . \; . \; . \quad (II)$$

This $\chi_{Ni\,salt}$ multiplied by the molecular weight of the nickelsalt in question gives the molecular coefficient of magnetisation χ^m. From χ^m the coefficient of magnetisation χ^a_{Ni} of the nickelatom has been deduced by making a correction for the diamagnetism of the anion.

These were taken:

$$\chi^m_{Cl_2} = -0.40 \, . \, 10^{-6}$$
$$\chi^m_{SO_4} = -0.37 \, . \, 10^{-6}$$
$$\chi^m_{(NO_3)_2} = -0.36 \, . \, 10^{-6}$$

which values have been deduced from those given by **Pascal** by making a correction for the value of χ_{water}, which **Pascal** has taken $-0.75 \, . \, 10^{-6}$.

The formula $\sigma_0 = \sqrt{(\chi^a_{Ni} \cdot 3RT)}$ gives σ_0 the magnetic moment of the nickel pro gramatom at the absolute zero of temperature.

$n = \frac{\sigma_0}{1123{,}5}$ finally gives the number of magnetons of the nickelatom.

§ 2. In the first place the aqueous solutions of $NiSO_4$, $NiCl_2$ and $Ni(NO_3)_2$ were investigated.

They have been prepared from distilled water and cobaltfree nickelsalts from **Kahlbaum**.

The concentration has been determined by analyzing the most concentrated solution after the electrolytic method [1]) with a platinum net for cathode and a platinum spiral for anode. The rest of the solutions were obtained from the analyzed by dilution. In order to insure accuracy some have been analyzed. For example the results of two analyses of a solution, which ought to contain 3,641 °/₀ $NiCl_2$ according to the way it was prepared, were found to be 3,643°/₀ and 3,640 °/₀ $NiCl_2$.

The following table gives the results obtained; in the fifth column are mentioned the values of χ^a_{Ni} reduced to 20° C. according to CURIE's law (comp. § 5).

Aqueous solutions of $NiSO_4$.

	°/₀ $NiSO_4$	T	$\chi^m_{NiSO_4} \cdot 10^5$	$\chi^a_{Ni} \cdot 10^5$	$\chi^a_{Ni\,20^\circ C.} \cdot 10^5$	n
param.	24.154 [2])	$291\overset{\circ}{.}6$	443.7	447.3	445.2	16.05
param.	16.345	291.3	444.0	447.7	445.0	16.05
param.	10.341	290.4	444.7	448.4	444.4	16.05
param.	3.116	290.2	446.6	450.3	446.0	16.07
				Average:	445.1	16.06

Aqueous solutions of $NiCl_2$.

	°/₀ $NiCl_2$	T	$\chi^m_{NiCl_2} \cdot 10^5$	$\chi^a_{Ni} \cdot 10^5$	$\chi^a_{Ni\,20^\circ C.} \cdot 10^5$	n
param.	22.690 [3])	$289\overset{\circ}{.}3$	446.6	450.7	445.0	16.05
param.	16.121	289.3	447.2	451.2	445.5	16.06
param.	9.516 [4])	291.2	444.8	448.8	446.1	16.07
param.	5.890	291.1	443.6	447.6	444.7	16.05
param.	3.641	290.9	443.4	447.5	444.3	16.04
param.	3.156	289.2	446.2	450.2	444.4	16.02
diam.	1.244	290.8	444.3	448.3	444.9	16.05
diam.	0.623	290.8	442.8	446.8	443.4	16.03
				Average:	444.8	16 05

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[1]) Treadwell. Quantitative Analyse.

[2]) Average of the results of two analyses: 24.154 and 24.154.

[3]) Average of the results of two analyses: 22,695 and 22,685.

[4]) Average of the results of two analyses: 9,513 and 9,519.

Aqueous solutions of $Ni(NO_3)_2$.

	$\%Ni(NO_3)_2$	T	$\chi^m_{Ni(NO_3)_2} \cdot 10^5$	$\chi^a_{Ni} \cdot 10^5$	$\chi^a_{Ni\,20^\circ C} \cdot 10^5$	n
param.	37.164 1)	289°.4	445.9	449.5	444.0	16.03
param.	26.953	289.4	447.9	451.5	445.9	16.07
param.	14.873	289.3	447.9	451.5	445.8	16.07
param.	7.098	289.3	448.0	451.7	446.0	16.07
diam.	1.016	289.2	447.8	451.4	445.5	16.06
				Average:	445.4	16.06

Before we draw conclusions from the results obtained their accuracy must be tested. The error in the value used for χ_{water} is not greater than $3^\circ/_{00}$ at most 2), from these, $2^\circ/_{00}$ are a consequence of the error in the measurement of the normal electromagnetic field. The proportion of the susceptibility of the solution to that of the water, however, is independent of the error in the field; as in this research the proportion of the susceptibility of the solution to that of the water has really been determined, it is only the inaccuracy in the determination of the ascension, which was $1^\circ/_{00}$ at most, which consists in that proportion obtained, while in the final results the error of χ_{water} remains as well. From the results of the analyses it is evident, that the error in the concentration always remains below $1^\circ/_{00}$.

Thus within the limits of experimental accuracy the value of $\chi^a_{Ni\,20^\circ C}$ and also the number of magnetons seems to be independent of the nature of the salt and of the concentration of the solution. This result agrees with that of CABRERA 3), who from his research about the aqueous solutions of nickelsalts also concluded the atomsusceptibility to be independent of the concentration and the nature of the salt. For the number of magnetons of the nickelatom in solutions of $NiSO_4$, $NiCl_2$, and $Ni(NO_3)_2$ he respectively gives the numbers 16,07, 16,03 and 16,02.

The number of magnetons of nickel in dissolved nickelsalts thus seems to be a whole number within the limits of experimental accuracy and as such supports the magneton theory.

§ 3. Then the ammoniacal solutions of nickelsalts were investigated.

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1) The analyses gave 37,164% and 37.131%, the former value has been taken, because the second is less reliable.

2) A. PICCARD, ibid. p. 53.

3) CABRERA, MOLES et GUZMAN, Arch. de Genève T. XXXVII, p. 330, 1914.

If ammonia is added to an aqueous solution of a nickelsalt, we get the blue coloured solution of the complex nickel-ammonia compound. As with these solutions the strong evaporation of the ammonia makes it impossible to determine with sufficient accuracy the correction for the magnetic susceptibility of the air, these measurements were carried out under an atmosphere of hydrogen and ammonia, which was obtained by leading the hydrogen through an aqueous NH_3-solution of about the same NH_3-concentration as the solution to be investigated. The magnetic susceptibility of this atmosphere is so small, that it may be taken equal to zero, thus formula (I) becomes, as with these measurements the water measurements also were made under a hydrogenatmosphere:

$$\chi_L = \frac{h_1}{h}\,\chi_{water} \,. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (I')$$

The calculation of $\chi_{Ni\ salt}$ from χ_L with the ammoniacal solutions is performed analogous to the calculation of $\chi_{Ni\ salt}$ from χ_L with the aqueous solutions. However not only the susceptibility of the water but also that of the ammonia must be taken into account. The measurements of aqueous ammonia solutions gave for χ_{NH_3}:

$$\begin{array}{rl} & -\,0{,}947 . 10^{-6} \\ & -\,0{,}950 . 10^{-6} \\ & -\,0{,}942 . 10^{-6} \\ & -\,0{,}954 . 10^{-6} \\ \hline \text{Average:} & -\,0{,}948 . 10^{-6} \end{array}$$

while Pascal gives: $\chi_{NH_3} = -\,0{,}881 . 10^{-6}$.

Instead of formula (II) we get:

$$\chi_L = \frac{(100-x-y)\,\chi_{water} + y\,\chi_{NH_3} + x\,\chi_{Ni\ salt}}{100} \,. \quad . \quad . \qquad (II')$$

where x indicates the percentage of nickelsalt, y that of ammonia.

As from some experiments in the beginning it was evident, that with a *certain* concentration of the nickelsalt within the limits of experimental accuracy a fixed value was found for $\chi_{Ni\ salt}$ calculated with formula (II) for *different* NH_3-concentrations, the conclusion may be drawn that χ_{NH_3} has the same value no matter in what degree the ammonia is bound to the nickelsalt or finds itself free in [illegible] may be assumed as an [illegible] for the ammonia may be [illegible] who [illegible] with the ammonical

Ammoniacal solutions of $NiSO_4$.[1]

	%$NiSO_4$	% NH_3	T	$\chi^m_{NiSO_4}\cdot 10^5$	$\chi^a_{Ni}\cdot 10^5$	$\chi^a_{Ni\,20^\circ C}\cdot 10^5$	n
param.	4.441	8.628	$290\overset{\circ}{.}1$	419.7	423.4	419.2	15.58
param.	3.244	8.061	290.0	419.9	423.6	419.3	15.58
diam	2.527	6.225	290.0	420.3	424.0	419.7	15.59
diam.	1.522	6.557	293.1	415.1	418.7	418.9	15.57
diam.	1.078	3.479	291.0	420.5	424.2	421.2	15.62
diam.	0.535	2.937	291.1	421.0	424.7	421.9	15.63
					Average:	420.0	15.59

Ammoniacal solutions of $NiCl_2$.[2]

	%$NiCl_2$	% NH_3	T	$\chi^m_{NiCl_2}\cdot 10^5$	$\chi^a_{Ni}\cdot 10^5$	$\chi^a_{Ni\,20^\circ C}\cdot 10^5$	n
param.	4.342	6.875	$290\overset{\circ}{.}9$	417.6	421.6	418.6	15.57
param.	3.141	7.517	291.0	417.0	421.0	418.2	15.56
diam.	2.209	6.704	289.4	418.2	422.3	417.1	15.54
diam.	1.688	4.478	290.8	417.5	421.5	418.4	15.56
diam.	1.197	3.744	289.4	420.1	424.2	419.0	15.58
diam.	0.569	1.901	289.5	421.5	425.6	420.5	15.60
					Average:	418.6	15.57

Ammoniacal solutions of $Ni(NO_3)_2$[3]

	%$Ni(NO_3)_2$	% NH_3	T	$\chi^m_{Ni(NO_3)_2}\cdot 10^5$	$\chi^a_{Ni}\cdot 10^5$	$\chi^a_{Ni\,20^\circ C}\cdot 10^5$	n
param.	5.276	5.520	$290\overset{\circ}{.}9$	417.2	420.8	417.8	15.55
param.	4.262	6.692	290.9	417.5	421.2	418.1	15.56
diam.	3.032	4.566	291.2	418.5	422.1	419.5	15.58
diam.	2.556	5.639	289.6	421.0	424.6	419.7	15.59
diam.	1.919	5.512	289.5	421.0	424.7	419.6	15.59
diam	1.041	4.918	289.5	420.7	424.4	419.3	15.58
					Average:	419.0	15.57

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[1] These solutions were prepared by dilution, and mixture of an aqueous $NiSO_4$-solution, for which two analyses gave 16,587 and 16,592% $NiSO_4$ and a solution of ammonia in water, for which two analyses gave 11,53 and 11,49 % NH_3. The ammonia analyses were performed by titration with 1/2 normal chloric acid.

[2] These solutions were prepared by dilution and mixture of an aqueous $NiCl_2$-solution for which two analyses gave 17.216 and 17.190 % $NiCl_2$ and a solution of ammonia in water for which two analyses gave 11.782 and 11.783 % NH_3.

[3] These solutions were prepared by dilution and mixture of an aqueous solution of $Ni(NO_3)_2$, for which two analyses gave 19.539 and 19.514 % $Ni(NO_3)_2$ and the same NH_3-solution in water as with the ammoniacal $NiCl_2$-solutions.

From the results obtained the conclusion may be drawn, that for the ammoniacal solutions $\chi^a_{\mathrm{Ni}\,20^\circ\mathrm{C}}$ and also the numbers of magnetons are somewhat smaller than the corresponding quantities for the aqueous solutions. For the three salts investigated this difference is the same within the limits of experimental accuracy, for instance this difference is for the number of magnetons 0.47 0.48 and 0.49 respectively for the $NiSO_4$, $NiCl_2$ and $Ni(NO_3)_2$ solution.

§ 4. Addition of H_2SO_4 to a aqueous solution of $NiSO_4$ and of $(NH_4)_2SO_4$ to an ammonical solution of $NiSO_4$ evidently was without influence on the number of magnetons:

% $NiSO_4$	% H_2SO_4	n
3.619		16.01
3.241	9.493	16.02

% $NiSO_4$	% NH_3	% $(NH_4)_2SO_4$	n
3.659	8.308		15.46
3.187	7.238	12.884	15.48

§ 5. Finally it has been investigated how χ^a_{Ni} depends on the temperature, by measurements of a aqueous $NiCl_2$-solution at 6°.0, 16°.7 and 89°.7 C. and of an ammoniacal $NiCl_2$-solution at 6°.7, 18°.8, 20°.2 and 56°.2 C.

As only that part of the tube which was in the magnetic field had the temperature T, while the rest of the tube and the basin in which the end of the tube had been immersed were at the temperature $t°$ C. of the room, a correction must be made for the inhomogeneity of the liquid in the tube and the basin; therefore formula (I′) becomes:

$$\chi_L = \frac{h_1 \dfrac{\gamma_T}{\gamma_t}}{h} \chi_{water}$$

where γ_T indicates the density of the solution at the temperature T, and γ_t the density of the solution at the temperature t.

The coefficients of dilatation necessary for the calculation of γ_T have been determined:

Coefficient of dilatation of an aqueous $NiCl_2$-solution containing 4.614 % $NiCl_2$ between 5°.0 C. and 18°.8 C.: 0.00021
between 5°.9 C. and 22°.0 C,: 0.00017
Average: 0.00019

between 18°.8 C. and 89°.5 C.: 0.00042
between 22°.0 C. and 90°.3 C : 0.00044
Average: 0.00043

Coefficient of dilatation of the solution containing 4.611 % $NiCl_2$ and 6.782 % NH_3 between 4°.8 C. and 19°.1 C.: 0.00023
between 3°.7 C. and 19°.8 C.: 0.00018
Average: 0.00020

between 19°.1 C. and 59°.0 C.: 0.00037
between 19°.8 C. and 60°.8 C.: 0.00039
Average: 0.00038

These measurements were also executed under a hydrogen atmosphere and gave the following results:

% $NiCl_2$	T	$\chi^a_{Ni} \cdot 10^5$	$\chi^a_{Ni} \cdot T$	t
4.614	279°.0	466.7	1.302	19°.1 C.
4.614	289.7	450.7	1.306	16.7
4.614	362.7	357.7	1.297	18.4
		Average:	1.302	

$\chi^a_{Ni} \cdot T$ calculated from the above average 444.8 for $\chi^a_{Ni\,20^0\,C.}$ gives **1.303**.

% $NiCl_2$	% NH_3	T	$\chi^a_{Ni} \cdot 10^5$	$\chi^a_{Ni} \cdot T$	t
4.611	6.782	297°.7	434.9	1.216	20°.9 C.
4.611	6.782	291.8	418 9	1.222	18.8
4.605	6.800	293.2	418.2	1.226	21.2
4.605	6.800	329.2	372.3	1.226	20.6
			Average:	1.223	

$\chi^{Ni}_a \cdot T$ calculated from the above average 418.6 for $\chi^a_{Ni\,20^0\,C.}$ gives **1.226**.

From the results obtained it is evident, that within the limits of experimental accuracy the atomsusceptibility of nickel in solutions of nickelsalts follows CURIE's law.

Zürich, July 1914. *Eidgenössisches Physikgebäude.*