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Ermann] a series of determinations from 1845—1846 by the Pulkova astronomers Schumacher, Porth and Moritz. They found [1]

the linear coefficient of dilatation of ice = 0.00006424 (Schumacher)
» » » » » » » = 0.00006387 (Porth)
» » » » » » » = 0.00006469 (Moritz)

The coefficient of cubic dilatation of the ice was determined by Brunner [2]

coefficient of cubic expansion of ice = 0.000113

This number is decidedly too small. More exact determinations on pure ice were made in 1852 by Plücker and Geissler [3]. The average results from 4 series of experiments executed with dilatometers of diminutive size but admirable workmanship were:

1) coefficient of cubic expansion of ice = 0.000155
2) » » » » » » = 0.000153
3) » » » » » » = 0.000156
4) » » » » » » = 0.000170

Plücker and Geissler concluded from their experiments, that the coefficient of expansion by heat of pure ice is constant and its dilatation regular at all temperatures (from 0° unto — 20° or — 24° C).

In 1879 the author, in company with H. Larson [4], tried to trace out the curve of volumes of the ice for every centigrade from 0° to — 12°.75 C. We found it easy to verify, that the average coefficient of expansion given by Plücker and Geissler was right, but we found serious reasons to doubt, that the dilatation of ice was uniform. On account of the imperfect construction of my dilatometer at this time and in want of a balance adapted for exact weighing of great quantities of mercury, we were obliged to postpone the verification of this observation.

In the following it will be shown, that we were not mistaken, though we then considerably overrated the irregularity of the dilatation of the ice.

But we certainly did not then expect to find, that the

[1] Recueil des Memoires des Astronomes de Pulkowa. 1853.
[2] Ann. chim. et phys. (3) 14. (1845).
[3] Pogg. Ann. LXXXVI.
[4] Öfvers. K. V. A. Förhandl. 1879.

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volume of ice *decreases*[1] in the vicinity of its melting point. As I deem this fact of importance to meteorology as well as to hydrography, I have tried to make the behavior of pure ice in the vicinity of zero one of the main objects of my investigation.

The preceding exposition is only intended to give a general view of the development of our knowledge of the properties of pure water and ice, which was to be the first object of my study [see page 253].

Regarding the problems II and III, viz. the properties of ice from brackish water and oceanwater, no previous researches have been published, nor has the change of volume etc. of ice formed in the open sea formerly been subject to quantitative measurements.

The volumes of oceanwater have recently been very carefully studied by L. F. Ekman, by means of Regnault's dilatometer. Mr H. Tornoe, hydrographer of the Norwegian expedition, has repeated the determinations of Ekman with the Sprengel pycnometer, another equally sensible instrument, and obtained almost identical results.[2]

I therefore thought it would be superfluous to again test the dilatation of salt water with my own dilatometer and resolved to confine my research to the dilatation of brackish water of little saltness, an object of still greater interest for my purpose, such water being formed by the melting of sea-ice. By special permission from professor Ekman, I was authorized to insert his curves [the blue lines in plate 23] of volume of salt water together with my own determinations on pure and brackish water, which are marked in plate 23 with black and red colours.

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[1] Nor did Plücker and Geissler observe any similar phenomenon. This result is entirely new and is due to the larger scale and the refined methods of measurement adopted in the present series of experiments.

[2] The numbers given by Ekman [K. V. A:s Handl. 1870] being thus confirmed by Tornoe [Norwegian North-Atlantic Expedition 1876—1878], I think it superfluous to discuss here the previous determinations by Hubbard, Thorpe, Rücker, Karsten a. O.

CHAPTER 2.

Methods and instruments.

In the course of the experimental research some delicate questions, requiring great accuracy in the determination of temperature, arose. I therefore think it advisable, first to give an exposition of the

A. Measurements of temperatures and determinations of the coefficient of apparent dilatation of mercury.

The temperature was observed by means of 3 normal mercury thermometers, manufactured expressly for these purposes by Dr. Geissler in Bonn and his successor, Mr. Franz Müller. In the following these instruments will be denoted by G_I, G_{II} & G_{III}

G_I	indicates	temperatures	from	— 1° C	to	+ 26° C
G_{II}	»	»	»	— 12° C	»	+ 5° C
G_{III}	»	»	»	— 22° C	»	— 7° C

G_I & G_{II} were made in 1875, G_{III} in 1880, consequently the correction for zero at present ought to be constant. It is however liable to little perturbations. Especially in G_I the final state of equilibrium of the molecules seems not to have been attained yet.

By a great number of observations it was ascertained, that the indications of the different thermometers above zero corresponded with each other within the limits of $0^\circ.01$ or $0^\circ.015$ of a centigrade degree. Below zero the correspondence could not be observed so closely, on account of the difficulty of maintaining the temperature steady for a long time. It must also be observed, that during the volumetric experiments the dilatometer and the thermometer were immersed in a mercury vessel of wrought iron. The pressure of the mercury caused a rise of $0^\circ.02$ C in the indication of temperature. This is a constant error, to which due reference has been made.

The correspondence of the different instruments being ascertained to be satisfactory, another question arose of equal

importance but greater difficulty: *are the indications of the normal thermometers of Dr. Geissler conformable to the real temperatures?* The author first tried to decide this question by a strict comparison of the Geissler thermometers with the air-thermometer, described in the Journal für prakt. Chemie [1] 1882. The result was the following:

The mercury thermometers only agree exactly with the air-thermometer a few degrees above and below zero, for higher temperatures the indications of the two instruments differ slightly, for lower temperatures the discrepancy gradually but rapidly increases and at — 20° C is considerable.

If the indications of the air-thermometer are considered to be the standard measure of temperature, the normal mercury thermometers are far from being right, especially below zero. It remained to be seen, if the Geissler thermometers were correctly adjusted after the principle of the mercury thermometers, i.e. if every centigrade degree on their scales corresponded to an equal apparent dilatation of the mercury in the bulb. I resolved to test this in the following way.

The dilatometer, see page 262 and plate 20, was filled with mercury, which was *boiled* [2] *in the reservoir*. After cooling, the instrument was placed in melting snow for several hours and the excess of mercury allowed to escape through »b,» until the dilatometer was filled exactly to the stopcocks and weighed. Afterwards the dilatometer was immersed in a mercury vessel and the dilatation of the mercury in the instrument between + 2°.65 C and — 17°.18 C determined in the ordinary way (see page 264) by means of a scale-tube. The Geissler thermometers were placed immediately beside the reservoir and the temperatures read off with a kathetometer. The dilatometer was thus transformed into a mercury thermometer of extraordinary size with a carefully calibrated stem (the scale-tube).

[1] Journ. pr. Ch [2] Bd 25 p. 103.

[2] In spite of the fragile form of the instrument, this operation is not very hazardous. Care must be taken, that the quantities of mercury entering through the capillary tube are heated beforehand to 200° or 300° C.

Table I. Series a.

Thermometer G_{II}, melting point of ice = + 0°.35 C on the scale.
1 normal m.m. of the scale-tube[1] = 0.0002312 cc.
Quantity of mercury in the dilatometer at 0° C = 558.400 Gr
Volume » » exposed to the variations of temperature = 41.0712 cc.

Temperature observed C.	Temperature corr. C.	Position of the mercury index (corr.) in the scale-tube.	Change of Volume for 1° C in millimetres (corr.) of the scale-tube.	Coefficient of apparent dilatation of mercury. β
+ 3°.00	+ 2°.65	847.18 m.m.		
			= 27.23	= 0.000153
+ 2°.00	+ 2°.65	819.95 »		
			= 27.03	= 0.000152
+ 1°.00	+ 0°.65	792.92 »		
			= 27.33	= 0.000153
0	— 0°.35	765.59 »		
			= 26.56	= 0.000149
— 1°.00	— 1°.35	739.03 »		
			= 26.59 = $\frac{53.18}{2}$	= 0.000149
— 3°.00	— 3°.35	685.85 »		
			= 26.91 = $\frac{53.82}{2}$	= 0.000151
— 5°.00	— 5°.35	632.03 »		
			= 27.30 = $\frac{54.60}{2}$	= 0.000153
— 7°.00	— 7°.35	577.43 »		
			= 26.93 = $\frac{53.87}{2}$	= 0.000151
— 9°.00	— 9°.35	523.56 »		
			= 27.02 = $\frac{54.04}{2}$	= 0.000152
— 11°.00	— 11°.35	469.52 »		
			= 27.41	= 0.000154
— 12°.00	— 12°.35	442.11 »		

Series b.

Thermometer G_{III}, melting point of ice = + 0°.18 C on the scale.

Temperature observed C.	Temperature corr. C.	Position of the mercury index (corr.) in the scale-tube.	Change of Volume for 1° C in millimetres (corr.) of the scale-tube.	Coefficient of apparent dilatation of mercury. β
0°	— 0°.18	750.83 m.m.		
			= 26.64 = $\frac{319.96}{12}$	= 0.000150
— 12°.00	— 12°.18	430.87 »		
			= 26.64 = $\frac{53.29}{2}$	= 0.000150
— 14°.00	— 14°.18	377.58 »		
			= 27.33 = $\frac{54.66}{2}$	= 0.000153
— 16°.00	— 16°.18	322.92 »		
			= 28.39 (?)	= 0.000159 (?)
— 17°.00	— 17°.18	294.53 »		

[1] The same scale-tube was employed in all the following experiments.

This table shows, that the apparent dilatation of the mercury in the dilatometer was equal [= 27... millimetres = 0.006242 cc] for every centigrade degree observed on the scales of the Geissler thermometers G_{II} & G_{III}. The variations [0.3 unto 0.7 millimetre] are due to the difficulty of maintaining a steady temperature in the mercury vessel for a sufficiently long time. I estimate the unavoidable oscillation of temperature at about 0°.02 C for temperatures above — 10° C. For lower temperatures (as for example — 16° to — 17° C) the error is somewhat greater.

This speaks strongly in favor of the Geissler thermometers. They are in fact excellently graduated after the principle of the mercury thermometers. I therefore, upon reflection, thought it advisable, to apply this principle exclusively to all measurements of temperature given in this paper. The numbers therefore refer to the indications of correctly calibrated mercury thermometers. Besides, all measurements of temperatures of ice or water, hitherto published in hydrographic researches, are made with mercury thermometers, and the following results would be incapable of comparison with those of my predecessors, if I were to apply another standard of temperature. Still I think it to be a serious inconvenience, that science nominally proclaims one standard of temperature [the dilatation of dry air] but practically applies another [the dilatation of mercury].

The preceding experiment also serves another purpose. For the following determinations it was necessary to know the coefficient of absolute dilatation of the glass reservoir of the dilatometer. This number is easily calculated from the last column of the table 1 series a & b. If

q denotes the coefficient of absolute dilatation of mercury,
β » » » » apparent » » »
g » » » » cubic dilatation of glass,

then

$$g = q - \beta.$$

β being a constant (see last column of table 1, a & b), the value of g depends upon what number is substituted for q. Here another great inconvenience arises from the uncertainty of the absolute coefficient of expansion of mercury at 0° and lower temperatures. According to Regnault's determinations

$$q = 0.00017905 \text{ at } 0°.$$

According to Wüllner's recalculation of Regnault's experiments, it ought to be

$$q = 0.00018116$$

in the first case g is $= 0.00002753$ [$q = 0.00017905$ Reg.]
» » second g » $= 0.00002974$ [$q = 0.00018116$ Wülln.]

This uncertainty, which does not amount to more than 0.00000221, will perhaps seem to be very unimportant but would indeed be most fatal, if it was not neutralized to a great degree by a stratagem in the method. An easy calculation shows that the influence, which this uncertainty, as to the real coefficient of expansion of mercury, excercises upon the final result, is in some cases about 5 to 10 times greater than the disturbance caused by unavoidable errors of observation. I think, that the original number 0.00017905 of Regnault represents the average coefficient of dilatation of mercury below zero more closely than 0.00018116. Therefore the following results are calculated by means of the constants

$$q = 0.00017905 \qquad g = 0.00002753$$

The volumes of *pure water* and *ice* are also calculated by means of

$$q = 0.00018116 \qquad g = 0.00002974$$

to facilitate the comparison with the calculations of Plücker and Geissler, which are founded upon a similar assumption.[1] In both cases the values of q and g are supposed to be constant within the temperatures of observation.

This assumption is of course not correct, but is an almost unavoidable consequence of the prevailing uncertainty as to the real dilatation of mercury[2] at low temperatures and from the chosen standard of temperature, which involves:

$$q - g = \text{constant}$$

from which it follows, that the variations of q and g must be equal. The value of g being only $^1/_6$ of q, it follows, that the expansion of glass varies 6 times more rapidly than that of mercury. In order to avoid the application of this consequence, which is hardly acceptable, if q is supposed to vary below zero in the ratio given by the formulae, I have supposed both q and g to remain constant and consequently to

[1] $q = 0.00018058$.

[2] In the course of this research the author has gained the conviction, that the dilatation of mercury below zero is not exactly represented by the formulae and the coefficients given by Regnault a. O. for higher temperatures, and that this subject highly needs a repeated experimental research. The alteration in the coefficient of dilatation, which begins to appear on approaching the point of solidification of mercury, is the real cause of the discrepancy between the air-thermometer and the mercury thermometers. The author hopes to return to this subject in a future paper.

denote the *average* coefficients of expansion of mercury and glass.

In the case, that q should be experimentally determined with exactness for temperatures below zero, all the elements are at hand for a recalculation of the following results.

B. Measurements of volume.

These are made by means of the dilatometer represented by fig. 2 on plate 20 in the following way. The reservoir B is filled to $^1/_3$ with mercury and cautiously heated, until the air adhering to the surface of the glass, in contact with the mercury, has escaped. When the last traces of air are removed, and a real ebullition of mercury seems to begin, the stopcock d is closed and the flame allowed to sweep the upper part of B. The pressure of the heated air and the mercury vapour makes the hot mercury rise in the capillary stem of the dilatometer and fill the side tubes b and c and the upper reservoir A. The volume of the mercury, which remains in B, must not exceed $^1/_{10}$ of the space of the reservoir. Then the stopcocks a, b and c are shut and the flame removed from B to C, the water of which is heated to boiling. The stopcock d is opened, and a jet of hot water passes from C to B, on account of the rarefied air in the reservoir. When B is half filled with water, a separate flame is applied to it, and the water in B and C is assiduously boiled, until every trace of air is removed. If B is allowed to cool, it is rapidly filled with air-free water from C, which is still kept boiling. When the temperature of the water in B has sunk to about 30° or 35° C, the capillary tube of the dilatometer is made to dip in the mercury, which covers the bottom of C, and then, on farther cooling, a tiny column of mercury enters the capillary tube in the manner shown in fig. 2. The stopcock d is shut, a is opened, and the operation of filling the instrument with water is completed.

If the dilatometer in this condition is combined with a calibrated scale-tube, the whole dilatation of water, from its boiling to far below its freezing point, can be easily determined, but if also the change of volume *by freezing* and the dilatation of the frozen water must be ascertained, which was the case in my experiments, another preparatory operation, which requires the greatest caution, is necessary.

The freezing of the water in the dilatometer must be con-

ducted *very slowly* from the upper part downwards, until the whole mass is transformed into a cylinder of ice. The tendency of the ice to form at the surface of the mercury, which on account of its superior conductivity is cooler than the glass, must be prevented by keeping the nether part of the instrument isolated with cotton.[1] The operation is best performed on a cold winter day, by placing the instrument in a snowdrift or exposing it to the free air. The freezing process is introduced from above, by surrounding the capillary tube with snow and a few crystals of $CaCl_2 + 6aq$. Ordinarily the formation of the whole cylinder lasted 6 to 8 hours. This cylinder was without a single bubble of air and entirely transparent, if the instrument was filled with pure water[2] and all operations correctly performed. The ice from salt water is somewhat opaque and shows a radial structure.

Afterwards the dilatometer is either dipped for a moment in water of + 10° or + 15° C or warmed by the hand, until the outer layer of ice, nearest to the glass, is melted, then the stopcock d is opened. The pressure of the mercury makes a thin film of metal ascend between the glass and the compact ice cylinder in the reservoir, which will thus be surrounded by an envelope of mercury. The melted ice leaves the instrument by the capillary tube. If this operation is conducted with address, the ice will be almost completely enveloped with a metallic rind and only be visible from without as a narrow stripe, where the ice cylinder touches the glass, (see plate 20).

Finally the stopcock d is shut and the dilatometer placed in an iron vessel, filled with mercury. An iron hook is fixed in the bottom, which keeps the reservoir and a part of the stem and the capillary tube of the dilatometer immersed in the fluid, which is constantly stirred by an iron paddle. A thermometer is placed beside the reservoir, and a calibrated scale-tube is joined to the dilatometer at c. Outside the vessel a cooling mixture of snow and NaCl is applied, which makes the temperature of the mercury sink very slowly.

When an observation is to be made, the regular sinking of the temperature in the mercury vessel is compensated by

[1] This part of the experiment requires the constant watchfulness of the experimentalist.

[2] In this case the danger of bursting is infinitely greater than otherwise, on account of the extreme hardness of absolutely pure ice. Ice from salt water is much weaker and seldom causes the bursting of the glass reservoir.

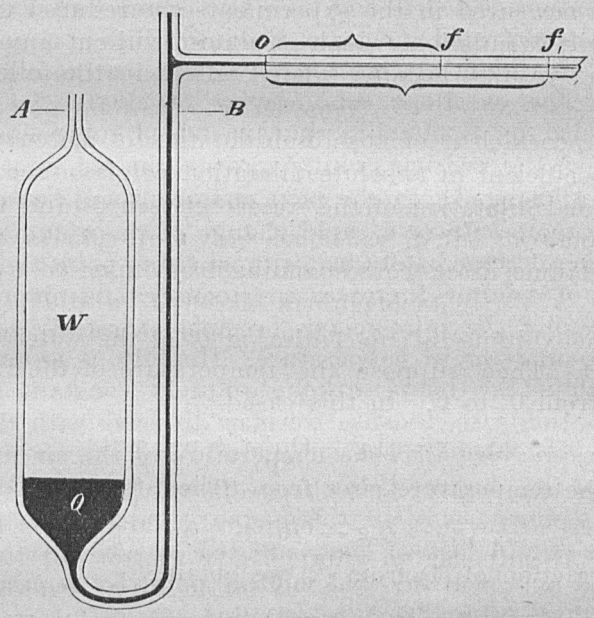
means of a test tube filled with warm water, which is dipped in the fluid. If the quantity of mercury is large [about 7 or 8 kilogrammes], and the stirrer is vigorously moved, the index of the thermometer can be kept almost stationary by means of this artifice,[1] with exception of a few oscillations, which only at very low temperatures amount to $0^{\circ}.10$ C but ordinarily do not exceed $0^{\circ}.03$ C. On account of the large capacity of the dilatometer, the oscillations of the mercury index of its scale-tube are not perceptible, the meniscus moves very regularly over the usual number of millimetres (30 unto 50) for every centigrade degree and then, two minutes after the thermometer has indicated the state of equilibrium of temperature in the mercury bath, attains a fixed position without any oscillations.[2] The excellent conductivity of air-free ice, which is surrounded by a metallic rind, is indeed surprising. In the vicinity of the melting point, however, the behavior of the ice is totally changed. In the next chapter it will be proved, that at these temperatures a rapid change of the volume of the ice takes place. Immediately below the melting point the abnormal change of volume increases enormously, and simultaneously the index of the dilatometer becomes extremely sensitive to slight oscillations of temperature. Happily, it is an easy task to maintain the temperature absolutely constant for a long time in this case, because we may dispense with the cooling mixture, provided that the temperature of the air in the room is kept a few degrees below zero. Then, by repeated introduction of a warm body in the mercury bath, we may compensate the slight loss of heat, suffered by conduction or radiation, and approach the real melting point by regular observations unto $0^{\circ}.02$ or $0^{\circ}.01$ C.

The dilatation of the frozen water being ascertained by one or two series of observations between -18° and the melting point, it remains to determine the change of volume by the melting of the ice and the expansion of the liquid water. For this purpose b is made to dip in a cup containing a weighed quantity of mercury, c is shut, b is opened and the temperature of the mercury bath raised above the melting-point of the ice. After several hours the instrument is allowed

[1] The operation, like most of these experiments, requires the aid of an assistant, who with a magnifying glass reads off the scale-tube of the dilatometer, while the experimentor regulates the temperature and observes the thermometer with a kathetometer.

[2] The temperature was of course kept constant much longer.

to assume its original temperature, and the contraction of volume caused by the melting process is determined by weighing the remaining quantity of mercury in the cup. Afterwards b is shut, c is opened again, and the expansion of the liquid for every centigrade degree measured by means of the scale-tube as before. But in this case the dilatometer needs much more time [6 to 8 minutes] to attain a uniform temperature throughout its whole mass than before. Therefore the time of each observation must be considerably prolonged [20 to 25 minutes].



When the volumetric determinations are completely finished, the instrument is taken from the mercury bath and placed in melting snow for a couple of hours. The superfluous mercury in the reservoir is removed, so that the dilatometer is filled exactly to the stopcocks a and c with mercury (and water) of 0° C. Afterwards it is cleaned and weighed at ordinary temperature. The mercury is collected and weighed separately.

The results are calculated in the following way.[1] From A, B and downwards the instrument is immersed in the mercury-bath and partakes of its variations of temperature. The volume

[1] See the preceding figure.

by zero of this part [the reservoir and stem] is denoted by L. Let Q be the volume of the mercury in the reservoir, the capillary and the stem unto A and B. The stand of the mercury column in the scale-tube at zero is 0. When the temperature of the mercury bath has risen t degrees above zero, the mercury index is supposed to have moved f millimetres. If the temperature rises to t_1 degrees, the mercury index will indicate f_1 millimetres. The scale-tube is supposed to possess the temperature of the room, which was regulated so as never to vary more than from 2 to 4 degrees from zero, and the mercury columns measured in the experiments are reduced to zero. I think this calculation, which is almost without any influence upon the results, may be safely omitted in the following formulæ.

q is the coefficient of absolute dilatation of mercury
g the coefficient of absolute dilatation of glass [see p. 261]
x the total dilatation of the water between 0° and t°
x_1 » total » » » » » 0° » t_1°
p » volume in cc. corresponding to f m.m.
p_1 » » » » » » f_1 »

W is the volume in cub-centim. at 0° of the water in the instrument. Then suppose the temperature of the instrument to rise from 0° to t°. In this case

$$(1) \ldots\ldots\ldots\ldots x = [Lg - Qq]\ t + p + pqt$$

and if the temperature rises from 0° to t_1°,

$$(2) \ldots\ldots\ldots x_1 = [Lg - Qq]\ t_1 + p_1 + p_1 q t_1.$$

By subtraction of (1) from (2) we obtain:

$$x_1 - x = [Lg - Qq]\ (t_1 - t) + p_1 - p + (p_1 t_1 - pt)\, q$$

$$(3) \ldots\ldots\ldots \frac{x_1 - x}{t_1 - t} = Lg - Qq + \frac{p_1 - p}{t_1 - t} + q\,\frac{p_1 t_1 - pt}{t_1 - t}.$$

The coefficient of expansion »w» of water between t° and t_1° referred to the unit of volume at 0° will be

$$(4) \ldots\ldots w = \frac{Lg - Qq + \frac{p_1 - p}{t_1 - t} + q\,\frac{p_1 t_1 - pt}{t_1 - t}}{W}.$$

This formula also holds good below zero, whether the water in the instrument is frozen or liquid. The standard unit in either case is the cub. centim. of liquid water at zero. Only in the case of pure ice another unit of volume is also introduced, viz. the cub. centim. of the ice at its melting point. In the case of ice from salt or brackish water this calculus be-

comes impossible, *because the ice from such water has no definite volume at its melting point.* [1]

We may simplify the calculation without the least injury to the exactness of the results, by assuming $p_1 = p$ in the quotient

$$q \frac{p_1 t_1 - p t}{t_1 - t}$$

for temperatures not exceeding the limits $-10°$ and $+10°$ C. The formula (4) then becomes

$$(5) \ldots\ldots\ldots\ldots w = \frac{Lg - Qq + qp_1 + \frac{p_1 - p}{t_1 - t}}{W}.$$

It is self-evident, that instead of the volumes L, Q, p, p_1, W we may as well substitute in the formula the weights of the corresponding quantities of mercury.

On page 261 I have alluded to the grave inconvenience, which the uncertainty of the real value of the coefficient of expansion of mercury involves. I will now try to show, how the errors arising from this deficiency in the present state of science can be counterbalanced and for a great part eliminated from the results by a special arrangement.

The quantities dependent upon the value ascribed to q in formula (5) are

$$Lg - Qq$$

and

$$qp_1.$$

The latter quantity is almost devoid of influence upon the result, on account of its smallness. We may also reduce the influence of the former considerably by selecting the quantities of mercury and of water so, that

$$Lg - Qq = 0.$$

In this case the quantity

$$\frac{p_1 - p}{t_1 - t},$$

which is independant of q and can be determined by direct observations with great exactness, will be predominating in the result, and the influence of erroneous assumptions of the values of q and g will be immaterial. [2]

In the series of determinations of the volumes of the frozen water I, A given in chapter 3

[1] This fact (hitherto unnoticed) is the reason, why I have referred the coefficients of dilatation to the quantity of *liquid* (instead of *solid)* water contained in 1 cc. at 0° C.

[2] It must be remembered, that the values of q and g are dependent on each other and must vary in the same sense.

$$Lg - Qq = -0.0004598_{\text{Reg}} \ldots = -0.0003776_{\text{Wülln.}}$$

$$\left.\begin{matrix} t_1 = -4^\circ \\ t = -3^\circ \end{matrix}\right\} \ldots qp_1 = 0.0000042 \text{ cc.}$$

and

$$\left.\begin{matrix} t_1 = -4^\circ \\ t = -3^\circ \end{matrix}\right\} \ldots \frac{p_1 - p}{t_1 - t} = 0.006698 \text{ cc.}$$

$$w = 0.0001740 \text{ [Reg]} \ldots w = 0.0001762 \text{ [Wülln]}$$

$$\text{Difference} \ldots = 1.2\ \%.$$

But it must be observed, that afterwards, when the volumes of the liquid are determined with the same instrument, the relation

$$Lg - Qq = -0.0004598 \text{ etc. } \ldots$$

holds good no longer. The volume of the water is diminished by the melting, and consequently the volume of mercury in the instrument is no longer Q but Q_1. The above values for liquid water then become

$$Lg - Q_1q = -0.0010409_{\text{Reg}} \ldots = -0.0009654_{\text{Wülln.}}$$

$$qp_1 = 0.000000 \ldots\ldots$$

$$\left.\begin{matrix} t_1 = -1^\circ \\ t = 0^\circ \end{matrix}\right\} \ldots \frac{p_1 - p}{t_1 - t} = -0.0017132$$

$$w = -0.0000767 \text{ [Reg]} \ldots w = -0.0000748 \text{ [Wülln]}$$

$$\text{Difference} \ldots = 2.5\ \%.$$

If the dilatometer is thus adjusted, so that for frozen water

$$Lg - Qq = 0 \text{ (or nearly 0)},$$

it will perform its functions under more unfavorable [1] circumstances, if afterwards applied to determine the expansion of the liquid water formed by melting of the ice.

The change of volume caused by the melting process is naturally independent of all irregularities of this kind, because the instrument is brought back again to its original temperature after the melting is finished. The operation of melting may therefore be considered to be accomplished at constant temperature.

The principle of the artifice just described was originally invented by Plücker and Geissler.

C. Determination of the latent heat of water.

The method invented for this purpose is minutely described in Journ. f. prakt. chem. [2] Bd. 24 p. 151 and must

[1] I have chosen here the most unfavorable example, which can occur, viz. the determination of the dilatation between 0° and — 1°.

therefore be mentioned very briefly here. A glass tube of the shape shown in fig. 1 on plate 20 is filled with water and placed in an iron calorimeter containing a weighed quantity of mercury. The calorimeter is protected from the condensing humidity of the air by means of an enclosing cylinder of metal. The air enclosed between the calorimeter and the envelope is kept dry by means of conc. sulphuric acid. The calorimeter rests upon three points of ivory and is nowhere in contact with the metallic capsule. The capsule being cooled from without by means of a freezing mixture of snow and NaCl, the temperature of the calorimeter slowly sinks by radiation to — 6° or — 8° C. During the whole time (the experiment ordinarily lasts 6 or 7 hours) the mercury is constantly stirred and the temperature observed every half minute, as soon as it has approached $1^1/_2$ or 2 degrees from the appointed temperature of solidification, which the experimentor is at liberty to fix beforehand, according to his pleasure. When the temperature has sunk sufficiently, an assistant introduces a thin thread of glass, which has been brought in contact with a snow flake, into the stem of the tube, the water of which is then immediately transformed into ice. The solidification is at — 6° or — 8° C almost instantaneous: a sudden crack is heard, the tube is broken into pieces, which are kept below the surface of the mercury in the calorimeter by a network of iron. The latent heat developed by the freezing of the water is measured by the rise of temperature observed by means of a kathetometer on the Geissler thermometer G_{II}. On account of the excellent conductivity of mercury relatively to the fluids ordinarily employed in calorimetric experiments, the equilibrium of temperature is established in a very short time and the curves representing the loss of heat by radiation can be constructed with the utmost regularity.

It will occur to the reader, that this method gives the latent heat of the fluid enclosed in the spiral by a temperature some degrees below its ordinary melting point. According to the law of Person the latent heat will vary a little with the temperature of freezing, variations, which may be calculated from the difference of the specific heat in the liquid and solid state. Let r denote the latent heat at the ordinary

[1] In the Journal f. prakt. Chem., where an illustration of the progress is inserted, the author has published his determinations of the latent heat of phosphorus at different temperatures below its real melting point.

melting point, c_1 the specific heat of the solid, c of the liquid body, then the variation in the latent heat may be expressed by

$$\frac{dr}{dt} = c_1 - c$$

According to Person the specific heat of ice is half of that of the water, then

$$\frac{dr}{dt} = -0.5$$

i.e. the latent heat of water will be found 0.5 calory smaller for every centigrade degree below zero.

By the calorimetric method just described these variations, predicted by theory, can be experimentally verified. The experiments relating to pure water are published in the Öfvers. K. V. A. Förhandl. 1878. It now remains to be seen, if *salt water* by freezing shows any remarkable anomaly with regard to its latent heat. Chapter 6 will be reserved for this subject.

D. Determinations of freezing points and specific gravity etc.

The freezing point of each water was first roughly ascertained by a preliminary experiment with an ordinary thermometer. Afterwards a considerable quantity was slowly cooled to about 0°.2 or 0°.3 C below its normal freezing point, then a crystal of snow was thrown into the beaker and the maximum of temperature observed by means of a Geissler thermometer. During the whole process the water was constantly mixed.

The following table shows the relation between the specific weights and the freezing points of different kinds of sea-water

σ = spec. gravity at $\frac{0°}{+4°}$	$\Delta\sigma$	$\tau°$ = freezing point	$\Delta\tau$	$\frac{\Delta\sigma}{\Delta\tau}$
1.0271		— 1°.895		
	..... 0.0027		..... 0°.18	— 0.0150
1.0244		— 1°.715		
	..... 0.0096		..... 0°.69	— 0.0139
1.0148		— 1°.025		
	..... 0.0026		..... 0°.175	— 0.0148
1.0122		— 0.°85		
	..... 0.0018		..... 0°.135	— 0.0133
1.0104		— 0°.715		
	..... 0.0063		..... 0°.445	— 0.0141
1.0041		— 0°.27		
			medium =	— 0.0142

i.e. an increase of 0.00014 in the spec. gravity of sea-water makes its freezing point sink 0°.01 C. We might therefore judge with sufficient accuracy of the specific gravity and the percentage of salt in sea-water from its freezing point, if determined under due precautions with a sensible thermometer.

All determinations of specific gravity were made with the Sprengel pycnometer.

CHAPTER 3.

On pure water.

Ermann[1] and Kopp[2], in their celebrated researches on the volumes of solid and liquid bodies, first called attention to the fact, that solids are sometimes liable to irregularities of volume in the vicinity of their melting point. Thus, for example, the volume of sulphur was found (by Kopp) to increase extraordinarily from + 70° C upwards. The melting process, which ordinarily is confined to a fixed temperature, here may be considered to begin more than 40 centigrades below the ordinary melting point. Other bodies, for example, phosphorus and ice, did not show any similar irregularity. Neither Plücker and Geissler, nor the author and H. Larson were able to discover any signs of premature melting of pure ice below zero. The cause of the anomaly of sulphur and still more of selenium is ordinarily attributed to the formation of allotropic modifications of these elements. Also in the case of compound bodies, as, for example, wax, stearine etc. showing similar properties, this explanation is commonly adopted. I think, however, that in some cases another interpretation may be possible.

From my previous experiments on the thermic and volumetric properties of the hydrates of acetic and formic acid I had learned, that the whole melting process of a solid body may be essentially altered, in case a slight quantity of another substance is present, *which is capable of entering into solution with the liquid body.* I found that traces of water, too slight to be detected by any chemical analysis, are able to disturb

[1] Pogg. Ann. IX.
[2] Liebig's Ann. XCIII.

the regular expansion of the solid hydrates HC00H and CH_3C00H for many degrees below their melting point. The considerable change of volume accompanying the melting process of these compounds then begins at a premature stage of temperature and gradually increases, until the whole mass is transformed into the liquid state.

In the same degree that the acetic acid was purified from adhering traces of water, these signs of premature melting rapidly diminished, and the curve of regular expansion of volume began to extend to the vicinity of the real melting point, but nevertheless the purest hydrate, which I could prepare by repeated distillation and crystallisation from 10 kilogrammes of ordinary acid. acet. puriss. did not show a sudden transition, at any definite temperature, of the specific volume of the solid into that of the liquid substance. I therefore suspected, that a slight trace of foreign substances would cause a similar anomaly in the melting-process of the ice, to that, which a trace of water occasions in the behavior of the solid acetic or formic hydrate; and that the negative results, hitherto obtained by Plücker and Geissler as well as by myself, were due to the absolute purity of the water. I resolved first to try ordinary distilled water from one of the glass reservoirs of the laboratory. The water had been kept there more than a week, protected from dust etc., but in communication with the air of the laboratory room. Silver nitrate and chlorid of mercury with carbonate of sodium occasioned a faint opalisation in the fluid; other agencies were powerless. A drop of the water, cautiously evaporated on a glass plate, left a visible residue. I concluded that, with the exception of slight traces of ammonium salts and of chlorine, the water was pure. The volumes of ice from this sample of water are recorded in table III. In the vicinity of the melting point the ice shows a remarkable contraction of volume, [1] which seems to begin already

[1] This fact recalls to our mind the old hypothesis, once supported by Muschenbroek and de Mairan, that the ice expands its volume, when cooled, and contracts, on being heated. Although this opinion was refuted by the experiments of Placidus Heinrich already in the beginning of this century, it was revived by Petzholdt in 1843, who tried to explain the movement of the glaciers by the dilatation of the ice, caused by the winter cold, and its contraction by the heat of the summer.

In order to corroborate his theory, Petzholdt determined the expansion of ice by weighing a silver bottle filled with pure frozen water in ether at different temperatures (from $-2°$ to $-8\,R°$) below zero. In fact the coefficient of expansion was found to be *negative at all temperatures.*

at — 0°.25 C. Still more easily this contraction may be followed by the deflection of the curve III (marked with red) on plate 22.

I next proceeded to the examination of entirely pure water, prepared by repeated distillation of water from the well of St. Eric in Upsala, which according to the analyses of Prof. Almén gives the purest drinking water in Sweden. Two separate experiments were made with such water. The volumes of the ice are found in tables I & II and are graphically represented in plate[1] 22 by the red curves I & II. These measurements were taken with two different dilatometers, but this circumstance will hardly suffice to account for the marked discrepancy of the curves of volumes. The real cause seems to be, that in experiment II the water was boiled for more than an hour by the operation of filling the instrument and therefore has dissolved a trace of the substance of the glass reservoir. In experiment I, which I undertook last of all, I purposely restricted the boiling operation to the least possible time. Still the inflection of curve I on plate 21 & 22 clearly shows, that the purest water, which can be employed in dilatometric experiments, also contracts its volume before melting.

». . . . Bei Abnahme der Temperatur fand stets eine Ausdehnung und bei Zunahme der Temperatur stets eine Zusammenziehung statt, und zwar ergab sich, wenn die Längenausdehnung bei — 1° R = 1 gesetzt wird,

die lineare Ausdehnung im mittel für Erkältung um 1° R

in d.	2ten	Versuchsreihe,	bei	Erkält.	v.	— 2° R	bis	— 7°.5 R	zu	0.00036	. .
» »	3ten	»	»	»	»	» — 2° »	»	— 7°	» »	0.00040	. .
» »	4ten	»	»	»	»	» — 2° »	»	— 8°	» »	0.00037	. .

etc. . .» [Beiträge zur Geognosie von Tyrol, Leipz. 1843].

If Petzholdt had employed ice from salt water in his experiments, we would find no difficulty in explaining the negative coefficient of expansion. In chapter 4 we will meet with some specimens of sea ice, which show very considerable contractions, when cooled. But as he asserts, that the ice of his experiments was formed from pure water (»luftfreies destillirtes Wasser»), which does not show any abnormal contraction below — 0°.3 C, we must admit the justness of the remark of Brunner, who in 1845 repeated the experiments of Petzholdt and found the coefficient of expansion of ice to be *positive* and greater than that of any other solid:

»Il résulte donc de mes expériences, que *la glace se contracte par le froid,* ainsi que les autres corps solides, ce qui est directement opposé aux observations de Mr. Petzholdt» (Bibliothèque universelle de Genève T. LVI).

Notwithstanding this, some of the observations of Petzholdt on glaciers highly merit our attention. If we confine the application of his theory to those limits, where a contraction by heat really takes place in the glacier-ice, i. e. *to temperatures in the immediate vicinity of zero,* we certainly can not deny, that this phenomenon must have something to do with the movement of the glaciers.

[1] For the sake of distinctness the curve II is left out in plate 21.

Table I, A.

Specific gravity of the ice at $\frac{0°}{+4°} = 0.91686$

L = 49.1840
Q = 10.1583
W = 39.0257
W_1 = 35.7811

Therm. G_{II} freez. p. = + 0°.39 C
» G_{III} » » = + 0°.20 C

q = 0.00017905 [Regn.]
g = 0.00002753

1 normal mm. corr. = 0.0002312 cc.

Lg = 0.0013589 Qq = 0.0018188

t° C. uncorr.	t° C. corr.	Scale-tube mm. corr.	Scale-tube cc. corr.	Total expansion of 1 cc. ice at 0°	Total expansion of 1 cc. water at 0°	Coefficient of expansion unit: 1 cc ice at 0°	Coefficient of expansion unit: 1 cc water at 0°
+ 0°.37	— 0°.02	.....	.....	.....	.....	.....	.....
+ 0°.36	— 0°.03	— 1	0.000231	— 0.0000060	— 0.0000065	— 0 000604	— 0.000659
+ 0°.24	— 0°.15	0	0	— 0.0000014	— 0.0000015	— 0.000011	— 0.000012
+ 0°.19	— 0°.20	+ 0.58	0.000134	+ 0.0000028	+ 0.0000031	+ 0.000056	+ 0.000062
+ 0°.09	— 0°.30	2.51	0.000580	0.0000136	0.0000149	0.000136	0.000149
— 0°.01	— 0°.40	2.30	0.000531	0.0000124	0.0000135	0.000124	0.000135
— 0°.11	— 0°.50	2.32	0.000536	0.0000125	0.0000137	0.000125	0.000137
— 0°.61	— 1°.00	12.71	0.002938	0.0000694	0.0000757	0.000138	0.000151
— 1°.61	— 2°.00	26.87	0.006212	0.0001474	0.0001608	0 000147	0.000160
— 2°.61	— 3°.00	26 96	0.006233	0.0001477	0.0001611	0.000147	0.000161
— 3°.61	— 4°.00	28.97	0.006698	0.0001594	0.0001740	0.000159	0.000174
— 5°.61	— 6°.00	57.00	0.012178	0.0003135	0.0003420	0 000156	0.000171
— 6°.61	— 7°.00	28.80	0.006658	0.0001590	0.0001734	0.000159	0.000173
— 8°.80	— 9°.00	57.71	0.013343	0.0003173	0.0003461	0.000158	0.000173
— 9°.80	— 10°.00	28.60	0.006612	0.0001570	0.0001713	0.000157	0.000171
— 16°.80	— 17°.00	193.74	0.044794	0.0010598	0.0011559	0.000151	0.000165
— 17°.80	— 18°.00	27.01	0.006244	0.0001479	0.0001605	0.000147	0.000160
——	——	——	——	——	——	——	——
						Determinations	
—0°.2—17°.8	—0°—18°	495.11	0.114473	.....	.....	0.000151	0.000164
—0°.2—18°.8	—0°—19°	518.41	0.11986	.....	.....	0.000147	0.000162

Pure water (ice).

cc at 0°
cc » »
cc » » (ice)
cc » » (water)

Change of Volume by melting between — 0°.03 C and 0° = 3.24468 cc
Calculated per 1 cc of water at 0° = 0.090686 cc
Volume of 1 cc of water, as ice at — 0°.03 C = 1.090686 cc

Lg — Qq = — 0.0004598		q = 0.00018116 [Wülln.] g = 0.00002974 Lg = 0.0014627 Qq = 0.0018403 Lg — Qq = — 0.0003776					
Volume at t° of		Total expansion of		Coefficient of expansion		Volume at t° of	
1 cc ice at 0°	1 cc. water at 0°	1 cc ice at 0°	1 cc water at 0°	unit: 1 cc ice at 0°	unit: 1 cc water at 0°	1 cc ice at 0°	1 cc water at 0°
1.0000000	1.0906794	.....	.....	.....	.....	1.0000000	1.0906795
1.000006	1.090686	— 0.0000060	— 0.0000065	— 0.000602	— 0.000656	1.000006	1.090686
1.000007	1.090688	— 0.0000011	— 0.0000012	— 0.000009	— 0.000010	1.000007	1.090687
1.000004	1.090685	+ 0.0000029	+ 0.0000032	+ 0.000059	+ 0.000064	1.000004	1.090684
0.999990	1.090670	0.0000139	0.0000151	0.000139	0.000151	0.999990	1.090669
0.999978	1.090656	0.0000126	0.0000138	0.000126	0.000138	0.999976	1.090655
0.999965	1.090642	0.0000127	0.0000139	0.000127	0.000139	0.999963	1.090641
0.999896	1.090567	0.0000704	0.0000768	0.000140	0.000153	0.999893	1.090564
0.999749	1.090406	0.0001495	0.0001630	0.000149	0.000163	0.999744	1.090401
0.999601	1.090245	0.0001500	0.0001636	0.000150	0.000163	0.999594	1.090238
0.999441	1.090071	0.0001614	0.0001762	0.000161	0.000176	0.999433	1.090061
0.999128	1.089729	0.0003177	0.0003466	0.000158	0.000173	0.999115	1.089715
0.998969	1.089555	0.0001609	0.0001755	0.000160	0.000175	0.998954	1.089539
0.998651	1.089209	0.0003216	0.0003507	0.000160	0.000175	0.998632	1.089188
0.998494	1.089038	0.0001592	0.0001736	0.000159	0.000173	0.998473	1.089015
0.997435	1.087882	0.0010745	0.0011720	0.000153	0.000167	0.997399	1.087843
0.997287	1.087721	0.0001493	0.0001628	0.000149	0.000162	0.997249	1.087680
—	—	—	—	—	—	—	—
of control							
0.997288	1.087728	.....	.....	0.000152	0.000166	0.997250	1.087680
0.997063	1.087585	.....	.....	0.000151	0.000165	0.997122	1.087541

Table I, B. Pure water (liquid).

$L = 49.1840$ cc at 0° C
$Q_1 = 13.4029$ » » » »
$W_1 = 35.7811$ » » » »

Therm. G_{II} freez. p. = + 0.°39 C » G_I » » = + 0.°56 C 1 normal mm. corr. = 0.0002312 cc.				q = 0.00017905 [Regn.] g = 0.00002753 Lg = 0.0013589 Q_1q = 0.0023998 Lg = Q_1q = — 0.0010409		q = 0.00018116 [Wülln.] g = 0.0002974 Lg = 0.00146273 Q_1q = 0.0024281 Lg — Q_1q = — 0.0009654	
t° C. uncorr.	t° C. corr.	Scale-tube mm. corr.	Scale-tube cc. corr.	Coeffic. of exp. unit: 1 cc. water at 0°	Volume at t° of 1 cc. water at 0°	Coeffic. of exp. unit: 1 cc. water at 0°	Volume at t° of 1 cc. water at 0°
— 3°.61	— 4°.00	.....	.....	.....	1.000408	.....	1.000400
— 2°.61	— 3°.00	— 15,04	0.003477	— 0.000126	1.000282	— 0.000124	1.000276
— 1°.61	— 2°.00	— 12.57	0.002906	— 0.000110	1.000172	— 0.000108	1.000168
— 0°.61	— 1°.00	— 10.26	0.002372	— 0.000095	1.000076	— 0.000093	1.000074
+ 0°.39	0	— 7.41	0.001713	— 0.000076	1.000000	— 0.000074	1.000000
+ 1°.39	+ 1°.00	— 4.68	0.001067	— 0.000059	0.999940	— 0.000057	0.999942
+ 2°.39	+ 2°.00	— 1.56	0.000360	— 0.000039	0.999901	— 0.000037	0.999905
+ 3°.39	+ 3°.00	+ 0.38	0.000087	— 0.000026	0.999874	— 0.000024	0.999881
+ 4°.39	+ 4°.00	3.36	0.000776	— 0.000007	0.999867	— 0.000005	0.999875
+ 5°.56	+ 5°.00	5.28	0.001220	+ 0.000005	0.999872	+ 0.000007	0.999883
+ 6°.56	+ 6°.00	7.89	0.001824	0.000021	0.999894	0.000024	0.999907
+ 7°.56	+ 7°.00	9,95	0.002300	0.000035	0.999929	0.000037	0.999944
+ 8°.56	+ 8°.00	12.10	0.002797	0.000049	0.999978	0.000051	0.999995
+ 9°.56	+ 9°.00	14.63	0.003382	0.000065	1.000044	0 000067	1.000063
+ 10°.56	+ 10°.00	16.28	0.003764	0.000076	1.000120	0.000078	1.000141
+ 11°.56	+ 11°.00	19.00	0.004392	0.000094	1.000214	0.000096	1.000238
+ 12°.56	+ 12°.00	20.79	0.004806	0.000105	1.000320	0.000107	1.000345
+ 13°.56	+ 13°.00	21.81	0.005042	0.000112	1.000433	0.000114	1.000460
+ 14°.56	+ 14°.00	23.91	0.005528	0.000125	1.000559	0.000128	1.000588
+ 15°.56	+ 15°.00	26.20	0.006057	0.000140	1.000699	0.000142	1.000731
——	——	——	——	——	——	——	——
Determinations of control							
— 3°.61	— 4°.00	.....	.....	.....	1.000408	.....	1.000399
+ 0°.39	0°	45.18	.....	.....	1.000000	.....	1.000000
+ 12°.56	+ 12°	.....	.....	0.0000271	1.000325	0.0000292	1.000350
+ 0°.56 + 13°.56	0° + 13°	126.99	.....	0.0000341	1.000444	0.0000362	1.000471

Every substance, as a rule, ought to expand its volume when heated and contract it on cooling. Every exception to this rule either in the apparent or in the real change of volume is in this and subsequent tables denoted by the sign —.

As starting-point for my dilatometric experiments [1] I have always chosen 0° C. The reason is obvious. This temperature can be maintained steady as long as you please, if the apparatus are surrounded with pure snow moistened with distilled water. I consider it to be the natural starting-point of all practical volumetric investigations, determinations of spec. gravity, calibrations etc. Therefore the unit of all volumes enumerated in this paper is 1 cc. of the liquid or solid substance at 0° C. The specific gravity was always determined by the Sprengel pycnometer at 0° C but afterwards referred to that of pure water at + 4° by calculation. I denote this by the sign

$$\frac{0^\circ}{+4^\circ}\ \mathrm{C}.$$

I take a special pleasure in mentioning, that I had the advantage of securing the assistance of my former companion Mr. Larson in a part of the foregoing and also of the subsequent series of determinations. At my wish Mr. Larson undertook the leading of experiment I and likewise of V in the next chapter. With the assistance of Mr. Larson I found it possible to take the observations at regular thermometric intervals of temperature.

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[1] In order to give a clear view of the experimental proceeding, I will here enumerate the weighing results belonging to I.

Weight of the mercury, which fills the dilatometer entirely at 0° C		676.1150 grm.
Weight of mercury in the capillary tubes, the stem, stopcocks etc. which are not exposed to changes of temperature		7.4136 »
L		668.7014 grm.
After the close of the experiments the weight of that mercury, which together with the water filled the instrument entirely at 0°, was found	= 189.6390 grm.	
therefrom to deduct	7.4136 »	
Q_1	182.2254 grm.	182.2254 grm.
W_1		486.4760 grm.
Weight of mercury imbibed through »b» at melting		44.1144 grm.

Table II.

L = 69.9374
Q = 15.4330
W = 54.5040
W_1 = 49.9660

Therm. G_I freez. p = + 0°.35 C

1 mm. corr. = 0.0002312 cc.

q = 0.00017905 [Regn.]
g = 0.00002753

Lg = 0.0019253 Qq = 0.0027632

t° uncorr. C.	t° corr. C.	Scale-tube		Total expansion		Coefficient of expansion	
		m.m. corr.	cc. corr.	of 1 cc of ice at −0°.05	of 1 cc of water at 0°	unit: 1 cc ice at −0°.05	unit: 1 cc water at 0°
+ 0°.34	− 0°.01	0	.....	.....	.....	.....	.....
+ 0°.32	− 0°.03	− 544...	0.12578	− 0.0023100	− 0.002520	− 0.11538	− 0.12587
+ 0°.30	− 0°.05	− 33.43	0.007730	− 0.0001421	− 0.0001550	− 0.007106	− 0.007751
+ 0°.20	− 0°.15	+ 1.46	0.000337	+ 0.0000046	+ 0.0000050	+ 0.000046	+ 0.000050
+ 0°.10	− 0°.25	2.93	0.000677	0.0000109	0.0000118	0.000109	0.000118
0°	− 0°.35	3.89	0.000899	0.0000149	0.0000163	0.000149	0.000163
− 0°.10	− 0°.45	3.43	0.000793	0.0000130	0.0000142	0.000130	0.000142
− 0°.20	− 0°.55	3.51	0.000811	0.0000133	0.0000145	0.000133	0.000145
− 0°.30	− 0°.65	3.79	0.000876	0.0000145	0.0000158	0.000145	0.000158
− 0°.40	− 0°.75	3.97	0.000917	0.0000153	0.0000166	0.000153	0.000166
− 0°.50	− 0°.85	3.85	0.000890	0.0000147	0.0000161	0.000147	0.000161
− 3°.00	− 3°.35	101.48	0.023463	0.0003920	0.0004276	0.000154	0.000168
− 4°.00	− 4°.35	41.34	0.009558	0.0001598	0.0001743	0.000159	0.000174
− 5°.00	− 5°.35	40.26	0.009308	0.0001552	0.0001693	0.000155	0.000169
− 6°.00	− 6°.35	41.35	0.009560	0.0001598	0.0001743	0.000159	0.000174
− 7°.00	− 7°.35	40.10	0.009271	0.0001545	0.0001685	0.000154	0.000168
− 8°.38	− 8°.73	54.36	0.012568	0.0002091	0.0002280	0.000151	0.000165
− 9°.38	− 9°.73	40.12	0.009276	0.0001545	0.0001685	0.000154	0.000168
− 10°.50	− 10°.85	43.80	0.010127	0.0001682	0.0001835	0.000150	0.000163
						Determinations	
− 10°.50	− 10°.85	0	.....	.....	.....	.....	.....
− 0°.50	− 0°.85	402.31	0.093133	0.0015519	0.0016950	0.000155	0.000169
——	——	——	——	——	——	——	——
0°	− 0°.35	0	.....	.....	.....	.....	.....
− 3°.00	− 3°.35	120.03	0.027751	0.0004630	0.0050511	0.000154	0.000168

Pure water (ice).

cc at 0° C
cc » » »
cc » —0°.05 C (ice)
cc » 0° C (water)

Lg — Qq = —0.0008379		q = 0.00018116 [Wülln.] g = 0.00002974 Lg = 0.0020800 Qq = 0.0027959				Lg — Qq = —0.0007159	
Volume at t° of		Total expansion		Coefficient of expansion		Volume at t° of	
1 cc of ice at —0°.05	1 cc of water at 0°	of 1 cc. of ice at —0°.05	of 1 cc. of water at 0°	unit: 1 cc ice at —0°.05	unit: 1 cc water at 0°	1 cc of ice at —0°.05	1 cc of water at 0°
0.997539	1.087993	.....	.....	.....	.....	0.997530	1.088000
0.999849	1.090513	—0.0023100	—0.0025200	—0.11538	—0.12587	0.999849	1.090512
0.999991	1.090668	—0.0001420	—0.0001550	—0.007106	—0.007751	0.999991	1.090667
0.999986	1.090663	+0.0000048	+0.0000053	+0.000048	+0.000053	0.999986	1.090661
0.999975	1.090652	0.0000111	0.0000121	0.000111	0.000121	0.999975	1.090649
0.999960	1.090636	0.0000151	0.0000166	0.000151	0.000166	0.999960	1.090633
0.999947	1.090622	0.0000132	0.0000144	0.000132	0.000144	0.999947	1.090618
0.999933	1.090607	0.0000135	0.0000148	0.000135	0.000148	0.999934	1.090603
0.999919	1.090592	0.0000147	0.0000161	0.000147	0.000161	0.999919	1.090587
0.999903	1.090575	0.0000155	0.0000169	0.000155	0.000169	0.999903	1.090570
0.999889	1.090559	0.0000150	0.0000163	0.000150	0,000163	0.999888	1.090554
0.999497	1.090131	0.0003976	0.0004297	0.000156	0.000170	0.999490	1.090124
0.999337	1.089956	0.0001621	0.0001768	0.000162	0.000176	0.999328	1.089947
0.999182	1.089787	0.0001575	0.0001718	0.000157	0.000171	0.999171	1.089776
0.999022	1.089613	0.0001620	0.0001768	0.000162	0.000176	0.999009	1.089599
0.998867	1.089444	0.0001567	0.0001710	0.000156	0.000171	0.998852	1.089428
0.998658	1.089216	0.0002122	0.0002314	0.000153	0.000167	0.998640	1.089196
0.998504	1.089048	0.0001567	0.0001710	0.000156	0.000171	0.998483	1.089025
0.998335	1.088864	0.0001707	0.0001862	0.000152	0.000166	0.998312	1.088839
of control							
0.998335	.....	.....	.....	.....	.....	.....	.....
0.999887	.....	.....	.....	.....	.....	.....	.....
——	——	——	——	——	——	——	——
.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	0.0004697	0.0005124	0.000156	0.000170	.....	.....

Table III. Ordinary

L = 56.5010
Q = 7.9988
W = 48.5022
W_1 = 44.4780

Therm. G_{II} freez. p. = + 0°.35 C
» G_{III} » » = + 0°.18 C

1 normal mm. corr. = 0.0002312 cc.

q = 0.00017905 [Regn.]
g = 0.00002753

Lg = 0.0015554 Qq = 0.0014321

t° uncorr. C.	t° corr. C.	Scale-tube		Total expansion		Coefficient of expansion	
		mm. corr.	cc. corr.	of 1 cc. of ice at — 0°.2	of 1 cc. of water at 0°	unit: 1 cc. ice at — 0°.2	unit: 1 cc. water at 0°
+ 0°.33	— 0°.02	.....	.....	.....	.....	.....	.....
+ 0°.32	— 0°.03	— 186.00	0.043005	.....	— 0.0009668	.....	— 0.096685
+ 0°.30	— 0°.05	— 140.00	0.03237	.....	— 0.0007277	.....	— 0.036387
+ 0°.20	— 0°.15	— 155.00	0.035837	— 0.0007388	— 0.0008057	— 0.007388	— 0.008057
+ 0°.10	— 0°.25	— 32.00	0.007398	— 0.0001525	— 0.0001663	— 0.000525	— 0.001663
0°	— 0°.35	— 7.00	0.001618	— 0.0000331	— 0.0000361	— 0.000331	— 0.000361
— 0°.20	— 0°.55	+ 3.23	0.000768	+ 0.0000159	+ 0.0000178	+ 0.000079	+ 0.000089
— 0°.70	— 1°.05	9.42	0.002178	0.0000461	0.0000500	0.000092	0.000100
— 1°.70	— 2°.05	32.22	0.007449	0.0001560	0.0001702	0.000156	0.000170
— 2°.70	— 3°.05	32.33	0.007474	0.0001565	0.0001707	0.000156	0.000170
— 3°.70	— 4°.05	32.30	0.007468	0.0001564	0.0001701	0.000156	0.000170
— 6°.70	— 7°.05	96.31	0.022267	0.0004660	0.0005082	0.000155	0.000169
— 7°.70	— 8°.05	32.17	0.007438	0.0001556	0.0001697	0.000155	0.000169
— 8°.70	— 9°.05	33.02	0.007634	0.0001597	0.0001741	0.000159	0.000174
— 9°.70	— 10°.05	32.10	0.007421	0.0001553	0.0001693	0.000155	0.000169
— 10°.70	— 11°.05	31.79	0.007350	0.0001538	0.0001677	0.000153	0.000167
— 11°.70	— 12°.05	31.79	0.007350	0.0001537	0.0001676	0.000153	0.000167
—	—	—	—	—	—	—	—
— 12°.86	— 13°.04	.....	.....	.....	.....	.....	.....
— 13°.86	— 14°.04	31.63	0.007313	0.0001525	0.0001663	0.000152	0.000166
— 14°.86	— 15°.04	32.02	0.007403	0.0001544	0.0001683	0.000154	0.000168
— 15°.86	— 16°.04	31.40	0.007259	0.0001514	0.0001650	0.000151	0.000165
— 16°.86	— 17°.04	31.10	0.007190	0.0001499	0.0001634	0.000149	0.000163
— 17°.86	— 18°.04	32.44	0.007500	0.0001561	0.0001703	0.000156	0.000170
— 19°.86	— 20°.04	61.08	0.014122	0.0002942	0.0003208	0.000147	0.000160
—	—	—	—	—	—	—	—
							Determinations
— 2°.0 — 12°.0	— 2°.35 — 12°.35	322.2	0.07449	0.0001558	0.0001699	0.000155	0.000169
— 7°.87 — 12°.86	— 8°.05 — 13°.04	159.00	0.036827	0.0001538	0.0001677	0.000153	0.000167

distilled water (ice).

cc at 0° C
cc » » »
cc » — 0°.20 C (ice)
cc » 0° C (water)

Change of Volume by melting between — 0°.05 and 0° = 3.98368 cc.
Calculated pr. 1 cc. of water at 0° = 0.089566 cc.
Volume of 1 cc. of water as ice at — 0°.05 = 1.089566 cc.

q = 0.00018116 [Wülln.]
g = 0.00002974

Lg — Qq = + 0.0001233 | Lg = 0.00016803 | Qq = 0.0014491 | Lg — Qq = + 0.0002312

Volume at t° of 1 cc. of water at 0°	Total expansion of 1 cc. of ice at — 0°.2	Total expansion of 1 cc. of water at 0°	Coefficient of expansion unit: 1 cc. ice at — 0° 2	Coefficient of expansion unit: 1 cc water at 0°	Volume at t° of 1 cc. of water at 0°
1.087871	.....	.....	.....	.....	.....
1.088838	.....	.....	.....	.....	.....
1.089566	.....	.....	.....	.....	.....
1.090371	.....	.....	.....	.....	.....
1.090538	.....	.....	.....	.....	.....
1.090574	.....	.....	.....	.....	1.090574
1.090556	+ 0.0000167	+ 0.0000183	+ 0.000083	+ 0.000091	1.090555
1.090506	0.0000472	0.0000515	0.000094	0.000103	1.090504
1.090336	0.0001583	0.0001726	0.000158	0.000172	1.090331
1.090165	0.0001587	0.0001722	0.000158	0.000172	1.090159
1.089995	0.0001585	0.0001729	0.000158	0.000172	1.089986
1.089487	0.0004727	0.0005155	0.000157	0.000171	1.089471
1.089317	0.0001578	0.0001721	0.000157	0.000172	1.089298
1.089143	0.0001619	0.0001765	0.000161	0.000176	1.089122
1.088973	0.0001575	0.0001717	0.000157	0.000171	1.088950
1.088806	0.0001561	0.0001709	0.000156	0.000170	1.088779
1.088638	0.0001560	0 0001701	0.000156	0.000170	1.088609
—	—	—	—	—	—
1.088478	.....	.....	.....	.....	1.088448
1.088312	0.0001547	0.0001688	0.000154	0.000168	1.088279
1.088144	0.0001566	0.0001708	0.000156	0.000170	1.088108
1.087979	0.0001536	0.0001674	0.000153	0.000167	1.087941
1.087815	0.0001521	0.0001659	0.000152	0.000165	1.087775
1.087645	0.0001584	0.0001727	0.000158	0.000172	1.087602
1.087324	0.0002986	0,0003257	0.000149	0.000162	1.087276
—	—	—	—	—	—
of control					
.....	.....	.....	0.000158	0.000172	.....
.....	.....	.....	0.000156	0.000170	.....

The determination of the change of volume by the melting of the ice in experiment II miscarried. I was obliged therefore to start from the volume of the ice (= 1.089038) at — 10° C found in experiment I, in calculating the volumes of the frozen water in Table II. It is evident that this circumstance does not alter the whole character or the outline of curve II in plate 22 in the slightest degree, although its position (i. e. the exact value of the sp. volume of the ice) may be either a few millionths higher or lower than the numbers given in Table II.

From the above tables and from the graphic representation in plates 21 & 22 it will be seen, that also the purest ice, which can be tested by experiments, is liable to premature contraction of volume before melting. It is impossible to decide, if absolutely pure water would be entirely free from this weakness or not, since we can not assume that water, which has boiled for a quarter of an hour or more in a glass vessel, is absolutely free from minimal quantities of foreign substances as f. ex. sodium salts, silicia etc. For my own part I am rather inclined to think, that absolutely pure water, if it could be tested, would show an absolutely fixed melting point, but I think, that this problem very much resembles another question still undecided, viz. *is absolutely pure water a conducting or non-conducting substance for electricity?* In fact Kohlrausch has found, that the purer the water is, the greater is the resistance, which it offers to the electric current, and that we may by chemical purification and repeated distillations etc. approach a point, where the resistance tends to be insurmountable for every electromotoric force. In the behavior of solid bodies just before their melting points I think I have found another, almost equally sensible, proof of their chemical purity. The regular coefficient of expansion of pure water in the solid state (see Table I) slowly increases from 0.000165 [the average value between — 17° C and — 10° C] to 0.000171 or 0.000174 [between — 4° and — 3° C] but then gradually begins to decrease and finally changes its sign between — 0°.15 and — 0°.03 C, where the ice begins to contract instead of expanding its volume. This point of inversion is reached by water II already between — 0°.30 and — 0°.05 C and by III between — 0°.35 and — 0°.25. In order to obtain a stricter comparison we must refer to the preceding tables, as the graphic representation on plate 22 does not give us a clear idea of variations beyond 0.00001 of the unit of volume [1 cc. of the water at 0°]

I		II		III	
t° C	extract from the 8th column of the table	t° C	extract from the 8th column of the table	t° C	extract from the 8th column of the table
— 7°.00	.....	— 4°.35	.....	— 8°.05	.....
— 6°.00	0.000173	— 3°.35	0.000174	— 7°.05	0.000169
— 4°.00	0.000171	— 0°.85	0.000168	— 4°.05	0.000169
— 3°.00	0.000174	— 0°.75	0.000161	— 3°.05	0.000170
— 2°.00	0.000161	— 0°.65	0.000166	— 2°.05	0.000170
— 1°.00	0.000160	— 0°.55	0.000158	— 1°.05	0.000170
— 0°.50	0.000151	— 0°.45	0.000145	— 0°.55	0.000100
— 0°.40	0.000137	— 0°.35	0.000142	— 0°.35	0.000089
— 0°.30	0.000135	— 0°.25	0.000163	— 0°.25	— 0.000361
— 0°.20	0.000149	— 0°.15	0.000118	— 0°.15	— 0.001663
— 0°.15	0.000063	— 0°.05	0.000050	— 0°.05	— 0.008057
— 0°.03	— 0.000012	— 0°.03	— 0 007751	— 0°.03	— 0.03638 . . .
— 0°.02	— 0.000689	— 0°.01	— 0.1258...	— 0°.02	— 0.09668 . . .

The different behavior of these samples of ice before melting is obvious, and yet from an analytical point of view they must be regarded as pure water, since no impurity can be detected by chemical agencies in I & II and only slight traces of chlorine etc.... were found in III.

If we admit, that minimal quantities of foreign substances are the real cause of the peculiar behavior of the ice-samples I, II and III, we will be justified in concluding, that all kinds of ice or snow occurring in nature will show this irregularity in a still higher degree. The purest ice, that covers a highland lake in winter, will scarcely be as free from impurities as ice from destilled water (Number III) but will probably contain a minimal quantity of calcium-salts, sulphates etc, which must occasion a greater irregularity of expansion than that shown in table III. A transparent block of bluish glacier-ice will hardly surpass III in purity and in all cases be inferior to II. Consequently we must acknowledge the fact, *that the ice-masses of the glaciers are liable to contraction of volume at temperatures below their melting point,* a circumstance, which henceforth can not be left without consideration in the theory of glaciers.

Although the contraction of volume, which precedes the melting of the ice, may be new to science, there is no lack of

observations already collected long ago to corroborate this fact. It has long been a subject of discussion, whether the ice is a brittle or a plastic substance. All observers agree, that pure ice, taken far below zero under ordinary pressure, is not plastic at all. But we nevertheless must confess, that ice in the vicinity of 0° somehow or other can behave like a plastic body, in order to account for a great many well known facts and in the first place for the movement of the glaciers. We may f. ex. attribute the fact, that two blocks of ice, which are brought into contact in a warm room, immediately adhere to each other like wax, to the peculiar molecular state of the ice particles at the free surfaces, which by their contact are brought into altered conditions of cohesion, or we may ascribe this and similar phenomena to a *regelation,* i. e. a temporary melting process, caused by the lowering of the melting point by pressure and restoration of the initial state of aggregation, as soon as the pressure ceases; we may, in short, declare the plastic condition of the ice at its melting point to depend on an *apparent* instead of a real toughness of its substance — but we still can not deny such observations, which plainly show us, that every kind of ice, which we may test, *softens before melting.*

In his admirable researches on the latent heat of melting bodies, Person[1] observed some irregularities in the specific heat of ice below zero, which led him to adopt the theory, that the ice does not melt at once at a fixed temperature, but already some degrees below the melting point begins to weaken.

The mechanical softening of pure ice below zero has been testified by many observers. It will suffice to cite a few lines from a paper by Pfaff entitled »Versuche über die Plasticität des Eises».[2]

»Es geht aus meinen Versuchen hervor, dass auch der *geringste* Druck hinreicht, um Eistheilchen zu verschieben, wenn er *anhaltend wirkt und die Temperatur des Eises und der Umgebung nahe dem Schmelzpunkte ist.*»

»Es ergiebt sich, dass das Eis sich nahe seinem Schmelzpunkte in *der That wie Wachs* verhält und bei einem Drucke von nur zwei Atmosphären sich so nachgiebig zeigt, dass z. B. ein hohler Cylinder von Eisen von 11.5 m.m. Durchmesser und 1.7 Wandstärke in zwei Stunden bei einer Temperatur zwischen —1 und 0.5 Grad 3 m.m. tief in das Eis eindrang. Welchen

[1] C. R. XXX p. 526.
[2] Pogg. Ann. CLIV 1875.

Einfluss die Temperatur hat, dafür will ich nur einige Data aus meinen Versuchen anführen.»

»Derselbe Eisencylinder sank unter demselben Drucke bei einer Temperatur zwichen —4° und —1° in 12 Stunden um $1^1/_4$ m.m. tief ein, während bei einer zwischen —6° und —12° schwankenden Temperatur in 5 Tagen bei einem Drucke von 5 Atmosphären das Einsinken nur 1 m.m. betrug, also in 12 Stunden *nur* $^1/_{10}$ *m.m.*»

»Steigt die Temperatur der Umgebung über den Schmelzpunkt, so wird die Weichheit des Eises so gross, dass in einer Stunde schon derselbe Eisencylinder 3 c.m. tief unter dem gleich geringen Drucke sich senkte, obwohl er vollständig von Schnee eingehüllt war, um die Erhöhung der Temperatur des Eisencylinders über Null zu vermeiden.»

I think that these observations of Person, Pfaff a. O. concern the same change in the molecular constitution of the ice, *which in my dilatometric experiments appears as a shrinking of its volume,* and I also think, that this contraction of volume, which we may study by regular observations for every tenth or hundredth of a centigrade degree, affords us *the best measurement*[1] of the progress of the weakening of the ice. It will also appear from the above experiments and likewise from the determinations in the next chapter on ice from salt water, that this emollescence most probably is no inherent property of the chemical compound H_2O but is caused by the influence of slight quantities of foreign substances, salts, etc., the presence of which has the power of modifying the whole melting-process astoundingly.

The process of thawing may thus be considered always to begin below zero. Every kind of ice, which occurs in nature, will at a sufficiently low temperature be hard and brittle. In this state, the ice, if tested, will also be found to *expand regularly.* The commencement of the thawing or emollescence of the ice is entirely dependent upon the amount of salt etc. it contains. Volumetrically the softening of the ice is announced by a gradual diminution of the coefficient of expansion and finally by a real contraction of its volume. The tables in this and the following chapter, together with the curves on plate 21 will

[1] As a good example of the congruent results of widely different methods we may point out the fact, that Person could not detect any signs of softening in pure ice below —2° C. Now a glance at the extract from table I on page 274 will show us, that the regular coefficient of expansion of volume begins to diminish *just before* —2° C.

in some degree afford a scale for our appreciation of the influence of the foreign substances in the ice. If we consider:

that an amount of chlorine of 0.273 per cent causes the ice [see table V and curve V on plate 21] to contract already at — 14° C

that a sample of ice, which contains 0.015 p. c. of chlorine begins to contract at — 4° C (see table IV and curve IV)

and that ice from ordinary distilled water, which contains scarcely perceptible traces of chlorine, begins to shrink in volume at about — 0°.25 C, we will hardly feel inclined to underrate the influence of foreign substances on the entire physical behavior of the ice and especially on the thawing process. Many facts, familiar to most of my readers, will find their interpretation from this circumstance.

Walking upon a snowy plain on a winter day, when the thermometer shows about — 7° or — 8° C in the air, we will perceive, that every footstep causes a keen, crunching sound from the ice-particles crushed under our feet. Suppose the temperature of the atmosphere to rise a few centigrades f. ex. to — 5° or — 4° C, then we will tread quite noiselessly upon the snow. The ice particles still retain their solid form, but the thawing has already begun; instead of a network of hard and brittle crystal needles, we tread upon a soft mass, which shrinks beneath our feet to a plastic mould and retains the impression of the footsteps.

Our pleasure of skating is very much dependent upon the temperature, but also in a certain degree upon the purity of the ice. If the temperature of the air, and consequently also of the upper layer of the ice, is next to zero, the steel of the skates will draw deeper furrows in the ice, and the friction will be considerably increased. The same will be the case, if we practise upon a frozen fiord, where the ice has formed from salt water, instead of on the ice of an inland lake.

Ice, which arises by the freezing of salt water, retains a part of its saltness, the greater, the more suddenly the freezing has begun. We are told by eye witnesses, such as Weyprecht, Nordenskiöld a. O. that the new ice, which arises by sudden freezing of the calm surface of the arctic sea, is a *tough* substance, which can be wrinkled and folded by external pressure without breaking. Although it may be thick enough to bear the weight of a man, it is so plastic, that a footstep makes a deep impression as in mouldable clay. »If you

chance to walk over a plain of newly formed ice before any snow has fallen, you will be astonished to find every footstep impressed in the mass just as in melting snow. If unacquainted with the fact, you will in vain try to understand; how the solid ice can be in a melting condition at a temperature of —40° C or still more» [Weyprecht]. The specimen of ice examined in series VI of the following chapter and represented in curve VI of plate 21 claims to be a representative of this kind of polar ice. It is formed by sudden freezing of ocean water of ordinary saltness from the Siberian sea and itself contains 0.649 p. c. of chlorine, according to the titration.

The plastic properties of such ice, described by Weyprecht, will be found to correspond to a premature contraction of volume, which begins already at —20° C. The preceding diminution of expansion dates from a stage of temperature far beyond —20° C, the limit of my investigations.

We may now understand, why people of the trade are so very particular about the locality, from which the ice of commerce is taken. Everbody knows, that ice from the open sea would not do for the market, but I dare say, that everybody does not know the reason why. Somebody may hint, that ice from salt water must be disagreeable to the taste, but this is far from being always the case. The most refined palate will fail to detect the slight saltness of *old* sea-ice. At Cloven cliff, northwest of Spitzbergen, I have collected blocks of ice from the polar drift-current, which contained less than one fourth of the amount of chlorides, which is found in the drinking water of Stockholm. It is solely on account of the physical properties accompanying this diminutive percentage of salt, that sea-ice is rejected by the trade. Only the almost chemically pure ice, produced by freezing of inland lakes, deficient in chlorides etc. will bear transportation without crumbling and conserve the glass-like hardness and transparency, which is an indispensable condition of ice as an article of consumption and of luxury.

Any physicist, familiar with the use of Bunsen's ice calorimeter, will also, like the author, be familiar with the capriciousness of this instrument. Bunsen prescribes, that the calorimeter should be placed in a big vessel filled with *entirely pure* snow. Although I have had abundant quantities of the purest snow at my disposal, I do not hesitate to declare, having tried during a whole winter to obtain reliable results with the original arrangement of the inventor, that

the instrument would be impracticable to me, without the improvement devised by Schuller and Wartha, viz. to immerse the calorimeter in a vessel containing ice and pure water at 0°. Still the advantage of this arrangement is not to prevent variations in the position of the mercury index of the instrument, but to make them quite regular.

The variations are declared by some physicists to depend upon the vacillations of the atmospheric pressure, which lowers or raises the melting point of the ice, but I dare say from long experience, that the movement of the mercury column is in some way influenced by the temperature of the air in the room, but is wholly independent of the barometric variations. The real cause of the unsteadiness of the index seems to me to lie in the impurities absorbed by the water, which has been kept boiling for almost an hour in the glass reservoir by the filling of the instrument. Thus the ice will be exactly in the same condition as the sample II in the above tables, viz. it will possess no *absolutely fixed volume* just below its melting point. The specific volume of the ice in the instrument will thus correspond to some point of the sloping branch of the curve II, see plate 22, between —0°.05 and 0°. Now suppose the water in the external vessel to be either a little purer than that of the calorimeter or vice versa. In the former case its temperature, i. e. its melting point will be situated a few thousandths of a centigrade higher, and the volume of the ice in the calorimeter will move downwards on the branch of the curve in the attempt to gain the temperature of the surrounding medium. Then the index will move slowly backwards, in the other case the coordinate of specific volume of the ice will move upwards on the sloping branch, and the index of the scale-tube will march forward. I think we could diminish this inconvenience by filling the scrupulously cleansed calorimeter with repeatedly distilled water and by confining the boiling operation to the least possible time.

In studying the phenomena of the movement of glaciers, we of course must acknowledge the powerful action of pressure, but we will do well also to bear in mind, that an increase of pressure, equal to the weight of a vertical column of ice of 400 feet, is required only in order to make the melting

[1] Still I cannot dispute the possibility of the hypothesis upheld by my former companion, Professor Nilson, viz. that the contraction of the glass reservoir may have something to do with these variations.

point of the ice sink 0°.10 C below zero, while the presence of a minimal quantity of impurity [the influence of which can not be ignored in that part of the glacier, which is in contact with the rocky ground and the *débris* separated from it by erosion] is sufficient, to lower the melting point considerably and make the ice soften and shrink in volume long before. It must, in short, be taken into consideration, that every kind of ice in nature becomes plastic and tough *in the vicinity of its melting point.* [1]

I next proceeded to the determination of the volumes of the liquid water [sample I]. These numbers [see table I, B] are graphically represented by the red line in plate 23. The curve is traced under the assumption of

$$q = 0.00017905$$
$$g = 0.00002754.$$

It will give the reader an opportunity of comparing the performance of the new dilatometer with the results obtained formerly by means of other methods.

CHAPTER 4.

On ice and water of little saltness.

From the reasons given in chapter 1, pages 250—253, I have ventured to draw the conclusion, that the ice of the Siberian sea is formed to a great part by the freezing of the brackish

[1] With this restriction I think we may safely adopt the glacier theory of Rendu or Forbes. Some important observations made on glaciers will thereby be explained in the most natural manner, viz. the relatively rapid progress of the ice masses in summertime and the birth of the glacier remnants, which, according to eye-witnesses, takes place most frequently in hot weather. Petzholdt in the work already alluded to in this chapter cites some observations concerning this subject by Hugi, Agassiz, Vogt a. O. In every case the breaking up of a rift in the glacier was observed on some very hot summer day. The rift was at first only a few inches deep, but gradually increased, and the bursting of the ice was accompanied by a sharp crack, like a peleton fire. From the behavior of the ice represented on plate 23 we might just expect such effects to take place. The upper layer of the ice at first expands very regularly under the influence of the summer heat, but, as its temperature approaches the melting point, suddenly begins to contract its volume enormously. This causes a hard strain upon its surface, which ends with the breaking up of fissures and remnants.

water of little saltness, which is abundantly expanded over the arctic sea from the æstuaries of the great Siberian rivers. I therefore considered it a question of importance to examine the behavior of ice, which has been formed under similar conditions. Among the material collected by the Vega expedition and forwarded to me, there was however no samples of water formed by melting of real arctic ice. Still I deemed it indispensable to test the properties of such ice, which really had existed *as ice* in the sea and therefore tried by the kind assistance of Captain Malmberg, Director of the Swedish Nautical Meteorological Bureau, to obtain samples of sea ice from several places of the Baltic and likewise from the coast of Bohuslän. Minute instructions, enjoining the necessary precautions to be taken in collecting the ice, were issued from the Bureau to the functionaries of the pilot office, and every sample was accompanied by a report. The specimen chosen for the first of the following experiments was collected in February or March 1880 in the midst of the Baltic sea just outside the harbor of Wisby. After the termination of the experiment, the specific gravity, the latent heat and the percentage of chlorine were ascertained immediately *in the same quantity of water, which had been employed in the dilatometer.* The water quantity was just sufficient for these purposes. But for the chlorine determination the sample was found to be scanty. I therefore made another titration with a greater quantity of the original ice-water.

	Original sample.	Ice-water IV.
spec. gr. at $\frac{0^\circ}{+4^\circ}$ C	——	1.00030
p. c. of Cl	0.016	0.014

I consider this specimen of ice to be a good representative of that kind of arctic ice, which is commonly called bay-ice. A sample of such ice, which I found myself in July 1882 in Danes Gat at Spitzbergen, contained 0.014 % chlorine. Another sample from the Ice-fiord contained 0.010 % Cl. But the manifold gradation in the saltness of the polar ice, whereof the reader will get an idea by a glance at the tables in the next chapter, forbids us to rely exclusively on conclusions drawn from the examination of a single specimen. Besides, the percentage of chlorine is no adequate criterium of the chemical constitution of *ice* [although it is a good standard of comparison for seawater], on account of the chemical metamorphosis, which gradually takes place in the ice. Therefore I chose for

the next series of determinations another specimen of ice-water from the sea-ice in Kattegatt, obtained in December 1881 at Marstrand.

When the outer layer of the frozen ice in the dilatometer is thawed, in order to get the solid cylindre surrounded by a rind of mercury (see the discription of this operation on page 263 and fig. 2 on plate 1), one or two cc. of water are ordinarily expelled through the capillary. In this case the water was found to be of an extremely *bitter* salt taste. The original ice-water had thus separated in two parts of different chemical constituents. The remaining quantity of ice in the dilatometer was naturally deficient in saltness relatively to the ice formed at first. After the close of the experiment, the melted ice-water of the dilatometer was examined as usual with regard to its latent heat, its percentage of chlorine and specific gravity. The water of sample V was found to possess:

	Original sample.	Ice-water V.
spec. gr. at $\frac{0^\circ}{+4^\circ}$ C	1.0110	1.0053
p. c. of Cl.	0.727	0.273.

The important question of the latent heat of the ice-water will be discussed in the last chapter.

Finally I repeated exactly the same series of operations and measurements with a real specimen of salt water from the deeper strata of the Siberian sea, in order to study the formation of ice from real ocean water. The ice, which had formed at first in the instrument, on superficial thawing, gave off a few cc. of a very concentrated solution of *bitter* taste.

	Original sample.	Ice-water VI.
spec. gr. at $\frac{0^\circ}{+4^\circ}$ C	1.0278	1.0094
p. c. of Cl.	1.91	0.649.

The numerical results of the determinations on the samples IV, V, VI are recorded in tables IV, V, VI and are graphically represented on plate 21 (the volumes of the ice) and on plate 23 (the vol. of the waters). In the calculation of the volumes I have started from the assumption

$$q = 0.00017905$$
$$g = 0.00002753$$

to avoid unnecessary complication. All the numbers given in this chapter refer to special kinds of sea-ice and cannot be considered to be fixed constants of nature, like the volumes of pure ice and pure water, which must be calculated with the utmost accuracy attainable in the present state of physical science.

Table IV. Ice from

Specific gravity at $\frac{0^\circ}{+4^\circ}$ C = 1.00030

A. Ice.

L = 51.1922 cc at 0° C
Q = 7.5584 » » —0°.9 C
W_1 = 40.1024 » » 0° C (water)
q = 0.00017905 [Regn.]
g = 0.00002753

Lg = 0.0014144 Qq = 0.0013533 Lg — Qq = + 0.0000611

t° C corr.	Scale-tube		Total expansion of 1 cc. water at 0°	Coeff. of expans. unit. 1 cc. water at 0°	Volume at t° C of 1 cc. water at 0°
	mm. corr.	cc. corr.			
— 0°.90	.....	.....	.....	.....	1.088132
— 1°.60	— 35.00	0.008092	— 0.000200	— 0.000286	1.088333
— 2°.60	— 28.12	0.006501	— 0.000160	— 0.000160	1.088494
— 4°.60	+ 30.62	0.007079	+ 0.000179	+ 0.000089	1.088314
— 5°.60	19.50	0.004510	0.000114	0.000114	1.088200
— 6°.60	23.00	0.005317	0.000134	0.000134	1.088066
— 7°.20	13.51	0.003123	0.000078	0.000131	1.087987
— 9°.20	51.24	0.011847	0.000298	0.000149	1.087689
— 11°.20	54.16	0.012522	0.000315	0.000157	1.087374
— 13°.20	54.41	0.012580	0.000316	0.000158	1.087057
— 14°.20	26.53	0.006133	0.000154	0.000154	1.086903
— 15°.20	27.15	0.006277	0.000158	0.000158	1.086745
— 16°.20	27.06	0.006256	0.000157	0.000157	1.086587
Determinations of control					
— 0°.9	.....	.....	.....	.....	1.088132
— 6°.2	+ 4.00	0.000924	— 0.000031	+ 0.0000058	1.088101
— 0°.9 / — 16°.2	264.06	0.061052	+ 0.001541	— 0.0001007	1.086591

Total change of volume by liquefaction at — 0°.90 C = 3.5314 cc.
Calculated for 1 cc. of the water = 0.088059 cc.
Volume of 1 cc. water at 0° as ice at — 0°.90 C = 1.088132 cc.

the Baltic (Wisby).

percentage of chlorine = 0.014.

B. Water.

$L = 51.1922$ cc at 0° C
$Q_1 = 11.0898$ » » 0°
$W_1 = 40.1024$ » » 0°
$q = 0.00017905$ [Regn.]
$g = 0.00002753$

$Lg = 0.0014144$ $Qq = 0.0019856$ $Lg - Qq = -0.0005711$

t° C corr.	Scale-tube		Total expansion of 1 cc. water at 0°	Coeff. of expans. unit. 1 cc. water at 0°	Volume at t° C of 1 cc. water at 0°
	mm. corr.	cc. corr.			
— 4°.00	.....	.....	.....	.....	1.000405
— 3°.00	— 20.06	0.004638	— 0.000130	— 0.000130	1.000275
— 2°.00	— 16.70	0.003861	— 0.000110	— 0.000110	1.000164
— 0°.90	.....	.....	.....	.....	1.000074
— 2°.00 / 0	— 23.60	0.005456	— 0.000164	— 0.000082	1.000000
+ 1°.00	— 7.40	0.001711	— 0.000056	— 0.000056	0.999943
+ 2°.00	— 4 70	0.001086	— 0.000041	— 0.000041	0.999901
+ 3°.00	— 1.40	0.000323	— 0.000022	— 0.000022	0.999879
+ 4°.00	+ 0.90	0.000208	— 0.000009	— 0.000009	0.999870
+ 5°.00	3 20	0.000739	+ 0.000004	+ 0.000004	0.999874
+ 6°.00	7.00	0.001618	0.000026	0 000026	0.999900
+ 7°.00	8.80	0.002034	0.000036	0.000036	0.999937
+ 8°.00	10.80	0.002497	0.000048	0.000048	0.999985
+ 9°.00	13.20	0.003052	0.000062	0.000062	1.000047
+ 10°.00	15,20	0.003514	0.000073	0.000073	1.000120
+ 11°.00	18.77	0.004339	0.000094	0.000094	1.000214
+ 12°.00	20.40	0.004716	0.000103	0.000103	1.000317
+ 13°.00	23.02	0.005322	0.000118	0.000118	1.000435
+ 14°.00	25.39	0 005870	0.000132	0.000132	1.000568
+ 15°.00	27.92	0.006455	0.000146	0.000146	1.000715
Determinations of control					
0	.....	.....	.....	.....	1.000000
10°.00	45.60	0.01273	0.000121	0:000012	1.000121
15°.00	161.10	0.03724	0.000717	0.000047	1.000717

Table V. Ice from

Specific gravity (ice-water) at $\frac{0°}{+4°}$ = 1.00534

A. Ice.

L = 49.1840 cc at 0° C
Q = 11.5978 » » — 2°.2 C
W_1 = 34.9040 » » 0° C (water)
q = 0.00017905 [Regn.]
g = 0.00002753

Lg = 0.0013589 Qq = 0.0020765 Lg — Qq = — 0.0007176

t° C corr.	Scale-tube		Total expansion of 1 cc. water at 0°	Coeff. of expans. unit. 1 cc. water at 0°	Volume at t° C of 1 cc. water at 0°
	mm. corr.	cc. corr.			
— 2°.20	.....	.....	.....	.....	1.076784
— 3°.20	— 586.87	0.13569	— 0.003907	— 0.003907	1.080691
— 4°.20	— 343.94	0.07952	— 0.002298	— 0.002298	1.082990
— 5°.20	— 175.92	0.04067	— 0.001186	— 0.001186	1.084176
— 6°.20	— 106.00	0.02450	— 0.000722	— 0.000722	1.084898
— 7°.20	— 81.90	0.018936	— 0.000563	— 0.000563	1.085461
— 8°.20	— 49.97	0.011553	— 0.000351	— 0.000351	1.085812
— 9°.20	— 33.37	0.007715	— 0.000241	— 0.000241	1.086053
— 10°.20	— 21.04	0.004864	— 0.000159	— 0.000159	1.086212
— 11°.20	— 10.05	0.002323	— 0.000087	— 0.000087	1.086299
— 12°.20	— 4.93	0.001139	— 0.000053	— 0.000053	1.086352
— 13°.20	+ 0.98	0.000226	— 0.000014	— 0.000014	1.086366
— 14°.20	3.95	0.000858	+ 0.000005	+ 0.000005	1.086361
— 15°.20	7.20	0.001664	0.000027	0.000027	1.086334
— 16°.20	9.56	0.002210	0.000043	0.000043	1.086291
Determination of control					
— 2°.20	.....	.....	.....	.....	1.076784
— 12°.20	— 1415	0.32716	— 0.009558	— 0.000955	1.086342

The change in the volume by the liquefaction of the ice was determined between — 2°.20 C and — 0°.39 C.

Total change of volume between — 2°.2 C & — 0°.39 C = 2.67985 cc.
Calculated for 1 cc. of the water = 0.076772 cc.
Volume of 1 cc. of water at 0° as ice at — 2°.2 C = 1.076784 cc.
Increase of volume of the water, if solidif. at — 2°.2 C = 0.076650 cc.

Kattegatt (Marstrand).

percentage of chlorine (ice-water) = 0.273.

B. Water.

L = 49.1840 cc at 0° C
Q_1 = 14.2800 » » 0° C
W_1 = 34.9040 » » 0° C
q = 0.00017905 [Regn.]
g = 0.00002753

Lg = 0.0013589 Qq = 0.0025568 Lg — Qq = — 0.0011978

t° C corr.	Scale-tube mm. corr.	Scale-tube cc. corr.	Total expansion of 1 cc. water at 0°	Coeff. of expans. unit. 1 cc. water at 0°	Volume at t° C of 1 cc. water at 0°
— 8°.40	— 23.45	0.005420	— 0.000189	— 0.000189	1.001008
— 7°.40	— 21.65	0.005004	— 0.000177	— 0.000177	1.000818
— 6°.40	— 17.75	0.004103	— 0.000151	— 0.000151	1.000641
— 5°.40	— 14.73	0.003405	— 0.000129	— 0.000129	1.000489
— 4°.40 / — 0°.10	— 31.34	0.007246	— 0.000358	— 0.000081	1.000358
— 3°.40	— 9.41	0.002175	— 0.000096	— 0.000096	1.000251
— 2°.40 / — 0°.10	— 10.46	0.002418	— 0.000155	— 0.000064	1.000155
— 2°.40 / — 1°.40	— 6.38	0.001461	— 0.000076	— 0.000076	1.000078
— 0°.10	.....	.....	.....	.....	1.000002
+ 0°.90	— 0.58	0.000134	— 0.000038	— 0.000038	0.999963
— 0°.10 / + 1°.90	+ 1.88	0.000434	— 0.000056	— 0.000028	0.999945
— 0°.10 / + 2°.27	2.08	0.000480	— 0.000067	— 0.000028	0.999934
— 0°.10 / + 2°.90	6.51	0.001505	— 0.000059	— 0.000019	0.999942
— 0°.10 / + 3°.90	12.93	0.002989	— 0.000051	— 0.000013	0.999950
+ 4°.90	8.91	0.002060	+ 0.000024	+ 0.000024	0.999975
+ 5°.90	11.78	0.002723	0.000043	0.000043	1.000018
+ 6°.90	13.02	0.003010	0.000051	0.000051	1.000070
+ 7°.90	15.12	0.003495	0.000065	0.000065	1.000136
+ 8°.90	17.41	0.004025	0.000081	0.000081	1.000217
+ 9°.90	19.10	0.004416	0.000092	0.000092	1.000309
— 0°.10 / + 9°.90	98.27	0.022759	0.000308	0.000030	1.000310
+ 10°.90	21.60	0.004994	0.000108	0.000108	1.000418
+ 11°.90	22.70	0.005249	0.000116	0.000116	1.000534
+ 12°.90	24.90	0.005757	0.000130	0.000130	1.000665
+ 13°.90	26.20	0.006057	0.000139	0.000139	1.000804
+ 14°.90	28.17	0.006513	0.000152	0.000152	1.000957
Determinations of control					
— 0°.10 / — 6°.40	— 62.42	0.014499	— 0.000634	— 0.000099	1.000634
— 0°.10 / + 14°.90	+ 221.84	0.051419	+ 0.000960	+ 0.000064	1.000960

Table VI. Ocean water (arctic) 76°04′ Lat.

Specific gravity (ice-water) at $\frac{0°}{+4°}$ = 1.00940

A. Ice.

L = 51.1922 cc. at 0° C
Q = 16.6967 cc. at — 4°.4 C
W_1 = 32.042 cc. at 0° C (water)
q = 0.00017905 [Regn.]
g = 0.00002753

Lg = 0.0014144 Qq = 0.0029895 Lg — Qq = — 0.0015751

t° C corr.	Scale-tube		Total expansion of 1 cc. water at 0°	Coeffic. of exp. unit: 1 cc. water at 0°	Volume at t° of 1 cc. water at 0°
	mm. corr.	cc. corr.			
— 4°.40	.....	.....	.....	.....	1.076845
— 6°.40	— 396.20	0.091604	— 0.002957	— 0.001478	1.079802
— 7°.20	— 134.14	0.031014	— 0.001025	— 0.000854	1.080828
— 8°.20	— 103.68	0.023995	— 0.000795	— 0.000795	1.081624
— 9°.20	— 75.14	0.017375	— 0.000589	— 0.000589	1.082213
— 10°.20	— 54.43	0.012584	— 0.000440	— 0.000440	1.082653
— 11°.20	— 40.46	0.009354	— 0.000339	— 0.000339	1.082993
— 12°.20	— 26.24	0.006066	— 0.000237	— 0.000237	1.083230
— 13°.20	— 21.47	0.004964	— 0.000202	— 0.000202	1.083432
— 14°.20	— 13.66	0.003158	— 0.000146	— 0.000146	1.083578
— 15°.20	— 6.78	0.001567	— 0.000096	— 0.000096	1.083675
— 16°.20	— 4.86	0.001123	— 0.000085	— 0.000085	1.083760
— 17°.20	+ 0.97	0.000224	— 0.000043	— 0.000043	1.083804
— 18°.20	2.92	0.000675	— 0.000029	— 0.000029	1.083833
— 19°.20	5.83	0.001347	— 0.000008	— 0.000008	1.083841
Determination of control					
— 10°.2	.....	.....	.....	.....	1.082653
— 16°.2	— 113.50	0.026235	— 0.001105	— 0.000184	1.083758

The change in the volume by the liquefaction of the ice was determined at — 4°.4 C.

Total change of volume at — 4°.4 C = 2.45353
Calculated for 1 cc. of the water = 0.076597
Volume of 1 cc. of water at 0° as ice at — 4°.4 C = 1.076845

116°09′ Long. E. G. Depth 59 Metres.

percentage of chlorine (ice-water) = 0.649.

B. Water.

L = 51.1922 cc. at 0° C
Q_1 = 19.1502 » » » »
W_1 = 32.0420 » » » »
q = 0.00017905 [Regn.]
g = 0.00002753

Lg = 0.0014144 Qq = 0.0034288 Lg — Qq = — 0.0020144

t° C corr.	Scale-tube mm. corr.	Scale-tube cc. corr.	Total expansion of 1 cc. water at 0°	Coeffic. of exp. unit: 1 cc. water at 0°	Volume at t° of 1 cc. water at 0°
— 8°.40 / — 0°.60	— 42.83	0.009902	— 0.000792	— 0.000010	1.000804
— 8°.40	— 28.21	0.006522	— 0.000329	— 0.000164	1.000803
— 6°.40	— 13.80	0.003190	— 0.000225	— 0.000112	1.000473
— 4°.40	— 4.44	0.001026	— 0.000094	— 0.000094	1.000248
— 3°.40	+ 0.49	0.000113	— 0.000059	— 0.000059	1.000153
— 2°.40	1.97	0.000455	— 0.000048	— 0.000048	1.000094
— 1°.40	3.46	0.000799	— 0.000037	— 0.000037	1.000045
— 0°.60	.....	.....	.....	.....	1.000012
— 0°.40	1.97	0.000455	— 0.000007	— 0.000022	1.000007
0	.....	.....	.....	.....	1.000000
— 0°.60 / + 0°.60	7.21	0.001667	— 0.000023	— 0.000019	0.999988
— 0°.60 / + 2°.60	23.55	0.005445	— 0.000029	— 0.000009	0.999982
— 0°.60 / + 3°.65	36.40	0.008416	— 0.000004	— 0.000001	1.000007
— 0°.60 / + 4°.85	52.77	0.012201	+ 0.000038	+ 0.000007	1.000050
— 0°.60 / + 5°.40	62.22	0.014386	0.000071	0.000011	1.000083
— 0°.60 / + 6°.40	78.64	0.018182	0.000127	0.000018	1.000139
— 0°.60 / + 9°.48	144.61	0.033435	0.000418	0.000041	1.000427
— 0°.60 / + 13°.40	252.61	0.058406	0.000942	0.000067	1.000954

We must now try to get an idea of the bearing of the above results [1] on the phenomena, which really take place in the arctic sea. On plate 21 we will find representations of the most prominent kinds of polar ice. I have ventured to establish the following types of ice, partly from their manner of formation, partly from the resemblance in their chemical composition shown by titration. We may understand the red line III approximately to designate the volumes of fresh water-ice, as for example the glacier-ice. The changes in the volume of such ice are most uniform and regular, and therefore the ice-blocks and icebergs arriving from the ice fiords of Greenland will conserve their form and size longer than any other kind of ice, in spite of the abrupt changes of atmospheric temperature, which the icebergs must be exposed to, incomparably more than all other kinds of ice. This ice will survive the mouldering process, which incessantly frets upon such ice as contains a minimal quantity of salt, even at low temperatures, and will succumb only to the influence of a warmer atmosphere or to the corrosion of the warm water of the Atlantic upon its base. But we may see from the abruptly sloping branch of curve III, that just in the vicinity of the melting point destruction rapidly approaches the solid framework of the ice-colosses; an extremely little variation in temperature will cause expansions or contractions in the mass, which may suffice to carve out and split the gigantic structures into fantastical shapes.

The Curve IV will give us a representation of the volumes of *old bay-ice* and of the freshly formed ice of brackish water [see page 308 & 309]. Also the ice of the torosses or hummocks, which has been long exposed to the air, belongs to this type (see the titrations on page 308 by Nordenskiöld, Palander, Almqvist a. O. on samples of toross-ice). According to the analytical determination on page 307 the constitution of sample V accords well with that of the *new bay-ice,* which successively formed during the winter at the coast of Pitlekaj. The titrations by Nordenskiöld a. O. indicate a percentage of chlorine of about 0.17.. in such ice. We may therefore consider V to represent the type of ice, which in the winter covers the bays and fiords of the arctic sea. In the sample VI we meet with an exact counterfeit [2] of that

[1] Owing to the system of observation, adopted in the experimental series V, B and VI, B, the arrangement of the numbers enumerated in the tables is somewhat different from the usual.

[2] According to its manner of formation (see page 291).

kind of ice, which is formed directly by the freezing of the water of the open ocean, before it has been subject to the thawing influence of the weather in the spring or of the arctic summer.

The reports of arctic explorers, who have passed winters in the midst of the polar ice, abound in descriptions of the terrors caused by the pressure of the pack-ice. A ship, fettered for the winter within the boundaries of the pack-ice of the open sea, seems to be doomed to ultimate destruction. The danger of the situation lies in the incessantly renewed rifts in the ice:[1] »The ice is broken up and limed together again into new combinations of the *débris* by the united efforts of the winds and sea-currents, as well as by the influence of the cold, which causes the ice to contract its volume and thus gives birth to innumerable rifts. By sudden *fall of temperature* these rifts increase in number astoundingly. If the snow is swept away in the spring, there will scarcely be found a square-meter, which is destitute of such rifts» .....

If the pack-ice of the open sea possessed the property of regular expansion, which characterizes the pure ice, it would be wholly incomprehensible to us, how the rifts can be formed so abundantly or give birth to such pernicious effects. But a glance at the curve of volumes of sample V and VI will give us a clue, how to explain the breaking up of innumerable rifts in the ice *by a sudden fall of temperature.*

Suppose the ice to have been formed by freezing of ocean-water of ordinary saltness, then the variations of its volumes will be approximately represented either by V or VI. A sudden fall of temperature only affects the upper layers of the ice, while that part of the ice submerged into, or in contact with the water, retains the constant temperature of its freezing point i. e. — 1° or — 2° C. From the graphic illustration we see, that *instead of being contracted by the cold the volume of the ice increases extraordinarily.* Between — 2° and —3° C ice of the type V will expand 0.0039, and between — 4°.4 and — 6°.4 C ice of the same kind as VI expands its volume 0.002957. Such extraordinary variations of volume, which are contrary to all former notions of the behavior of the ice, can not be compared to the ordinary expansion or contraction by heat of any liquid or solid body, but will only bear comparison with the changes of volume effected by temperature in gaseous bodies. The effect will be a hard strain upon the upper

[1] The following description is taken principally from Weyprecht.

strata, which will tend to bend the ice upwards. Still the ice will not generally break, on account of its toughness, until the temperature has sunk below the point of inflection of the curves V or VI. Then the ice will begin to assume the properties of a hard body and, being unable to resist the strain on the upper strata any longer, will break up into innumerable rifts. The violence of the catastrophe announces itself by sudden cracks, which by some witnesses have been compared to the explosions of thunder or the report of a cannon. By external pressure of the surrounding pack-ice the dislocated pieces will be piled up *against* each other, or *on* each other, to those hummocks or torosses, so eloquently described by arctic travellers, which make sledging excursions over the ice a thing next to impossible and caused one of the members of the 1860 expedition of Hayes to stigmatize the difficulty of penetrating farther to the north over the gigantic torosses of the ice of the polar basin thus: »you might as well try to cross the city of NewYork over the tops of the houses.»

I think the result of the present research can be briefly expressed thus: we must henceforth attribute the frequent ruptures of the sea ice and the heaping of its fragments into hummocks or torosses by pressure to an *expansion* instead of a *contraction* of its volume. The sole cause of this phenomenon we have found to lie in the peculiar modification of the physical properties of the solid water by a slight quantity of dissolved salt. We must of course acknowledge the fact, that sea-ice begins to contract its volume, like any other kind of ice, at a sufficiently low temperature, but it must be observed, that the coefficient of the *regular* expansion of sea-ice is *less* than that of pure water and widely inferior to the great changes in volume of the reverse order, which take place nearer to the melting point.

We may also draw the conclusion from the numerical data, that every kind of sea-ice is remarkably inferior in volume to fresh-water ice and consequently sinks deeper into the water.

On plate 23 the reader will find a graphic representation of the volumes of the ice-waters from samples V and VI at different temperatures. The volumes of IV are recorded in table IV, B, but the curve belonging to this water could not be traced on plate 23 with distinctness, because it would be hardly discernible from the red line representing the volumes of pure water. The slight saltness of sample IV (only 0.014 % of chlor-

ine) occasions no great discrepancy in the behavior of the liquid water IV from that of pure water. In the solid state however, the difference is very considerable.

CHAPTER 5.

Chemical changes in the composition of water caused by freezing.

From the preceding chapters the reader must have discovered the weighty influence, which the saltness of the ice, however slight it be, has upon its physical properties. I hope, it will appear from this exposition, that the composition of the sea-ice is a subject of such importance, that it ought to attract the attention of the chemists as well as the physicists more and more. For my part I confess, that I write this chapter more in the hope of winning the interest of my readers for the following questions than from any hope I have of being able to give a conclusive answer to them myself.

Is the salt a constant and normal component of the sea-ice? Mr. F. Guthrie tried to decide this question by artificial freezing of sea-water from Dover. The ice, which formed freely from the sea-water, contained about $^4/_5$ of the usual percentage of salt, but a part of it, which had been pressed between linen and flannel in a screw-press, was found to hold only $^1/_{15}$. Guthrie observes, »that the almost undiminished saltness of the unpressed ice is due, as suggested by Dr. Rae, to the entanglement amidst the ice-crystals of a brine richer in solid constituents than the original water itself. Such brine, which is here squeezed out in the press, drains in nature down from the upper surface of the ice-floe by gravitation and also is replaced by osmic action by new sea-water, which again yields up fresh ice, so that, while new floes are porous and salt, old ones are more compact and much fresher, as the traveller observed». All other observers, except Dr. Buchanan,[1] agree in the opinion, that the saltness of the sea-ice is due to the entanglement of salt brine in the

[1] Proc. R. S. XXIV, p. 611.

network of the crystallized water, and that the brine is afterwards separated from the ice by the influence of variations of temperature. On the nature of this metamorphosis, two different hypotheses have been propounded, which are diametrically opposite to each other. Dr. Walker[1] believed, that the brine was squeezed out by the contraction of the ice *by cold*. I think the impossibility of this hypothesis is sufficiently proved in the foregoing chapter. In fact, sea-ice, which contains any considerable part of its original saltness, is expanded instead of contracted by the cold. Professor Nordenskiöld and Dr. Almqvist are prone to conclude, from their observations during the winter 1878 at Pitlekaj, »that the included brine slowly frets its way *to the surface of the icefloe*, where it was found on several occasions as a concentrated overflow, which frequently deposited an *efflorescence*[2] of crystal-needles consisting of an aqueous double salt of NaCl and $CaCl_2$. For this metamorphosis of the salt ice a temperature near the melting point is necessary, as the peculiar condition of the ice at those temperatures facilitates the penetration of the bladders and drops of salt brine to the surface».

The general opinion thus seems to be, that the ice, even if it separates from salt water, is chemically entirely free from salt, although it may contain a slight quantity mechanically, which adheres to it as salt-crystals or salt-solution. Although combatted by at least one important authority, Dr. Buchanan of the Challenger expedition, this opinion still predominates among the majority of natural philosophers. One reason at least speaks strongly in its favour, viz. the changeable amount of salt, which is found in the ice. To those, who are prone to limit the dominion of Chemistry to only combinations of fixed proportions, the sea-ice never will appear to be anything but a mechanical mingling of crystallized water with an insignificant quantity of sodium- and calciumsalts etc. I have tried to do full justice to this point of view, just because it is not my own. I do not pretend to see a well defined chemical compound in every bit of floating sea-ice, but I think I can show, that at the formation of the ice of the ocean forces of quite another order, than the mechanical adhesion, are at work to connect the salt with the ice.

[1] Of the M'Clintock expedition 1857—59.

[2] The efflorescence of salt crystals upon the surface of newly frozen ice was observed also by Wrangel and is minutely described by Weyprecht a. O.

To begin with, it can be proved, that the freezing of sea-water involves a total revolution of its chemical constitution. Chemical analysis shows, that the quantitative proportion of the constituents Ca, Mg, Na, Ka, Cl, H_2SO_4 is other in ice than in sea water.

It was believed formerly that the composition of the water did change from one part of the ocean to another, until Forchammer, by application of exact analytical methods, showed, that the chemical constitution of sea-water is *nearly* the same over the whole earth. The relation of the chemical components of the salt of the ocean is according to Forchammer (if the amount of Chlorine is assumed = 100)

Cl	CaO	MgO	SO_3	Total amount of salt.
100	2.93	11.03	11.88	181.1

These numbers are on the whole confirmed by recent investigations. Only with regard to the proportions of MgO and SO_3 differences have been found, which are however so slight, that the hydrographers are uncertain, whether to attribute them to a real unsteadiness in the composition of sea-water or to inevitable analytical errors. I will return to this remarkable circumstance later.

Those, who support the common theory, that sea-ice is in itself wholly destitute of salt and only mechanically encloses a certain quantity of unfrozen and concentrated sea-water, must confess, that we in this case ought to find by chemical analysis exactly the same proportion between Cl, MgO, CaO, SO_3 etc... in the ice and in the brine as in the sea-water itself.

In order to decide the question, I requested Mr. Forsberg, the assistant teacher of analytic chemistry of the laboratory, to undertake a complete quantitative analysis of the following six water-samples. № 1—4 I chose out of the collections of the Vega, so as to represent the constitution of the Siberian sea-water at different depths and of different specific gravity. № 5 & 6 are samples of unfrozen brine collected by the Vega-explorers on the surface of the ice during cold winter days. I feel bound on this occasion to express my sincere gratitude to Mr. Forsberg for his skilful assistance. The particulars of the analyses, the methods etc. will be treated in next paper, which is specially devoted to the hydrography of the Siberian sea. The numbers of this table represent the proportions of the constituents if chlorine is = 100

Table 1. Sea-waters.

№	Date.	Lat.	Long. E. Green.	Depth in metres.	Spec. gravity (found).	Temperature. C.	Cl	Ca 0	Mg 0	S 0_3	$Ka_2 0$	$Na_2 0$
1	20 Aug. 1878	77° 40′	105° 10′	128	1.0274	— 1°.2	100	2.97	11.32	11.70	2.59	74.99
2	6-7 Sept. »	70° 14′	170° 17′	22	1.0242	— 1°.2	100	3.01	11.60	11.49	2.60	73.53
3	25 Aug. »	73° 59′	113° 12′	11	1.0151	+ 2°.6	100	3.00	11.60	11.71	2.48	73.40
4	31 » »	73° 05′	144° 20′	7	1.0110	+ 1°.8	100	3.14	11.44	11.89	2.48	74.38

Table 2. Brines.

№	Date.	Physical conditions of the sample etc.	Spec. gravity (found).	Temperature. C.	Cl	Ca 0	Mg 0	S 0_3	$Ka_2 0$	$Na_2 0$
5	2 March 1879	liquid brine	1.1259	—30° (in the air)	100	3.52	14.52	1.14	2.11	62.32
6	» » »	brine separated from crystals (snow?)	1.1749	—32° (in the air)	100	4.48	19.80	1.67	1.87	58.84

This shows, that the brine, which is eliminated from newly formed sea-ice, can not be regarded as concentrated sea-water, since it has a *totally different chemical composition.* The freezing of sea-water consequently must involve some chemical process, which alters the proportions of its constituents. I deemed it necessary to study the proportions of some of the chemical components of the sea-ice, in order to get a clearer idea of this matter. Unhappily for my purpose, the Vega-expedition had not brought home any samples of melted ice. I therefore tested several specimens of sea-ice from Kattegatt, the Baltic and from Spitzbergen. [1]

[1] After a consultation with Prof. Nordenskiöld I resolved to ask permission of the government to accompany the Swedish meteorological expedition of last year to Spitzbergen. Being commissioned by the R. Academy of Sciences, I visited the coast of Spitzbergen in July and August last year on board of H. M^s ship *Urd* and, thanks to the kind aid of the commander of the expedition, Captain Palander af Vega, was able to procure ample specimens of arctic ice of different origin. My experiments with this material being far from terminated, I can here give only a part of the results concerning the chemical constitution of sea-ice.

Table 3. Sea-ice.

Ice-water from	Percentage of chlorine (titr.).	Cl (= 100)	SO_3
Marstrand	0.727 . %	100	12.80
Danes Gat (Spitzbergen)	0.0145 %	100	14.97
Cloven cliff »	0.0020 %	100	43.65
» » »	0.0019 %	100	43.67
Magdalena Bay »	0.0014 %	100	62.8 . .
Ice-fiord » glacial ice (floating)	0.0010 %	100	76.6 . .

From the above tables we may draw the following conclusions:

I. Ocean-water is divided by freezing, not into pure water and a more or less concentrated solution of ordinary sea-salt, as was formerly believed, but into two saliniferous parts, one liquid and one solid, which are of different chemical composition.

II. The formation of sea-ice is chemically a selective process. Some of the elements of the salt water are more fit than others to enter into the solid state by freezing, those, which are rejected by the ice, will be preponderating in the brine and *vice versa*. Taking the relation $Cl : SO_3$ as standard of comparison, we may characterize the most striking feature of the freezing process thus: that the ice is richer in sulphates, the brine in chlorides.

III. The extraordinary variation both in saltness and in chemical composition of every individual specimen of sea-ice and sea-brine, shown by the tables, depends upon a secondary process or metamorphosis of the ice. Its ultimate tendency is similar to that of the original act of freezing. The ice seems to give up its chlorides more and more, but to retain its sulphates. The cause of this metamorphosis has justly been ascribed to the combined influence of time and variations of temperature.

IV. The circumstance just alluded to forbids us to regard the percentage of chlorine, found by titration in the ice or in the brine, as a standard index of its entire saltness, but it will prove invaluable to us, if we wish to form an idea of the development of the metamorphosing action of time and temperature on sea-ice. In the daily journal of the Vega for the winter months 1878—79 many titrations on ice-waters and on salt brines are recorded. The results are given in the fol-

lowing table together with some titrations on samples of sea-ice from other localities.

All numbers in the two following tables denote *grammes of chlorine in 100 cc. of the liquid.* The titrations signed V are executed by members of the Vega-expedition. [The others are signed: P = Pettersson. L = Larsson. E = Ekendahl. F = Forsberg.] »Rossol» is the denomination used by Nordenskiöld on crystallized combinations of sea-salt with ice.

Salt brines, snow, "Rossol", crystals, etc.

Date.	Temperature of the air. C.	Physical conditions of the sample, etc.	Cl in grammes.	titr. by
1878				
Oct. 21	— 11°	Water inundating the ice. The temperature had been still lower (— 20° C) during the day	1.440	V
Dec. 8	— 16°	»Rossol» (salt snow). The temperature of the sample was found — 16° C.	0.952	V
1879				
Jan. 12	—	A specimen of hard snow from a compact layer, 1 c.m. thick	0.585	V
Febr. 28	—	Samples of snow on the ice, which had been moistened previously by overflowing water from fissures in the ice	0.854	V
		D:o d:o	1.163	V
March 2	— 38°	»Rossol», beautifully crystallized needles [the crystals were up to 4 c.m. each and did not seem to be hexagonal] as efflorescences on a snow drift, which had been penetrated by inundating water from remnants in the ice. Two samples were taken		
		I carefully selected sample of crystal needles	4.726	V
		II moist snow and crystals	7.978	V
» »	— 32°	Salt brine,[1] which had remained unfrozen on the ice in — 32° C since the 23th of Febr:	15.673	V
		Brine,[1] intermingled with snow but unfrozen	10.622	P

[1] These samples were afterwards quantitatively analysed by Mr. Forsberg, see table 2 of this chapter.

Date.	Temperature of the air. C.	Physical conditions of the sample, etc.	Cl in grammes.	Ana. by
April 22 & 23	— 15° to — 20°	Hexagonal crystals resembling snow-flakes taken from the surface of newly frozen ice	3.163 3.091	P V
?	?	»Rossol» in needles	6.184	P
?	?	a slight quantity of »Rossol» collected on the ice	3.77	V

It is interesting to follow the increasing concentration of the overflowing waters and brines with the winter cold. We know, that such brines have been used at several localities of the Siberian coast in the fabrication of salt.[1] From the analyses in table 2, of this chapter, we see, that this method of fabrication has its drawbacks (at least theoretically). By concentration by cold the proportion of sodium is diminished and the amount of magnesium increased in the brine.

Ice formed during the winter 1878—79.

Date.	The sample was taken „ centim: from the surface of the ice-floe.	Ice-floe formed by freezing of the sea water during the winter. Physical conditions of the sample, etc.	Cl in grammes.	Ana. by
1879				
Jan. 12	0 c.m.	The ice-floe was 75 c.m. thick, greenish	0.432	V
» »	4 »	and of homogeneous structure. The	0.134	V
» »	26 »	layer of compact snow on its sur-	0.111	V
» »	72—75 »	face possessed an amount of 0.585 of Cl.	0.182	V
March 1	0 »	The ice-floe was 115 c.m. thick	0.214	V
	35 »		0.142	V
	75 »		0.175	V
	115 »		0.133	V
April 1	0 »	Thickness of the ice = 120 c.m. Its	0.086	V
	40 »	undermost part was very loose	0.086	V
	80 »	and porous.	0.119	V
	120 »		0.011	V

[1] Soumise à la congélation l'eau de mer fournit de la glace pure, et la partie restée liquide se concentre. On finit par avoir une eau très chargée, dont on achève la concentration dans des chaudières. On obtient ainsi un sel impure... (Extrait from Würtz' Dictionnaire de Chimie.)

Date.	The sample was taken » centim: from the surface of the ice-floe.	Ice-floe formed by freezing of the sea-water during the winter. Physical conditions of the sample, etc.	Cl in grammes.	filtr. by
June 1	one side	Samples from a block of ice, which	0.060	V
	the midst	had been left standing on the deck	0.062	V
	the other side	of the Vega from 1st of March until 1st of June, when it partly melted.	0.045	V
—	—	—	—	—
Febr. 28	the top	Ice-sample taken from a toross, which	0.035	
	» »	had been formed of newly frozen ice	0.063	
	the surface	by the screwing of the pack-ice in November to a height of 6—7 metres	0.069	

From these and similar observations Nordenskiöld drew the conclusions:

that the saltness is greatest in the upper layers of the ice-floes and gradually changes its place, from the inner part of the ice, until it reaches the surface;

that the rise of temperature in spring or summer is the chief cause of this metamorphosis.

It can hardly be denied, that the saltness somehow or other has the power of penetrating through the mass of the ice to its surface, and that this is effected, not by any contraction of the mass of the ice by cold, but by the thawing process, which, as we have seen before, commences in the sea-ice far below its melting point. Therefore the age of the sea-ice has a decided influence on its chemical constitution. This will be seen more clearly from the following titrations on ice-samples from old sea-ice.

Old sea-ice.

Date.	Locality.	Physical conditions of the sample, etc.	Cl in grammes.	filtr. by
1878				
Oct. 1	Pitlekaj	Sample from a foundered ice-floe ...	0.0068	V
» 16	»	» of green ice	0.0012	V
» 18	»	» » blue » } drift-ice	0.0016	V
» 18	»	» » blue » } drift-ice	0.0010	V

Date.	Locality.	Physical conditions of the sample, etc.	Cl in grammes.	tit. by
March 5	Pitlekaj	Drinking water obtained from a great blue ice-block	0.0025	V
» »	»	D:o from old blue ice	0.0319	V
» »	»	D:o » » » »	0.0193	V
—	—	—	—	—
1880	The Baltic	Collected outside the harbour of Wisby	0.0140	L
1882 July	Danes Gat Spitzbergen	Old bay-ice	0.0146	E
			0.0145	E
»	Cloven cliff Spitzbergen	Ice from the polar drift-current	0.0020	E
			0.0019	E
»	Magd. Bay Spitzbergen	Glacier ice floating upon the sea	0.0014	E
			0.0014	E
»	The Icefiord Spitzbergen	D:o » » » »	0.0010	E
			0.0010	E

Most of the above samples are representatives of the last stage of the metamorphosis of the sea-ice. Ice of this kind shows, according to the analyses in table 2, of this chapter, quite another proportion between its chemical constituents than sea-water. The amount of sulphates has increased enormously in proportion to the chlorides. Therefore we must conclude, that sulphates of sodium and calcium will be carried far away from the arctic ocean by the drift-ice. This fact gives us the clue to the observations already mentioned, that the percentage of sulphuric acid in the sea-water is slightly variable. By Forchammer and recently by Mr. Schmelck,[1] hydrographer of the Norwegian expedition 1876—78, it was ascertained, that the maximum amount of sulphuric acid in the sea between Greenland and Norway is found *south of the polar circle.*[2] To this fact we must also attribute the observations of Mr. Schmelck and of Prof. Ekman, that the per-

[1] Nyt Magazin for Naturvidenskaberne 1879. It is very remarkable, that Schmelck did not find any increase of the percentage of SO_3 in that part of the sea crossed by the great ice-current at the eastern coast of Greenland. This shows, that the sea-ice does not part with its sulphates before it is entirely liquefied.

[2] In this part of the ocean, which is swept by the Gulf-stream, the last products of the original decomposition of the arctic sea-water by freezing can still be discovered by chemical analysis, although these traces most probably have twice crossed the Atlantic.

centage of sulphuric acid is *greater at the surface of the sea than at the bottom.*

I think the theory »on salt solutions and attached water» published in 1875 by Prof. Guthrie will best account for the observations enumerated above. Prof. Guthrie found, that every diluted salt solution, on being cooled sufficiently, yields up ice, until its temperature reaches a certain point peculiar to the salt, when it solidifies as a whole, maintaining throughout that constant temperature. The proportion of water relatively to the salt in these »cryohydrates» is ordinarily very large and makes the molecular formulæ given to these combinations appear somewhat exuberant to the chemist. This must have induced a short-sighted critic to overlook the importance of the discovery of Mr. Guthrie, which still affords the only starting-point for an acceptable theory of the origin of the sea-ice.

»Bearing in mind the existence of the cryohydrates, certainly of sulphate of magnesium and doubtless also of chloride of calcium (?), at temperatures not far below 0° C, a rapid fall of temperature may be accompanied by more complex phenomena of gelation; for if the ice be quickly removed from a large mass of water by freezing, the resulting brine may easily be so enriched, as to throw out one or more cryohydrates, which thus perpetuate *in situ* a definite amount of saline matter..... The saltness of a floe depends not only upon its age but also upon the rapidity, with which it was at first formed and upon the lowest temperature, to which it has subsequently been exposed.»

We will leave the question of the appropriate chemical formula of the cryohydrates aside and listen to some simple facts, told us by Prof. Guthrie, about the freezing points and the chemical composition of some of the cryohydrates, which can possibly arise from the freezing of sea-water.

The cryohydrate of	contains	solidifies at
$NaCl$	76.39 % water	— 22° C
$KaCl$	80.00 % »	— 11°.4 C
$CaCl_2$	72.00 % »	— 37°.0 C
$MgSO_4$	78.14 % »	— 5°.0 C
Na_2SO_4	95.45 % »	— 0°.7 C

According to this table we ought to expect, that the cryohydrate of Na_2SO_4

$$4.55\ \%\ \text{of}\ Na_2SO_4 + 95.45\ \%\ \text{of}\ H_2O$$

would be among the first to separate from the cooled sea-water already at — 0°.7 C. This agrees well with the table 1, of this chapter, which shows, that of all the constituents of the sea-water the brines are most deficient in Na_2O and SO_3. The percentage of sulphuric acid in ocean water is about 0.2228 (calculated as SO_3). Suppose all this to combine with its equivalent of Na_2O and freeze out as a cryohydrate in the ratio

$$[0.3954\ \%\ Na_2O^2SO^2 + 8.3947\ \%\ H_2O] + 91.3\ldots\ \%\ \text{aq.}$$
$$\text{(cryohydrate)}^1 \qquad \text{(ice)}$$

then 8.69 % of the frozen sea-ice ought to consist of the solid cryohydrate of Na_2SO_4 instead of pure ice with a few drops of concentrated brine, as is ordinarily assumed. It would be impossible to explain, how an amount of 0.3954 % of foreign matter could so essentially modify the physical properties of the ice, as is seen in the foregoing chapters, if the substance was included in the ice as solid crystals or as adhering drops of brine, but we will have no difficulty to admit, that the presence of 8.69 % of a solid cryohydrate, which physically and chemically is a different body from the pure ice, can modify its properties considerably. Moreover this solid has its melting point at — 0°.7 C. Consequently it will endure in the solid state as long as the ice itself. Other cryohydrates, as for example $MgSO_4$, $MgCl_2$, $CaCl_2$, $NaCl$, which arise at lower temperatures, will consequently melt again long before the rest of the ice. Therefore every rise of temperature will promote the metamorphosis of the ice extraordinarily. The cryohydrates of the chlorides will liquefy and escape, if any chance is left to them. This is realized by the abnormal contraction of the sea-ice by the fall of temperature, which causes a strain and a bending on its surface, which finally ends with its bursting and breaking up into remnants and fissures.[2] When the temperature rises again, the liquefied

[1] The reader will of course perceive, that I do not mean to say, that the sulphuric acid of the sea-water freezes out at once as a cryohydrate at — 0.°7 etc. but that I only wish to give an idea of the whole, very complicated, process by the chosen example.

[2] The uppermost layer of the ice, having acquired the temperature of the air, will begin to assume the properties of a hard body and *contract its volume* (while the next layers, to which the atmospheric cold penetrates more slowly, is still *expanding*) and consequently breaks up into innumerable rifts. In short I believe, that the *regular* expansion or contraction seldom causes any violent dislocation of the ice. Such effects are due to the great *abnormal* changes of volume, which take place in fresh-water ice,

cryohydrates will escape to the surface of the ice through these channels and engender those unfrozen brines, which attracted the attention of Nordenskiöld and his followers.

The sea-ice is certainly no homogeneous body. I would compare it to a crystalline rock, for example a granite, which contains a number of different crystallized combinations. Every one of the constituents: the feldspar, the mica, the silicia is liable to decomposition in its own peculiar way. The products of this decomposition escape in the form of aqeous solutions, until the remainder, which can not be decomposed any more *in situ,* is mechanically carried off as clay and sand with the glaciers or with the water of the rivers to give birth to new geological formations. Thus the crystallized constituents of the sea-ice, one by one, are attacked by decomposition, even before the arctic summer has broken the ties, which bind the ice-floe to its birth-place. The rest, which can not be attained by metamorphosis in these high latitudes, viz. the pure ice and the most perdurable cryohydrates, is caught by the mechanical force of the ice-current, which carries the skeletons of the polar ice back to southern latitudes to unite again with the warmer parts of the ocean.

CHAPTER 6.

On the latent heat of fresh and salt water, conclusions.

Pure water.

The latent heat of pure water below zero is, as already mentioned, theoretically calculated by Person. From my experimental verification[1] of his formula the following table is cited:

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when the temperature approaches the melting-point, and in sea-ice by fall of temperature (see the illustrations on plate 21 & 22).

[1] The following table is reproduced here, because the subject is of essential importance to the description of the physical properties of pure

Table 1.

Exp:	Weight of the water	Initial temp. of freezing C	Final temp. of the exp. C	Final temp. correct. C	Total increase of temp.	Developed heat in calories	Heat developed by 1 gr. water	Heat calc. for 1 gr. water
1	3.23095	— 2°.80	— 1°.105	— 0°.945	1°.855	251.09	77.71	77.85
2	1.3027	— 4°.995	— 4° 30	— 4°.26	0°.735	99.79	76.60	76.75
3	5.4814	— 6°.28	— 3°.46	— 3°.235	3°.045	416.27	75.94	76.11
4	3.5088	— 6°.50	— 4°.61	— 4°.55	1°.95	266.79	76.03	76.00
5	2.5630	— 6°.62	— 5°.21	— 5°.18	1°.44	194.77	75.99	75.94

Weight of the mercury of the calorimeter in exp. 1 & 2	3899.114	gr.
D:o in 3, 4 & 5	3862.607	»
Weight of the iron vessel & stirrer	45.017	»
Weight of the mercury of the thermometer.....	25.04.	»
Weight » » glass » » »	2.05	»
Spec. heat of the mercury at 0°	0.033266.	

Salt water.

Immediately after the close of the volumetric experiments the latent heat was determined of the water-samples IV, V & VI. In the following table I give also a description of some determinations on a watersample taken by Mr. Tornoe from the surface of the arctic sea, south-east of Jan Mayn, 68° 32′ Lat. 6° 26′ Long. W. G., and kindly forwarded to me, and of fresh water from the surface, formed by the melting of the sea-ice at Pitlekaj.

Table 2.

Watersample	Locality	Spec. gravity $\frac{0°}{+4°}$	Cl %	salt in %
I (sea-water)	Jan Mayn	1.0282	1.927	3.53
VI (ice-water)	Siberian sea	1.0090	0.649	—
V d:o	Kattegatt	1.0053	0.273	—
IV d:o	Baltic	1.0003	0.014	—
J	Pitlekaj	1.000..	0.00..	—

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water. Moreover I have hitherto only published these results in the Swedish language (Öfversigt K. V. A. Förh. 1878) and especially wish to correct an inadvertence in the description of exp. 2, where an erroneous number, relating to an unsuccessful experiment, was inserted in the original instead of the right one [1.3027 grammes of water].

Water sample	Weight of water in gr.	Thermal constant of the entire system in calor.	Initial temperature C	Final temperature corr. C	Developed heat		
					found in calor.	calculated pr. salt + aqua[1]	found pr 1 gr. of the water
I	3.9736	137.02	— 9°.00	— 7°.47	209.6	286	52.7
	3.74545	136.84	— 8°.35	— 6°.94	192.9	271	51.5
VI	4.8761	134.99	— 7°.31	— 4°.855	331.4	364	67.9
	4.5972	139.53	— 6°.77	— 4°.605	302.1	344	65.7
V	2.7555	133.59	— 7°.78	— 6°.285	199.8	206	72.5
	5.6358	140.70	— 6°.49	— 3°.685	394.6	426	70.0
IV	4.0949	136.99	— 5°.81	— 3°.55	309.5	312	75.6
Δ	3.9313	134.49	— 5°.46	— 3°.22	301.2	301	76.6

It strikes us at once, that the latent heat, developed by the freezing of sea-water, is *extraordinarily inferior to that of pure water*. We further observe, that the law of Person has no application to sea-water. Its latent heat seems to be greater at lower temperatures than nearer to its melting-point. Unhappily the ratio of this alteration of the latent heat cannot be determined with the same exactness as in pure water, on account of the slowness of the freezing process in salt water. Still I think much can be done by further experiments in this way, for the present it will suffice to call attention to the fact, that water of the sample V at — 7°.78 showed a latent heat of 72.5 cal. and at — 6°.49 only 70.0 cal. etc.

From these observations the following conclusions are inevitable:

I. Any theory, which considers the salt of the sea-ice to be mechanically included as crystallized salt, must be false. For in this case we ought to have found for the developed heat the values of column 7 instead of those in column 6.

II. Any theory, which ascribes the saltness to adhering drops of liquid, concentrated brine, will prove insufficient.

Sea-water seems to be divided by freezing into three parts: ice, solid cryohydrates and liquid brine containing dissolved salts. The relative proportion of these components depends upon the freezing temperature. By the freezing of sea-water in nature, the salt brine for the most part separates from the ice and mingles with the adjacent unfrozen water. This was not the case in my experiments. The brine remained in the

[1] The slight amount of heat, which ought to be developed by the supposed crystallisation of the salt, is not taken into account here.

spiral (see p. 269) together with the frozen substance. Thereby we may in some degree account for the extremely low latent heat of the watersamples *I'* (ocean-water from Jan Mayn), but the difficulty still remains to account for the deficiency in latent heat of the following water-samples VI, V, IV, which were obtained by melting of sea-ice and *consequently only ought to contain such constituents as are capable of solidification.* From sample VI, which was formed by freezing of sea-water, the liquid brine had been separated previously (see p. 291). We must, however, admit as probable, that even in these cases (VI & V) a diminutive part of the sample was kept from freezing, until lower temperatures, as a concentrated brine, from the fact, that the latent heat as well as the volume of the frozen substance (see plate 21, VI & V) *increased* as the freezing temperature sunk. But as an explanation it is insufficient. It does not hold good in case of sample IV, which is certainly solidified entirely at $-5^{\circ}.81$ C, and also in V & VI the discrepancy of the latent heat calculated and found is sufficiently great to authorize the conclusion, that:

III. The latent heat of ice is diminished, if it separates from salt water and in combination with some part of the salt. We could form an idea as to the causes of the low latent heat developed by VI & V at -6° or -8° C by supposing, that the formula of the depression of the latent heat with the freezing temperature given by Clausius and Person

$$\frac{dr}{dt} = -0.5 \ldots .$$

does not hold good for such ice, on account of its spec. heat in the solid and liquid state c and c_1 being different from that of pure ice.

Everybody must admit, that the latent heat developed by the freezing of the sea-water has the greatest influence on the conditions of the arctic oceans and on the climate of arctic countries. It will be important then to observe, that the latent heat, which is developed immediately by the solidification of ocean-water, is very inferior to that of fresh water, but that the freezing process, from a thermic point of view, is not *entirely* concluded with the solidification of the sea-water. On further sinking of the temperature, still unfrozen cryohydrates will be solidified and develop heat, until the whole mass of the ice-floe, at sufficiently low temperature, is a solid rock of crystallized matter. At the rise of temperature

these substances will melt, one by one, and absorb heat in so doing. Thus the thermal processes in the mass of the ice-floes will to a certain degree counteract the influence of the sudden variations in temperature of the atmosphere.

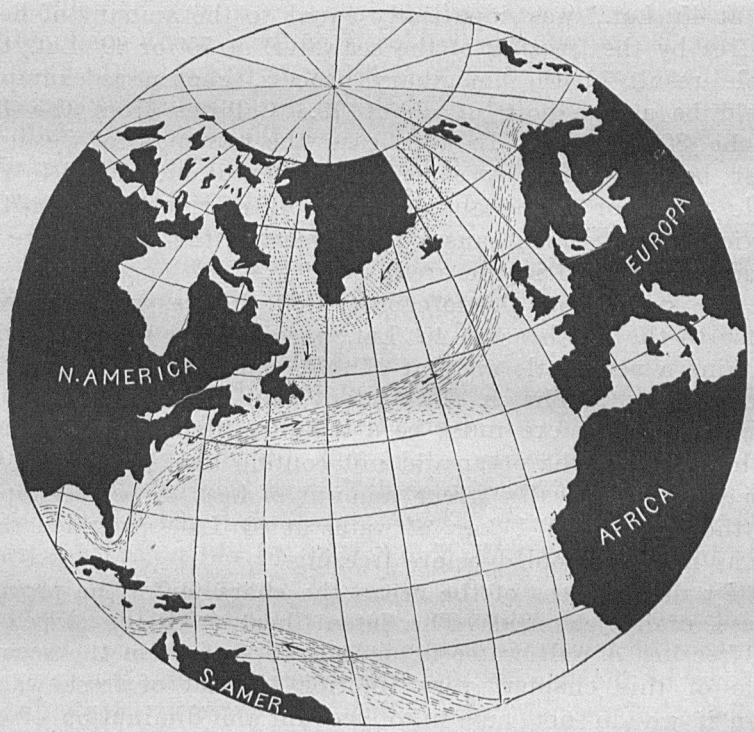
I have already mentioned the fact, that I found during my dilatometric researches, that pure ice did assume the temperature of the mercury-bath surprisingly soon, and that the case was quite reversed, when I operated with ice containing any amount of salt, especially at those temperatures, where it upon cooling showed an abnormal expansion of volume. I can not decide, whether sea-ice is really a worse conductor of heat than pure ice, or if this behavior is due to the thermal processes just alluded to, having no quantitative measurements to judge from, but I consider, that the sea-ice will behave in nature just as it did, when tested in my apparatus, viz. very slowly propagate thermic impulses from without.

There is every reason to believe, that the formation of ice in that part of the arctic ocean north of Europe even in winter-time is limited to very high latitudes. In winter as well as in summer a mighty stream of warm water sets in between Scotland and Iceland sweeping the coast of Norway (which is entirely free of ice) and spreading its waters unto the coasts of Spitzbergen and Novaya Zemlya. Thereby the freezing of the arctic ocean is prevented and delayed, until very high latitudes. We know, that the old polar-ice is transported along the eastern shore of Greenland and America to relatively low latitudes, where it melts by the combined influence of a warmer atmosphere and a warmer sea. Thus the melting of the sea-ice and the freezing of the sea-water are processes of reverse order, which take place at widely distant latitudes. The solar heat stored up in the ice by its liquefaction at low latitudes is developed again at 70° or 80° Lat. N. by the latent heat of the freezing sea-water. Its effects will naturally not consist in any raising of the temperature of the sea, but indirectly it will counteract the heaping of great ice masses north of Europe, because:

»Water can not freeze to ice, even at its freezing point, if it can not transfer its latent heat to a colder medium» [Edlund].

The influence of the Gulf-stream on the climate of Europe is said to be a theme nearly worn out, but I think the influence

of the *latent heat* of its water is well-nigh overlooked. The influence of its temperature being a few degrees above zero is of little consequence compared to the quantity of solar energy stored up in its water as latent heat, which is made useful by freezing. Moreover the warm temperature of its water is reduced considerably during its course by the influence of the atmosphere, but the latent heat is a reserved capital, which can not be expended before the exact moment of freezing.



East of Newfoundland, at 45° or 47° Lat. N., the arctic current in spring and early in summer pours great masses of polar ice into the midst of the Gulf-stream. Another battle-field of the warm and cold Atlantic currents is, according to Petermann,[1] Irminger[2] a. O, the sea east of Iceland and west of Beeren Island. In each of these places masses of drift-ice are melted at the cost of the solar energy stored up

[1] Der Golfstrom, Mitth. 1870.
[2] Die Temperatur im Nördl. Atl. Meer etc., Mitth. 1870.

in the water of the warm Atlantic stream. We can therefore safely imagine the following cycle to take place.

Suppose a quantity of ice, say 1 kgr, to melt at 45° Lat. N. and the issuing water to be transported with the Atlantic current up to the western coast of Spitzbergen, where it at last solidifies by the influence of the winter cold and is afterwards brought back again with the arctic current to 45° Lat., there to melt once more in the heated water of the Gulf-stream.

If the latent heat absorbed by the melting of 1 kgr. of ice, at 45° Lat., was identically equal to the amount of heat set free by the freezing of the seawater, at 75° or 80° Lat., the whole result of the imaginary process, chosen as example, would be a transport of about 79.2 Calories from the 45th to the 80th parallel. In this case the transport of the heat must be performed by some *external* force, due either to the trade winds or to the abundant supply of river water to the Mexican Gulf, which causes the niveau of the water there to stand higher than in the arctic sea. [1]

We know from the foregoing, that the ice, which arrives so far to the south as to 45° Lat., is relatively pure and only contains a very little amount of salt, consisting principally of chlorides and sulphates. The latent heat absorbed at its melting (= Q) therefore must be a trifle *less* than 79.25 Calories. If the water of the ocean did not contain any salt, we might expect an identically great amount of heat to be developed by the freezing of 1 kgr. of water at 80° Lat., provided that it was not over-cooled before freezing.

By the saltness of the ocean the character of the process is essentially changed. The latent heat (= R) developed at the freezing of salt water is, as will be seen from the second table of this chapter, very inferior to that of fresh water. Even if we do not take into account the diminution of the latent heat caused by the dissolved salt (which is however very considerable), we must admit, that:

$$R < Q,$$

because the maximum temperature [T = — 2° C or — 1°.9 C] of freezing ocean-water is considerably *lower* [2] than the melting

[1] The difference of level at the equator and at the pole ought to be about 2 metres, according to Colding [Skand. Nat. Forskare-Sällsk. Möte 1863, Bilaga D] and Guldberg [Polyt. Tidskrift, 3, 1872].

[2] As a thermometer immersed in a mixture of snow and sea-water, *which is constantly stirred*, indicates — 1°.8 C, we may regard this as the upper limit of the freezing- and the nether limit of the melting-temperatures.

temperature [$T_1 = -0°$... C] of nearly pure ice. *Water can not absorb or develop the same quantity of latent heat at two different temperatures.* Besides, the presence of salt in freezing water has the property of diminishing its latent heat, at least if the solidification, as always in nature, takes place a few degrees below zero.[1] 2 or 3 p.c. of salt dissolved in pure water has the same depressing influence on its latent heat and likewise on its freezing temperature as an increase of pressure amounting to some hundreds of atmospheres.

From these premises we can draw the following conclusions:

1. In the imagined example a complete *cycle*[2] of heat takes place. The quantity of ice (= 1 kgrm), which was supposed to melt in the warm water of the Gulf-stream, is also supposed to return to its original point of depart, in its initial state of pure or nearly pure ice.

2. Meanwhile it undergoes the following transformations:

it melts at $-0°$.. [absolute temperature $T = 273°$].

Thereby it absorbs the latent heat Q . . . . . $\frac{Q}{T}$

it mingles with the surrounding ocean-water and thereby absorbs heat, q_1 . . . . . $\frac{q_1}{T_1}$

of sea-water. But in those parts of the ocean, where a real *melting* of sea-ice takes place, the temperature *never sinks so low.* That part of the ice, which is first liquefied, forms a stratum of fresh water around the ice-floe wherein the rest of the ice liquefies at its ordinary melting point. Very often the fresh or diluted sea-water in the vicinity of melting ice is found to be of surprisingly high temperature. The lowest temperature observed on the bank of New-Foundland during 5 years was $-0°.9$ R, the mean temperature was $+3°.01$ R. [Proceedings of R. S. 1869. № 3.] On the other hand the temperature of *freezing* sea-water has never been found to be higher than the ordinary freezing point of the water. See the observations of Scoresby 1810—1817 and those of the Vega-expedition in Sept. 1878 a. O.

[1] I consider this reservation to be necessary, because the temperatures of the freezing experiments, enumerated in table 2 of this chapter, do not exceed the limits $-9°$ C and $-3°$ C. Having no experiments to rely upon at lower or higher temperatures, I do not wish to extend the rule beyond the dominions of experience.

[2] In order to prepare the application of Carnot's theorem to the example in question, I denote the quantities of heat absorbed or developed by the water at every one of these secondary changes by »q» and in the case of ice by »r». The corresponding absolute temperatures are T, T_1, T_2... T', T'_1,... Thus we may form the quotients $\frac{q_1}{T_1}$, $\frac{q_2}{T_2}$... $\frac{r_1}{T'_1}$, $\frac{r_2}{T'_2}$ etc... [»die Aequivalenzwerthe» of Clausius].

it receives and gives out heat to the atmosphere, the surrounding water, etc... by radiation and convection, q_2, q_3, ... $\frac{q_2}{T_2}, \frac{q_3}{T_3} \ldots$

it separates from the surrounding water at $-2°$ C [abs. temp. $T' = 271$] by freezing as ice + solid cryohydrates,[1] thereby developing the latent heat R . . . . . $\frac{R}{T'}$,

the ice receives and imparts heat to the atmosphere etc... r_1, r_2, ... $\frac{r_1}{T_1'}, \frac{r_2}{T_2'} \ldots$

3. The algebraic sum of the fractions:

$$\frac{Q}{T}, \frac{q_1}{T_1} \ldots \frac{R}{T'}, \frac{r_1}{T_1'} \ldots \text{etc.} \ldots \overline{\overline{<}}\, 0,$$

since the ice is supposed to return to its initial state. We can not evaluate all these quantities, but we nevertheless can form an idea of the character of the whole cycle from the head members

$$\frac{Q}{T} \text{ and } \frac{R}{T'},$$

the influence of which must be predominating. If we leave aside the secondary changes, represented by $\frac{q_1}{T_1}, \frac{q_2}{T_2} \ldots \frac{r_1}{T'}, \frac{r_2}{T_2'}$ etc... we conclude from the fact, that

$$Q > R \text{ and } T > T',$$

that the result of the melting and freezing of sea-ice is twofold, viz:

a quantity of heat, R, is transported as thermic energy from one part of the ocean (where the melting takes place) to another (where the water freezes again);

another quantity of heat *can* simultaneously be transformed into mechanic energy. If we assume $T = -0° \ldots$ C and $T' = -1°.9$, the quantity of heat *available* for mechanic effect would be

$$Q \frac{T - T_1}{T} = 0.55 \ldots \text{ Cal. for every kgr. of ice.}$$

We must expect it to be *far less* in reality. That part of the available energy, which is really transformed into work, is surely *too small* to influence the experimental measurements. Exact calculus is impossible at present, because we do not know the exact value of the quantities T, R, q_1, q_2 ... etc...

[1] Some unfrozen cryohydrates will also be enclosed in the new sea-ice, which afterwards solidify and melt as the temperature falls or rises. The thermic influence of these processes will on the whole neutralize each other.

The numbers found in the experiments V & VI of table 2 of this chapter can not be substituted for R, because these determinations were executed at temperatures 6 or 7 degrees lower than T' and the latent heat is calculated for 1 kgr. *of the salt water examined,* without deduction for that part, which must be enclosed as unfrozen brine, in case the temperature at the freezing was so high as T'. Besides we have hitherto supposed the whole process to be a *regular cycle,* where every alteration represented by the fractions $\frac{Q}{T}, \frac{q_1}{T_1} \ldots \frac{R}{T'}, \frac{r_1}{T_1'} \ldots$, is *reversible.* From this there will in reality be found to be several exceptions, since many phenomena connected with the freezing of sea-water, the overcooling etc... are *not* of reversible nature, and the evaporation, which constantly takes place from the water and the ice, gives rise to a series of thermodynamic processes, which doubtlessly are of influence upon the movement of the ocean, but fall entirely beyond the reach of the present discussion.

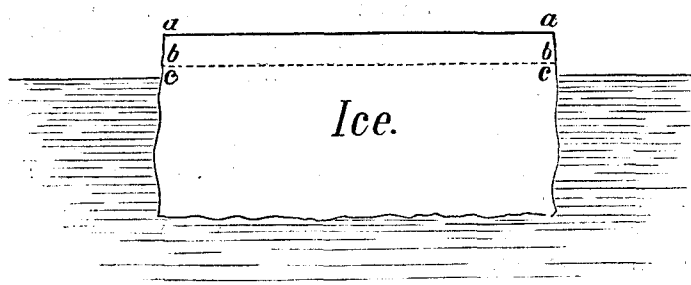
Nevertheless it seems probable from the general outlines of the phenomenon, which I have endeavoured to sketch in the foregoing, that the transport of the warm water across the ocean to high latitudes need not to be attributed solely to external forces, *since the melting and freezing of sea-ice is found to involve the possibility of a transformation of thermic energy into mechanic force.*

If we admit the possibility that by the peculiar conditions, under which the melting and freezing of sea-water takes place, a certain quantity of solar heat is made useful for mechanic purposes, it can not be difficult to understand *how* the melting of ice in sea-water can give rise to an ocean current. Professor Ekman in his paper upon the origin of currents [1] has proved that this must be the effect of the melting, as follows:

Suppose a bit of pure ice, which swims *freely* in salt water, to melt and the liquefied ice to retain its former place, then the level of the fresh water will stand *higher* than the surrounding sea, on account of the greater spec. volume of the fresh water. This makes it expand above the surface of the salt water. Pure ice, melting in pure water, occasions no current, because its spec. volume is equal to that of the surrounding fluid. — — — If we pursue the subject further, we find, that the sea-water in the moment of freezing must perform a certain amount of *work,* by raising a part of the ice above the

[1] Öfvers. K. V. A. Förh. 1875. N:o 7.

level of the sea, contrary to the action of gravitation. This amount of work, which must be executed at the cost of the latent heat developed by the water [because it is the immediate consequence of its freezing], is stored up in the ice and can not be expended before the moment of melting, when it is transformed into actual energy or *vis viva* of the water particles, derived from the higher level of the ice-water relatively to that of the surrounding sea, which, as Ekman justly observed, must occasion a surface current.[1] The ice, which the



By the freezing of the water the surface of the ice-floe is lifted the distance *ac* contrary to the action of the gravitation [and of course also to the atmospheric pressure]. *bb* is the niveau of the ice-water after melting. The difference *bc* causes the surface-current. At the melting of ice in fresh water *bc* is $= 0$.

arctic current forces into the angle between the American continent and the powerful stream from the Mexican Gulf, must, when melted, spread over the ocean in north-easterly direction. The rotation of the earth exercises upon this current a directing, but nowhere an impelling force.[2] We are accustomed to ascribe the movements of the currents of the atmosphere and the ocean to the solar heat. True; but solar heat can not be transformed into mechanic energy without the conditions of the second principle of thermodynamics being fulfilled. The cycle of heat performed by the freezing and melting of ice is of a different nature from the cycle of free heat in the water caused by radiation and refrigeration,

[1] At the freezing of *fresh* water, as for example rivers, lakes etc... one part of the latent heat is likewise transformed into work, which is again changed into heat at the melting of the ice, *without* giving rise to any mechanic effects, or motion of the water, currents etc.

[2] See Guldberg: Theorien for vandets og luftens strömninger paa jordens overflade, Polytekn. Tidsskr. 1872.

1) because the heat, which passes over from T to T′ is latent, and

2) because its influence is localized to those parts of the ocean, where the arctic current pours its ice-masses into the warm stream.

It has long since attracted the attention of hydrographers, that the Gulf-stream *increases* considerably after every combat with the arctic current, although the temperature of its water diminishes. According to Mr. Findlay[1] and Dr. Carpenter[2] the original stream from the Gulf of Mexico and the Florida strait can hardly be recognized in the great Atlantic current, which sweeps the coasts of Europe. A glance at the maps in the Geogr. Mitth. of Petermann representing the Gulf-stream in summer and winter convinces us at once of the remarkable influence of the seasons upon its course. In winter, when the supply of cold water from the arctic current is reduced to its minimum, the water of the Gulf-stream is limited to a narrower space than in summer. Colding[3] has called special attention to the fact, that the Gulf-stream takes a more northerly direction, whenever the influence of the arctic current diminishes. Thus it *may* be possible, that it reaches farther to the East in winter, when it is unimpaired by the arctic ice-masses, than in summer. This would be the only plausible explanation of the observations cited by Middendorff[4] and Petermann,[5] according to which the winter climate of the northern part of Novaya Zemlya and the Taimur peninsula is milder than that of Siberia. For, as I intend to show in the next paper from the observations of the Vega-expedition, there is scarcely to be found, from a hydrographic point of view, any direct signs of the influence of the warm water of the Gulf-stream upon the sea north of the Taimur peninsula and Cape Tcheljuskin in summer time.

[1] Proceed. R. G. S. XIII.
[2] Ocean circulation, Contemp. Review, 1875.
[3] l. c.
[4] Der Golfstrom, Geogr. Mitth. 1870.
[5] Der Golfstrom ostwärts vom Nordkap, Geogr. Mitth. 1871.

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CONTRIBUTIONS

TO

THE HYDROGRAPHY

OF THE

SIBERIAN SEA

BY

OTTO PETTERSSON.

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Introductory remarks.

During the voyage of the Vega along the Siberian coast great attention was paid to the hydrographic constitution of the sea. Beside the regular observations at midnight, 4 & 8 a.m., noon, 4 & 8 p.m., of the temperature and density of the water at the surface, which are registered in the meteorological journal, a serial deep-sounding was made at least once a day by means of the isolating apparatus invented by Professor F. L. Ekman. This instrument is too well known by professional experimenters and students of hydrography to need any description here. For a shallow sea, like the Siberian (the depth of which nowhere exceeds 200 metres), with very variable water-strata, it is indeed unequalled. Immediately after the isolated capsule, containing a sample of water from a certain depth had been hauled on board, the temperature of the water was determined with a thermometer [1] and its density with an areometer manufactured by Åderman.

Lieutenant G. Bove of the R. Italian Navy had the management of the hydrographic operations during the expedition. I have calculated the following results from his annotations in the hydrographic journal of the Vega.

The observations are regularly registered in the journal from the departure of the Vega from Yugor Schar, the southern entrance to the Kara Sea, on the 1st August, 1878, until the arrival at Koljutchin bay on the 23rd Sept., about 119′ from the Behring strait. During the winter some observations concerning the temperature of the sea-water, the thickness of the ice etc... were made by various members of the expedition. Some of these observations I have discussed in the preceding paper. The regular series of hydrographic annota-

[1] This instrument is graduated in $^2/_{10}$ of a centigrade, although $^1/_{10}$ can be easily estimated by the observer. It is of very elaborate workmanship and possesses the remarkable advantage of an almost steady point of zero, like most of the Åderman thermometers.

tions commenced again on July 24th, 1879, at Port Clarence and was continued during the cruise of the Vega in the Behring Sea until August 7th.

The available material for scientific investigation consisted of:

1). A complete series of observations regarding the temperature and specific gravity of sea-water from different depths.

2). Annotations concerning the percentage of chlorine in samples of water and ice found by titration on board the ship. As far as regards the samples of ice water these titrations are recorded in chapter 5 of the preceding paper. According to the annotations these determinations seem to have been executed by Nordenskiöld, Palander, Almqvist and other members of the expedition.

3). A collection of about 30 water-samples [1] sealed up in flasks of 250 cc. each. Among these I found 4 specimens of melted rossol and of very concentrated brines collected on cold winter days from the surface of ice-floes.

4) The thermometer (Åderman) and *one* of the areometers (also by Åderman) employed in the hydrographic measurements (for waters of the spec. gravity from 1.0290 to 1.0150).

It must be obvious to the reader that our discussion of the hydrographic conformation of the Siberian sea must be based principally on the observations 1). In order to calculate the percentage of salt in the waters from their spec. gravity the latter must be referred to one common standard of temperature.

The advantage of choosing the point of 0° C for this purpose is so great, that I dare say, that every calculus based upon an other principle, instead of simplifying the matter, would prove to be an unnecessary complication.

In the sixth column of the following tables I, II, III & IV the temperatures of the water-samples *in situ* are recorded. We may see from this, that zero is the natural point of comparison, aye, almost the arithmetical mean of these numbers, the greater part of the temperatures being situated a few degrees above or below 0° C. The only exception is due to the warm water *of slight specific weight* from the surface, especially in the vicinity of the rivers. A few metres lower the usual temperature of the water, from — 2° to + 1° or + 2° C, prevails almost

[1] The original number, which was far greater, was reduced to this, every flask being rejected, which was not authentically signed or hermetically closed.

unexceptionally. I therefore, as already mentioned in the foregoing, consider 0° theoretically and practically to be the natural starting-point of all volumetric experiments connected with *arctic* hydrography. Consequently I intend to refer the observed numbers of specific gravity to the common standard $\frac{0^\circ}{+4^\circ}$ C, *notwithstanding the areometer was adjusted conformably to another, viz.* $\frac{+15^\circ}{+15^\circ}$ *C.*

The practical advantages will best be seen from the following [1] example.

Suppose the areometer to have attained its equilibrium in the water. Then the weight of the instrument is counterbalanced by the weight of the displaced volume of water — therefore it sinks in the fluid to a certain mark and not further. In order to obtain satisfactory results the glass body of the areometer must have the temperature of the fluid. Only in the case of the dilatation of the fluid being equal to that of the glass it would be immaterial to our purpose, at what temperature the measurement was performed, and the readings of the areometer could be used without any corrections whatever. The coefficient of dilatation of sea-water, as may be seen from the tables and plates of the foregoing paper, is highly dependant upon its amount of salt and likewise upon its temperature. At + 15° C and + 17°.5 C, the points, to which ordinarily areometric measurements are referred, the difference of the expansion of sea-water and of glass is very great and necessitates careful corrections, but at temperatures not exceeding a few degrees on either side of 0° C we may totally dispense with every correction depending on the temperature and still obtain numbers representing the specific gravity of the water with correctness in the fourth decimal.

The areometer used on the Vega and afterwards forwarded for my inspection was graduated so as to allow observations of 0.0001 of the specific gravity. For the present problems of hydrography this approximation is quite sufficient, because it enables us to calculate the saltness of the water unto 0.01 %.

[1] The following application of the principle of Archimedes could easily be disguised in a more mathematical garb. The advantage, however, of more generalized formulæ would not in the eyes of the author compensate for the loss of a plain manner of demonstration, intelligible to every student of hydrography.

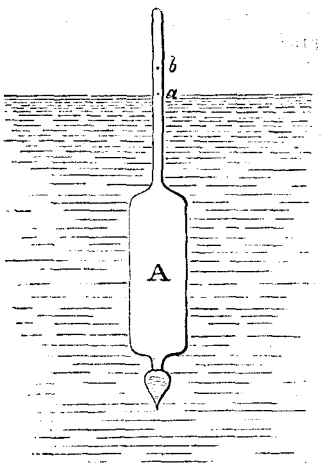
Suppose a glass vessel A measuring exactly 1 cc. to be immersed in sea-water of 1.0280 sp. gravity $\left(\frac{0^\circ}{+4^\circ}\right)$ at 0°. The weight of the vessel and likewise of the displaced volume of water must be exactly

$$1.0280 \text{ gr.}$$

If we substitute sea-water of 1.0279 sp. gr. instead of the original liquid, the weight of the displaced water (supposing the temperature constant and the instrument to occupy its former position), which tends to lift the vessel, is also 1.0279 gr. instead of 1.0280 gr. The difference

$$0.0001 \text{ gr.}$$

makes A sink to the next mark »b» on its scale, where it attains a new state of equilibrium.



Now we could produce exactly the same effect by raising the temperature of vessel and liquid simultaneously. The dilatation of 1 cc. of glass for every centigrade is

$$g = 0.00002753$$

(see the preceding paper). Consequently the volume of A at + 1° C is

$$1.00002753 \text{ cc.}$$

The volume of sea-water, which is displaced by A at + 1° C weighs

$$1.00002753 \times 1.0280 \frac{1}{x}$$

if x denotes the volume of 1 cc. of sea-water (of 0° C) at + 1° C. This weight, which tends to lift the instrument, is inferior to the weight of A (= 1.0280 gr.) if $x > 1.00002753$. The difference

$$1.0280 - 1.00002753 \frac{1.0280}{x} = \frac{1.0280}{x}(x - 1.00002753)$$

makes the vessel A sink deeper in the fluid. By equalling this quantity to the weight 0.0001 gr., which is necessary in order to produce an appreciable effect, i.e. make the instrument sink to the next mark, we may form an idea as to the influence exercised by the temperature, at which the areometric experiment is performed, upon the exactness of the specific gravity

$$0.0001 = \frac{1.0280}{x}(x - 1.00002754)$$
$$x = 1.000124$$

that is: only in case the coefficient of expansion of the water was $= 0.000124$ or greater, would the rise of temperature from 0° to + 1° C have any perceptible influence on the areometric determination of the spec. gravity. According to Ekmans determinations, which are graphically represented in plate 23, the volume at + 1° of 1 cc. of the sea-water in question is about

$$x = 1.000060$$

the coefficient of expansion between 0° and + 1° C being less than 0.000062. We would therefore obtain with our instrument precisely the same result at + 1° C as at zero, and the number found at + 1° C can be used indiscriminately to denote the specific gravity at 0°. Pursuing this calculus further we find, that we need not apply any correction on account of the temperature to

water of 1.0280 spec. gr. from a few degrees below 0° to + 3° C
» » 1.0170 » » » 0° . . . . . to + 5° C
» » 1.0090 » » » 0° . . . . . to + 9°.5 C.

I have tested the truth of this experimentally with the Vega areometer and 3 samples of sea-water of different spec. gravity 1.02819, 1.02548 and 1.01703 and found, that the instrument floats quite immovably in these waters between the aforesaid limits of temperature.

We may infer from this, that the freezing point of water theoretically and practically is the best adapted starting-point for areometric measurements of the specific gravity of all kinds of sea-water, *as the instrument in the vicinity of zero is freed from the disturbing influence of variations of temperature.* If experimenting a few degrees above or below zero, as was usually the case on board the Vega, we need not mind the temperature at all,[1] the readings on the scale of the areometers denote without corrections the true specific gravity at $\frac{0°}{0°}$ or $\frac{0°}{+4°}$ C — provided the instrument was originally adjusted to these standards of temperature. Otherwise, as in the case of the Vega areometer, which is graduated at $\frac{+15°}{+15°}$ C, a special correction is necessary, which can only be supplied by experiment. For the numbers representing the specific gravity

[1] Not even to keep it constant!

between 1.0280 and 1.0150 this was tolerably easy, because the areometer was at my disposal, but for the numbers of lower spec. weight, the case looked somewhat doubtful, as the instrument had been lost during the voyage.

From the collection of the Vega I selected 3 hermetically sealed water-samples, the specific weight of which had been tested during the expedition with the areometers. By means of the Sprengel pycnometer I ascertained their spec. gravity at $\frac{0^\circ}{+4^\circ}$ C.

Date.	Depth.	Temp.	Spec. gr. (areometer).	Spec. gravity (Sprengel pycn.).	Diff.
1878 6 & 7 Sept.	12 M.	— 1°.3 C	1.0238	1.02440 at $\frac{0^\circ}{+4^\circ}$ C	0.00060
1878 25 Aug.	14 »	+ 2°.3 C	1.0146	1.01487 » » »	0.00027
1878 26 Aug.	5 »	+ 1°.5 C	1.0104	1.01040 » » »	0.

I next proceeded to the examination of the areometer. I prepared 2 samples of salt-water by diluting sea-water from Beeren Island of 1.02829 sp. gr. with distilled water. The third sample is a solution of *NaCl* in water used by Mr. Åderman as standard by the determinations of the point 1.0150 at $\frac{+15^\circ}{+15^\circ}$ C on his areometers. The spec. weight of the solutions was ascertained on the same occasion with the Sprengel pycnometer at $\frac{0^\circ}{+4^\circ}$ C. The result of the comparison was

Temp.	Spec. gr. (areometer).	Spec. gravity (Sprengel pycn.).	Diff.
— 0°.26 C	1.0250	1.02548 at $\frac{0^\circ}{+4^\circ}$ C	0.00048
+ 0°.11 C	1.0182	1.01862 » » »	0.00042
+ 2°.1 C	1.0158	1.01603 » » »	0.00023

The corrections, which can be deduced from both series of experiments, agree tolerably well. In order to supply the numbers still wanting, I made some determinations with the standard areometer of Mr. Åderman, which had served as controlling instrument in the fabrication of the Vega areometers, thereby assisted by Mr. Åderman himself. The following table of corrections is constructed by means of these experiments.

In order to obtain the true specific weights at $\frac{0^\circ}{+4^\circ}$ C from the areometric determinations registered in the Vega journal, I have added

1th areom. [1.030 to 1.015].	0.0005 to the obs. numbers of sp. weight, which are higher than		1.0235
	0.0005 » » » » » » »	from 1.0235 to	1.0200
	0.0004 » » » » » » »	» 1.0200 »	1.0180
	0.0003 » » » » » » »	» 1.0180 »	1.0150
2d areom. [1.015 to 1.000].	0.0003 » » » » » » »	» 1.0150 »	1.0140
	0.0002 » » » » » » »	» 1.0140 »	1.0104
	0. » » » » » » »	» 1.0104 »	1.0000

The greatest discrepancy between the corrections (= 0.00012) is at 1.0240 and I think the computed spec. weights can be considered to be true within 0.0002. This ambiguity causes an uncertainty of 0.02 p. C. in the calculated amount of salt. These corrections, however, are strictly applicable only in case the original observation was made within those limits of temperature, where the correction from the temperature of the water-sample *in situ* to $\frac{0^\circ}{+4^\circ}$ C is less than 0.0001 and consequently can be omitted. The observations taken on board the Vega generally fulfill this condition, with the exception of the determinations in the winter months, which were executed in the cabin at a temperature of about + 10° or + 11° C. I have recorded these observations without any corrections at all. Happily the titrations of chlorine executed on board the Vega are sufficient to give one an idea of the saltness of these water-samples.

From the reduced spec. weights at $\frac{0^\circ}{+4^\circ}$ C the percentage of salt in the water-samples is computed by means of the coefficient 123.8. I deduced this number from the analyses of the following 4 water-samples.

Date 1878.	Depth meters.	Temp. *in situ*.	Spec. gravity observed.	Spec. gravity reduced $\frac{0^\circ}{+4^\circ}$ C.	*Cl* titration.	Coefficient = $\frac{\text{Amount of salt}}{\text{Amount of } Cl}$	*Salt* analysis.	Coefficient = $\frac{\text{Amount of salt}}{\text{Spec. gravity} - 1}$
Aug. 20	128	— 1°.3	1.0274	1.0279	1.920 %	1.803	3.463 %	124.1
Sept. 7	22	— 1°.2	1.0242	1.0247	1.691 %	1.799	3.044 %	123.2
Aug. 25	11	+ 2°.6	1.0151	1.0154	1.064 %	1.796	1.911 %	124.1
Aug. 31	7	+ 1°.7	1.0110	1.0112	0.763 %	1.814	1.384 %	123.6
					mean =	1.803	mean =	123.8

The Kara Sea.

Ten years have scarcely elapsed since the Kara Sea was opened anew to the investigations of science as well as to traffic and trade by the expeditions of Nordenskiöld in 1875 & 1876. In order to ensure the interests and lessen the risks of the Siberian trade, nothing could be more desirable than a thorough knowledge of the hydrographic conformation of the ice and the water-strata of this sea. I hope, that the present paper will contribute to prove the importance of further investigations on this subject. For, as I will try to show in the following, there are reasons to suppose, that the possibility of safe navigation in this sea depends not only upon the mere changes of wind and weather or upon the influence of a warmer or colder summer, but also upon the conformation of its deeper strata. Little as we know at present of this subject, we can not fail to recognize the prevailing difference in saltness and temperature between the upper and lower layers of the Kara Sea as the most characteristic feature of its hydrographic constitution. In the summer months a thin layer of warm and relatively fresh water covers the surface of the Kara Sea, while a few metres below there is found a stratum of salt water, cooled unto (and in some cases even *beyond*) its freezing point. I have already alluded to this fact in the introductory chapter of the foregoing paper.

In the eastern and northern parts of the Kara Sea this difference is greatest on account of the masses of fresh and warm water emerging from the æstuaries of the Obi and Yenisei rivers. On the hydrographic map [plate 24] I have inserted some temperatures observed by Captain Mack, one of the first explorers of the Kara Sea in 1871, showing that the influence of these rivers still prevails at the latitudes of Cape Nassau and the Oranie Islands. According to Mack, Johannesen a. O. the water here is so fresh as to be almost drinkable, whenever the sea is calm and unruffled by tempest, which however soon mingles the water of the thin superficial stratum with the ice-cold water from below. As for the eastern part of the sea, I can refer to the observations of the Vega-expedition from the 10th to the 19th of August, 1878. The temperature of the surface, which was + 8° or + 9° at Port Dickson, gradually diminished and at last sunk below 0° C north

of the Taimur bay, at 77° Lat. N. At the bottom, however, the temperature was found — 1° C immediately north of Port Dickson. On the sections III, IV, V we can trace the isotherm of — 0°.5 C, which continually rises, until it reaches the surface of the sea a few miles *east* of Cape Tcheljuskin. Thus the Kara Sea north and east of the rivers Obi and Yenisei is covered by a layer of almost fresh flowing water, which at 73° 30′ Lat. occupies the entire depth of the sea (about 20 metres), from the surface to the bottom showing a temperature of + 6° to + 9° C, and then becomes gradually thinner and colder as it spreads wider to the north. In the highest latitudes ever reached by ship in the Kara Sea its original character of a fresh water stream is still well recognizable. This stream contains the united water-masses of the Obi and the Yenisei. On section II we can trace the influence of each river separately in the temperature of the surface, which shows two maxima, one at 75°.30 Long. E. G. [the Obi-stream] = + 6°.8 C, the other south of Port Dickson [the Yenisei-stream] = + 8°.9 C. A close scrutiny of the numbers on the map reveals to us the fact, that each current deviates considerably to the east, an observation, which, as we will see further below, is equally applicable to all rivers of Siberia. [1]

[1] These conclusions, which I will try to prove subsequently from the observations of the Vega-expedition, are already foreshadowed in the program of the expedition, presented in July, 1877, by Professor Nordenskiöld to H.-M. the King [see: Vegas färd kring Asien och Europa, page 11 of the Swedish edition].

»Between Port Dickson and the Beli-Island a mighty current of fresh water flows in northerly direction. As the influence of the earth's rotation at these latitudes upon currents moving in the direction of the meridian is very considerable it must impart an easterly direction to the flowing water. Therefore the river-water from the Obi—Yenisei must flow as an isolated stream along the Taimur coast as for as Cape Tcheljuskin, where it becomes free to spread farther to the north-east or east. At 74° Lat. N, in calm weather, I have observed a temperature of + 9°.4 C of the water north of the embouchure of the Yenisei [17th Aug. 1875] and + 8° C north of the Obi River [10th Aug. that year]. As usual this stream from the south gives rise to an undercurrent of cold water, which by tempests mixes with the superficial layer and makes its temperature sink. Likewise it engenders a cold icy sidewise current at the surface in the opposite direction, which, on account of the earth's rotation, takes a westerly direction and makes its way between Cape Tcheljuskin and the north point of Novaya Zemlya towards the east side of that island. This is probably the cause of the heaping of the drift-ice at this coast in summer. According to my own experience and to the unanimous statement of the crews of the Norwegian whaling ships this ice melts away in autumn completely.»

The influence of the Yenisei river announces itself still more clearly by the diminishing saltness of the water. On both sides of the Sibiriakoff island the saltness was found to be only 0.49 p. c. while the sea-water a few miles further to the west, which consists of the outflow from the Gulf of Obi, contains three times as much. In accordance with this fact we find, that also in the North, at 74.30 Lat., the saltness increases and the temperature diminishes the more we approach the west side of the Kara Sea and *vice versa*. See section XI, which is based upon the observations from 1875 together with those from 1878. The fresh and warm water from the Yenisei thus surging up to the east against the Taimur coast naturally makes the level of the sea stand higher in summer at this shore, on account of the higher temperature and greater spec. volume of the water. This difference of niveau, together with the reaction from the coast upon the flowing water, makes its *uppermost layers* [1] take a westerly direction towards Novaya Zemlya, where its influence is felt by the diminution of the saltness [2] and the melting of the ice-floes, formed during winter in this part of the sea. The melting of the ice, which requires an incessant supply of warm water, can not however be completed before late in the summer, in August or September, when the current from the river system of the Obi and Yenisei has had due time to develop its full vigor and direct all the resources of solar heat stored up in its waters to a successfull attack upon the ice of the western basin of the Kara Sea. Until then the warm water current, instead of clearing the sea from ice and opening navigable water, will have the contrary effect, viz. to barricade the eastern entrance to the Matochkin Schar by pressing the rest of the pack ice against the coast of Novaya Zemlya.

The intensity of the surface current, just spoken of, is sufficiently attested by the fact, that the yacht Pröven, belonging to the first Swedish expedition in 1875, on its return from Port Dickson, the 21th August, was driven from its course from 74° 0′ Lat. 71° 0′ Long. to 75° 14′ Lat. 68° 45′ Long., i. e. more than one degree northward and two degrees westward

[1] The pressure of which is not, like that of the deeper ones, equilibrated by the adjacent water strata and consequently must overflow.

[2] The saltness at the surface in this part of the sea varies between 2.30 p. c. and 3.04 p. c. (see the map, plate 24).

by the stream, in spite of a heavy gale from N and NNW blowing the whole day.[1]

According to the observations of Captain Johannesen[2] in 1870, one part of the stream takes a southerly direction along the coast of Novaya Zemlya,[3] while another part seems to round the northern point of that island and penetrate further into the arctic sea.

»Nach Johannesen treffen an dem nordöstlichsten Ende von Nowaja Semlä zwei Strömungen zusammen, von denen die eine von Westen kommt, der ganzen West- und Nordküste des Landes folgend, eine Fortsetzung des Golfstromes, die andere von Süden, eine Fortsetzung der Gewässer des Obi und Jenissei.»

As already mentioned, there begins to appear immediately north of Port Dickson and the 74th parallel a layer of cold and salt water at the bottom of the sea beneath the warm and fresh river-water at its surface. This is proved sufficiently by the deep-soundings in section XI [on plate 26]. I consider this cold stratum to be an influx of water from the arctic ocean[4] caused by the mechanical reaction of the surface water *in motion* upon the deeper layers.

The principle of this phenomenon is discussed in the paper upon the general causes of the ocean-currents, by Prof. F. L. Ekman, who shows, that every river, which flows into the sea, gives rise to an under-current of sea-water directed towards its embouchure. If there is no bank at the mouth of the river, which stops the intercourse of the deeper strata, the salt water from the ocean also penetrates into the bed of the river. Mr. Ekman has minutely studied a very remarkable example of this kind of under-current, which occurs in the Göta-Elf at Gothenburg.

»Here an under-current of salt water from the Kattegatt enters the Elfsborg-fiord towards the mouth of the river, where the salter water rises higher and nearer to the surface the more the stream approaches the embouchure of the river, so

[1] See the report of Dr. Kjellman in the description of the Swedish expedition in 1875 to the Yenisei river [Bih. K. V. A. Handl. B. 4 N:o 1].

[2] »Die Erschliessung eines Theils des nördl. Eismeeres in 1870», Petermann, Mitth. 1870, see also: Kapitän Johannesen's Umfahrung v. Nowaja Semlä im Sommer 1870, ibid.

[3] The original map (manuscript) of Captain Johannesen's voyage, on which the direction of this stream is marked out, is in the possession of Prof. Nordenskiöld.

[4] See the programme of the expedition by Nordenskiöld l. c.

that for a certain depth the saltness appears to increase in the direction towards the latter. This under-current also penetrates into the bed of the river itself, where its saltness at a given level now no longer increases; but neither does it decrease in any sensible degree in the lowest strata. While the under-current thus proceeds at the bottom of the river, it is constantly reduced in thickness; indeed its thickness at the innermost point, at which I could distinctly observe it, was less than two feet, as may be seen from the following special series taken on the 7th August, 18,500 ft. above the mouth:

Depth in foot.	Saltness in grammes on 1000 cc. of the water.
0	0.23
6	0.35
8	0.40
10	4.33
12 (bottom)	20.02.

»The existence of the under-current was made visible by means of a sunken body, which was moved by it in a contrary direction to that of the upper-stream. The water of the under-current was clear and cold, whereas that of the superficial stream was very muddy, a further proof that the under-current continually received fresh supplies from the fiord.»

The author then proceeds to show, that the force, which urges the under-current of salt water from the Kattegatt towards the mouth of the Göta Elf, a distance of at least 12,000 metres, and thence 5 to 6 kilometres up the river, simultaneously raising the niveau of the salt water stratum, can not be ascribed to any difference of spec. gravity or hydrostatic pressure, etc... but is due to a *dynamic* phenomenon, which is caused solely by the *vis viva* of the surface current. He concludes:

»A river may therefore, as regards its effect upon the sea-water at its embouchure, be compared to a pump, the piston of which throws out as much water[1] as it sucks up from behind; the force, that sets the pump-piston in motion, here corresponds to the river-waters' *vis viva.*»

[1] This of course does not refer to the fresh river-water itself, which by its kinetic energy sets the whole system of currents in motion, but to that part of the salt water, which by adhesion or diffusion becomes intermingled with the river-water inside or outside its embouchure and, partaking of its motion, is spread further over the surface of the sea. This water naturally requires to be supplied by sea water either from the side or from below. Hence the under-current.

We must expect, that the united water-masses of the rivers Obi and Yenisei by their outflow into the sea must give rise to a whole system of »reaction-currents» of salt water from the sides and from below. The question naturally arises, whether there is to be found any influx of cold arctic sea-water in the bed of the Yenisei river, similar to that observed by Ekman in the Göta-Elf at Gothenburg.

A deep-sounding, made the 24th August, 1876, in the Yenisei river at Korepovskoi, has settled this question.

Depth in metres.	Spec. weight at $\frac{+15°}{+15°}$ C.[1]	Salt[1] in p. C.
0	1.0001	0.01
3.56	1.0001	0.01
7.12	1.0001	0.01
10.68	1.0001	0.01
16.02	not salter than the above samples.	

If we may judge from this example, the entrance of an under-current of arctic water into the Yenisei seems to be cut off by the shallowness of the water at its embouchure.

Instead, we have positive proofs of the existence of *side-currents,* caused by the influence of the flowing river-water from the Obi and Yenisei upon the adjacent ocean-water. In the section I on plate 24 is represented the constitution of the Kara Sea along the course of the Vega according to the deep-soundings registered in the journal from the 1st August, the day of departure from the Yugor Schar, until the 4th Aug. at 8 o'clock a. m., when she rounded the north-western point of the Beli-Ostrow island. The observations from the 2nd Aug. 8 p. m. to the 3rd Aug. 8 p. m. are of special interest as showing, that a stream of fresh and warm river-water emerges from the Malygin strait, ploughing a furrow in the surrounding deeper strata of sea-water, which is surged up on both sides as banks of cold and salt water — doubtlessly by the sidewise reaction of the flowing warm water upon the adjacent layers. By its influence the cold and salt water [temperature — 2° or — 1°.8, saltness = 3.44 p. C], which originally belongs to a far deeper stratum of the sea, as we may see from the foregoing deep-soundings in the section, is lifted nearer to the surface to a level, which water of this kind never reaches any where else in the whole Kara Sea. The natural conse-

[1] The determinations of the sp. w. and saltness are made by F. L. Ekman.

quence of this is also to be seen in the graphic illustration on section I, viz. that the ice at the surface is prevented from melting by the vicinity of the ice-cold water a score of metres below. Just at those places indicated in section I, where the isothermal lines of —2° and —1°.8 rise from the deep to within 20 metres from the surface, the Vega encountered vast ice-floes. In his report to Dr. Oscar Dickson Nordenskiöld writes: [1]

»I had long indulged in the hope of reporting, that we had arrived at the Yenisei without meeting with a single block of ice. At our arrival at the latitudes of Beli Ostrow, however, waves and wind died away in a manner, which unmistakably indicated the presence of ice. Subsequently we encountered vast floes of drift ice, which, however, were sufficiently scattered and corroded not to put any serious obstacles to the progress of our ship. East of the Beli Ostrow island we found the sea entirely free from ice».

From a close inspection of the following sections [f. ex. III, VII & VIII] we learn, that almost in every place, where the ships journal tells us of an encounter with the ice, there is a marked tendency in the cold-water isotherms to rise towards the surface. In the following I intend to return once more to this fact.

Petermann, [2] endeavouring to trace the isotherms of the surface water of the Kara Sea for July and August from the Norwegian observations in 1870, stated the fact, that the middle part of the sea between Novaya Zemlya and the Beli Ostrow island has the *lowest* temperature and is frequently covered with ice in summer. This observation has been confirmed by every expedition of later years.

»Die Norwegischen Beobachtungen weisen hier für die Monate Juli und August in den meisten Theilen des Meeres eine durchschnittliche Temperatur zwischen 2° und 4° auf, ganz besonders im südwestlichen und nordöstlichen Theile, dazwischen in der Mitte des Meeres zeigt sich eine Stelle unter 2°, in ihrer Mitte eine noch geringere, unter 0° und bis — 0°.8 . . . . .» Es erinnert dies an den Schmelzprocess des Wintereises unserer Teiche auf denen zuletzt nur noch in der Mitte eine Eisscheibe übrig bleibt.»

[1] Vega-expeditionens vetenskapliga iakttagelser, Vol. 1, page 12.

[2] Geogr. Mitth. 1871. Die Erschliessung eines Theiles des nördl. Eismeeres, 1870.

The voyage of Nordenskiöld with the Ymer in 1876 gives a good example of the usual condition of this part of the Kara Sea in the summer. After entering the Kara Sea by the Matochkin strait the ship was obliged to take a semi-circular route to the southward, in order to avoid the still unmelted ice-floes in the midst of the sea, and reached the open sea north of the Beli Ostrow island after a struggle of some days with the ice west and south-west of this island.

From the observations of the Vega-expedition, which had the good luck of crossing the Kara Sea without any serious hindrance from the ice, we see (section I), that the temperature at the surface sunk and the saltness increased on approaching the middle of the sea, where the iso-saline curve indicating 3.03 p. c. of salt rose to the surface. I consider this surging up of cold and salt water from below, in the midst of the Kara Sea, to be due to the sidewise action of the great current from the Obi and Yenisei upon the adjacent water, just as the relatively little stream from the Malygin strait makes the cold water rise like a bank on both sides, as shown in section I. This cold water naturally prevents the melting of the ice or delays it until very late in the summer.

Besides, if we consider the salt water at the bottom of the deep western basin of the Kara Sea along the coast of Novaya Zemlya [see the profile of the bottom in sect. I & XI] to be an indraught of arctic water from the Siberian sea — which is by no means improbable, since the fauna of this part of the sea is almost exclusively of arctic origin — we must admit, that the deeper layers of this water ought, by its own motion, to be surged up around the banks in the midst of the Kara Sea between the 73rd and the 74th parallel. Great masses of foundered ice-blocks are frequently heaped up on these banks, which therefore have been mistaken for real islands by some explorers.

Beside the Vega-observations there are a few previous deep-soundings made in 1875 and 1876 by Nordenskiöld and Kjellman in the deep basin of the Kara Sea along the coast of Novaya Zemlya and the Waigatch island, which are of great importance as showing, that the conformation of the deep water-strata is left completely undisturbed from one year to the other by the influence of the temporary changes of the climate, the seasons, the winds etc., which affect the upper layers.

(1) . . . . Lat. 75° 14′; Long. 68° 10′ (22th Aug. 1875).

Depth.	Temp.	
0 m.	+ 5°.2 C	[Kjellman]
222 m.	— 1°.4 C	»

(2) . . . . . Lat. 75° 40′; Long. 65° [25th Aug. 1875].

Depth.	Temp.	
0 m.	+ 1°.4 C	[Kjellman]
107 m.	— 1°.8 C	»

(3) . . . . Lat. 75° 30′; Long. 64° 40′ [24th Aug. 1875].

Depth.	Saltness.	
0 m.	3.07 p. C.	[anal. by Ekman].
107 m.	3.41 p. C.	[» » »].

(4) . . . . . Lat. 73° 34′; Long. 58° [31th Aug. 1875].

Depth.	Temp.	
0 m.	+ 3°.9 C	[Kjellman]
44.5 m.	— 1°.4 C	»
98 m.	— 1°.7 C	»

(5) . . . . Lat. 70° 35; Long. 61° 42′ [7th Aug. 1876].

Depth.	Saltness.	
0 m.	2.67 p. C.	[anal. by Ekman]
3.5 m.	2.66 »	» » » »
7.1 m.	3.03 »	» » » »
8.9 m.	3.26 »	» » » »
35.6 m.	3.33 »	» » » »
107 m.	3.42 »	» » » »

(6) . . . . . Lat. 70° 10′; Long. 61° [3rd Aug. 1875].

Depth.	Saltness.	
0 m.	2.73 p. C.	[anal. by Ekman]
107 m.	3.19 »	» » » »

(7) . . . . Lat. 70° 22′; Long. 61° 10′ [3rd Aug. 1875].

Depth.	Temp.	
0 m.	+ 3°.9 C	[Kjellman]
17.8 m.	+ 0°.9 »	»
53.4 m.	— 1°.5 »	»
106.8 m.	— 1°.9 »	»
178 m.	— 1°.9 »	»

(8) . . . . . Lat. 70° 56′; Long. 63° [4th Aug. 1875].

Depth.	Saltness [Ekman].	Temp. [Kjellman].
0 m.	2.98 p. C.	+ 4°.2 C
26.7 m.	3.23 » »	— 1°.1 C
63.3 m.	3.28 » »	— 1°.3 C
115.7 m.	3.32 » »	— 1°.7 C
160.2 m.		— 1°.7 C

Some of these observations from 1875 & 1876 were taken nearly at the same place as those of the Vega-expedition in 1878.

1875, 3rd Aug.		1876, 7th Aug.		1878, 1st Aug.		
Lat. 70° 22′; Long. 61° 10′		Lat. 70° 35′; Long. 61° 42′		Lat. 70° 22′; Long. 61° 42′		
Depth.	Temperature.	Depth.	Saltness.	Depth.	Saltness.	Temperature.
0 metres	+ 3°.9 C	0 metres	2.67 p. c.	0 metres	2.91 p. c.	+ 5°.1 C
		7.1 »	3.03 »			
		8.9 »	3.26 »	10 »	2.96 »	+ 0°.3 C
17.8 »	+ 0°.9 C					
		35.6 »	3.33 »			
53.4 »	— 1°.5 C			50 »	3.46 »	— 1°.6 C
106.8 »	— 1°.9 C	106.8 »	3.42 »			
178 »	— 1°.9 C					

It may be worth observing, that in 1875 as well as in 1878, which was by far the most favorable for navigation, the cold and salt water, represented by the iso-saline of 3 p. c., was found at a greater distance from the surface than in 1876, the most unfavorable year of the three.

1875, 4th August.			1878, 2nd August.		
Lat. 70° 55′; Long. 63°			Lat. 71° 3′; Long. 63° 46′		
Depth.	Temperature.	Saltness.	Depth.	Temperature.	Saltness.
0 m.	+ 4°.2 C	2.98 p. c.	0 m.	+ 4°.1 C	3.03 p. c.
			10 m.	+ 3°.9 C	3.17 p. c.
26.7 m.	— 1°.1 C	3.23 p. c.			
			50 m.	— 1°.9 C	3.45 p. c.
115.7 m.	— 1°.7 C	3.32 p. c.	115 m.	— 1°.9 C	3.49 p. c.
160.2 m.	— 1°.7 C				

Thus the constitution of the water in the deeper strata and at the bottom was found to be almost unchanged in 1875, 76 & 78, and yet we know that, from a nautic point of view, the condition of the Kara Sea was very different in 1876 from in 1875 or 1878.

I next wish to call attention to the important fact, that the same constitution of the deeper water-strata with regard to saltness and temperature also prevails in that part of the Barentz Sea west of the Waigatch and Novaya Zemlya, as may be seen from the following observations by the Swedish expedition, 1875, and the Holland, 1881.

Western entrance to the Matochkin strait; 13th July 1875.

Depth	Temperature.	Saltness [anal. by Ekman].
0 m.	+ 6°.1 C.	3.03 p. c.
23 m.	+ 4°.2 C	
35 m. (bottom)	——	3.38 p. c.

Ibid. Lat. 73° 5′; Long. 52° 14′; 6th August 1881.

Depth.	Temperature.	
0 m.	+ 3°.0 C	[Holland expedition]
64 m. (bottom)	— 0°.4 C	» »

Barentz Sea, west of Besimannaya Bay, Lat. 72° 43′; Long. 52°; 30th June 1875.

Depth.	Temperature.	Saltness [anal. by Ekman].
0 m.	+ 0°.6 C	3.27 p. c.
17.8 m.	— 1°.4 C	——
35.6 m.	— 1°.9 C	——
53.4 m.	— 1°.7 C	——
89 m. (bottom)	——	3.42 p. c.

Barentz Sea, Lat. 70° 49′; Long. 50° 47′; 26th July 1881.

Depth.	Temperature.	
0 m.	— 0°.8 C	[Holland expedition]
120 m. (bottom)	— 1°.4 C	» »

Some miles farther to the south-west a very different result was obtained

Barentz Sea, Lat. 70° 30′; Long. 49° 41′; 29th 1881.

Depth.	Temperature.	
0 m.	+ 5°.7 C	[Holland expedition]
96 m. (bottom)	+ 3°.8 C	» »

As may be seen from the hydrographic map [plate 24] a channel of deep water extends along the west side of the Waigatch island and the southern part of Novaya Zemlya, containing at its bottom water of about the same saltness and temperature as the deep western basin of the Kara Sea. The question naturally arises, if there be any communication between the cold and salt water at the bottom of the sea, east and west of the Novaya Zemlya and Waigatch islands. The only way, in which this might take place would be through the Kara strait, since the Yugor Shar is not deep enough to allow any intercourse between the deeper strata. Besides, direct observations show, that the water at the bottom of the Yugor strait has a temperature above zero.

Yugor Shar 2nd August 1875.

Depth.	Temperature.	Saltness [anal. by Ekman].
0 m.	+ 4°.2 C	2.65 p. c.
5.3 m.	+ 1°.7 C	——
35 m. (bottom)	+ 0°.6 C	3.24 p. c.

In want of direct determinations of the saltness and temperature of the bottom-strata in the Kara strait, I can only try to settle this question by referring to the discovery of Lütke,[1] that a stream of cold water is flowing constantly from the Kara strait northward along the western coast of Novaya Zemlya. Middendorff writes:[2]

»An die Westküste Novaja Semlä's prallt der Golfstrom nicht unmittelbar an, sondern er wird von dem Lande durch einen beispielsweise 60 nautische Meilen breiten Küstenstreif kalten Wassers (wir beobachteten 6°.1, bis 4°1/2) geschieden, welches einer tiefen Thalfurche im Meeresgrunde entspricht, von der wenigstens die Südhälfte Nowaja Semlä's umgürtet wird.»

Strange to say, the Vega-observations from the 29th and 30th July, 1878, seem to bear out quite an opposite result. In the following table the observations of the Vega-expedition from the 25th July, the day of departure from Magerœ, until the 30th July, when she anchored at Chabarova in the Yugor strait, are enumerated.

[1] Viermalige Reise durch das nördliche Eismeer.

[2] Der Golf-strom ostwärts vom Nordkap, Geogr. Mitth. 1871. At the western side of this deep-water channel, Middendorf found the temperature at the bottom to be + 0°.8; at the eastern (at Kostin Schar) = + 2°.4 R.

Table I.

Hydrographic observations during the first part of the voyage, from Norway to the Yugor Shar, 25th July to 1st August, 1878.

Date.	Time of the day.	Lat. N.	Long. E. G.	Depth. Metres.	Temp. C.	Spec. grav. observed.	Spec. grav. red: to $\frac{t}{+4}$	p. c. of salt.
1878								
July 25	8 p. m.	Magerœ		0	+ 6°.6	1.0270	1.0275	3.40
» 26	0 a. m.	71° 3′	26° 41′	0	+ 7°.2	1.0270	1.0275	3.40
	4 a. m.	71° 16′	28° 6′	0	+ 7°.4	1.0280	1.0285	3.52
	8 a. m.	71° 14′	29° 40′	0	+ 7°.2	1.0268	1.0273	3.38
	noon	71° 11′	31° 12′	0	+ 6°.8	1.0268	1.0273	3.38
	4 p. m.	71° 9′	33° 1′	0	+ 6°.6	1.0272	1.0277	3.43
	8 p. m.	71° 12′	34° 33′	0	+ 6°.0	1.0266	1.0271	3.35
» 27	0 a. m.	71° 15′	35° 51′	0	+ 5°.6	1.0274	1.0279	3.45
	4 a. m.	71° 18′	37° 26′	0	+ 5°.4	1.0270	1.0275	3.40
	8 a. m.	71° 22′	38° 54′	0	+ 5°.5	1.0274	1.0279	3.45
	noon	71° 24′	40°	0	+ 5°.8	1.0268	1.0273	3.38
	4 p. m.	71° 28′	41° 9′	0	+ 6°.2	1.0276	1.0281	3.48
	8 p. m.	71° 30′	42° 6′	0	+ 5°.8	1.0270	1.0275	3.40
» 28	0 a. m.	71° 33′	43° 30′	0	+ 5°.8	1.0270	1.0275	3.40
	4 a. m.	71° 34′	44° 50′	0	+ 5°.2	1.0270	1.0275	3.40
	8 a. m.	71° 36′	45° 56′	0	+ 4°.7	1.0268	1.0273	3.38
	noon	71° 37′	47° 1′	0	+ 4°.8	1.0264	1.0269	3.33
	4 p. m.	71° 35′	48° 32′	0	+ 4°.8	1.0266	1.0271	3.35
	8 p. m.	71° 37′	50° 6′	0	+ 5°.2	1.0266	1.0271	3.35
» 29	0 a. m.	71° 33′	51° 36′	0	+ 5°.4	1.0260	1.0265	3.28
	4 a. m.	71° 14′	52° 13′	0	+ 5°.3	1.0258	1.0259	3.20
	8 a. m.	70° 57′	52° 45′	0	+ 6°.4	1.0245	1.0250	3.09
	noon	70° 43′	53° 7′	0	+ 7°.4	1.0240	1.0245	3.03
	4 p. m.	70° 32′	54° 13′	0	+ 9°.4	1.0240	1.0245	3.03
	8 p. m.	70° 20′	55° 24′	0	+ 7°.2	1.0235	1.0240	2.97
» 30	0 a. m.	70° 9′	56° 27′	0	+ 7°.6	1.0229	1.0234	2.83
	4 a. m.	70° 3′	57° 10′	0	+ 8°.2	1.0230	1.0235	2.90
	8 a. m.	69° 51′	58° 16′	0	+ 7°.5	1.0218	1.0223	2.76
	noon	69° 46′	59° 7′	0	+ 6°.4	1.0246	1.0251	3.10
	4 p. m.	69° 35′	61° 36′	0	+ 6°.4	1.0240	1.0245	3.03
	8 p. m.	Chabarova		0	+ 6°.0	1.0243	1.0248	3.07
» 31	0 a. m.	»		0	+ 5°.8	1.0250	1.0255	3.15
	4 a. m.	»		0	+ 4°.8	1.0251	1.0256	3.16
	8 a. m.	»		0	+ 5°.2	1.0253	1.0258	3.18
	noon	»		0	+ 4°.4	1.0255	1.0260	3.21
	4 p. m.	»		0	+ 6°.4	1.0246	1.0251	3.10
	8 p. m.	»		0	+ 7°.0	1.0230	1.0235	2.90
Aug. 1	0 a. m.	»		0	+ 4°.8	1.0260	1.0265	3.28
	4 a. m.	»		0	+ 4°.6	1.0260	1.0265	3.28
	8 a. m.	»		0	+ 4°.8	1.0255	1.0260	3.21
	noon	»		0	+ 6°.0	1.0250	1.0255	3.15

On the map [plate 24] we can follow the variations of temperature still more easily. From the description of Middendorff we ought to have expected, that the Vega, after a traverse of some days through the Barentz sea in relatively warm water, would have encountered a broad stripe of cold water 60 or 70 nautic miles from the coast of Novaya Zemlya. Instead the temperature rose from + 4°.8 C to + 9°.8 and + 6°.4 during the voyage along the coast of Novaya Zemlya and Wajgatch on the 29th and 30th July.

It is quite impossible *in this case* to ascribe the high temperatures of this part of the sea to the influence of the Gulf-stream, as Middendorff is prone to do, because the numbers registered in the journal on the 29th and 30th July are *higher* than the temperature of the western part of the Barentz sea. Besides, we see from the table, *that the saltness of the water diminishes as its temperature increases.* This effect can certainly not be due to the Gulf-stream.

The most plausible explanation seems to be, that the warm water at the surface is due to the outflow from the Russian rivers, especially the Petchora, together with the creeks and rivulets on Novaya Zemlya [1] and Waigatch.

We can gain an idea as to the powerful influence of the waters from the Petchora upon the surrounding sea from some observations of the Holland expedition in 1881.

Immediately north of the Timan coast, at 69° 6′ Lat. N. 55° 11′ Long. on the 31th July 1881, the temperature of the water at the surface was + 6°.0 C [spec. weight = 1.0155] and a little farther to the north, Lat. 69° 23′, Long. 54° 50′ (the following day), it was found = + 9°.1 C [spec. weight = 1.0100].

But the outflow from the Petchora, like that of rivers in general, does not extend its warming influence to the lower strata. The Holland expedition found the temperature at the bottom on the banks outside the mouth of the Petchora [2] = + 0°.5 C (depth = 9 m.) and = — 0°.8 C (depth = 29 m.).

We can trace the warming and diluting effect of the outflow from the Petchora, and adjacent rivers at the coast,

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[1] The remarkably rapid effect of the summer heat upon the ice and snow in these places has attracted the attention of several travellers as Middendorff, Nordenskiöld a. O.

[2] »De laag warm en vrij zœt water was dus zeer dunn en bestond zeker hoofzakelijk uit water van de Petshora, die hier in de nabijheid in zee valt.» Verslagen omtrent den vierden Tocht van de Willem Barentz naar de ijszee in den zomer van 1881, page 48.

upon the sea to the north and especially to the east. According to the Norwegian observations in July, August and September, 1870, the sea-water along the west coast of Wajgatch and also in the south-eastern part of the Kara Sea had a *brown colour and possessed an exceedingly high temperature*[1] *(+ 9° C to + 11° C).* This superficial layer of warm water together with the frequent rain-fall and the thunder-storms, which often occur here in summer, must have the effect of accelerating the melting of the ice and the opening of the southern entrances of the Kara Sea to navigation. Ordinarily the Yugor strait seems to be more free from ice than the Kara strait. The cause of this can be twofold:

1) The Yugor strait is, according to its situation, more exposed to the influence of the river water from the coast;

2) There is no under-current of cold water at the bottom of this strait, which could tend to neutralize the heat of the superficial stratum of warm water.

The high temperature of the sea, found by the Vega-expedition the 29th and 30th of July, 1878, may thus be due to a superficial layer of warm water, which occasionally overflows[2] the cold water emerging from the Kara strait. A single deep-sounding would have sufficed to settle this question!

From the Matochkin strait we have discrepant statements.[3]

[1] See the map: »Die Temperaturverhältnisse im Karischen Meere im Sommer 1870.» Geogr. Mitth. 1871.

[2] In the Yugor Shar the surface current changes its direction with the winds and the tides. According to the statements of Swedish and Norwegian travellers the same observation is due also to the Kara strait. Krusenstern, however, in 1860 and Ssidoroff in 1869 found that the water in this strait flowed steadily from west to east.

Russische Nordpolar-Forschungen 1869 & 1870. Geogr. Mitth. 1870.

[3] The Swedish expedition in 1875 found:

Western entrance to the Matochkin, 13th July.		Middle part of the strait, 8th Sept.	
Depth.	Temperature.	Depth.	Temperature.
0 m.	+ 6°.1 C	0 m.	+ 6°.0 C
21.3 m.	+ 4°.2 C	12.4 m.	+ 5°.5 C
23.1 m.	+ 4°.2 C		

From these observations Nordenskiöld concluded (in accordance with former investigators), »that a warm stream, probably a branch of the Gulf-stream, fills the entire depth of this sound». In the report of the Holland expedition in 1881, however, we read the following lines (page 63): »Wij namen eene temperatuurwaarneming op verschillende diepten [in the Matochkin strait near the hut of Rosmyslow]. Wij kregen daarmede geheel andere uitkomsten dan Nordenskiöld in 1875 aan bord van de Pröven gevonden had. Op den bodem (37 vaam) was de temperatur nu — 0°.9, op

It seems probable that the direction of the upper- and under-current in this strait is variable and depends upon causes, which highly require repeated investigation.

The investigation of the conditions of the Kara Sea and adjacent parts of the arctic ocean is of course a very complicated problem to the metereologists as well as to the hydrographers. The climate of the north Asiatic continent in winter is excessively cold and even the sudden change of temperature in the summer months, witnessed by the rise of the June and July isotherms, would be insufficient to break the icy boundaries of the sea, if the warm water from the Siberian rivers did not conduce to the same effect. Therefore the condition of the Kara Sea in August and September, the only season adapted for navigation, must to a great part be dependent upon the amount of sunshine and rain-fall bestowed in the course of spring and summer upon countries far away from the Yalmal and Taimur coasts.

Moreover the effect of the heat of the river-water upon the sea is limited to its surface, where it is absorbed in the melting of the ice. From a few metres beneath the ice to the bottom, there is an indraught of salt water from the arctic sea north of Siberia, which is sufficiently cold [— 1°.3 unto — 1°.7 or — 1°.9 C] to prevent the melting of the ice and even to make the inundating superficial stratum of brackish water give up ice, if it does not constantly receive fresh supply from the rivers.

An excellent illustration of this statement is the curious experiment mentioned by Nordenskiöld in his work »Vegas färd kring Asien och Europa». If a vessel filled with water from the surface of the Kara Sea is immersed deeper into the sea, then the water in the vessel soon freezes into ice.

Moreover Nordenskiöld asserts that the brackish water at the surface acts like poison upon most part of the animals living below.

The mechanic reaction of the flowing water makes the cold water below rise nearer to the surface in some parts of the Kara Sea, *which accordingly are found to be more impracticable*

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30 vademen — 1°.5, op 20 vademen — 1°.4, op 10 vademen — 0°.4 en aan de oppervlakte + 0°.6 .... De bovenstroom liep hier onafgebroken om de west, doch door eene waarneming met den duiker bleek, det het onderwater òf om de oost liep òf wel stationair bleef. Heet voortdurend om de west loopen van den stroom in de Matoschkinsharr, waarvan Lutke en andere spreken, hadden wij vroeger, d. i. in 1878 en 1879, niet kunnen waarnemen.»

to navigation than otherwise. This circumstance alone is sufficient to make a hydrographic survey [1] of the Kara Sea highly desirable; for in spite of the changeable condition of the upper strata, there is every reason to expect that the conformation of the deeper layers will be found to be far more constant and regular.

Another circumstance, which must exert the greatest influence upon the condition of the Kara Sea in summer is *the direction of the winds.* By *southern winds* the superficial layer of warm water, flowing from the rivers northwards, which contains the necessary amount of heat for the liquefaction of the ice, must be accelerated and spread further to the north or north-east over the arctic sea and thus withdrawn from acting upon the ice. On the other hand we can infer, that winds from the north or north-east must have the effect of retaining the greatest part of the flowing water within the limits of the Kara Sea.

It can be proved that the main direction of the winds in August during the years most favorable to navigation was N and NNE.

In 1870, August and September, the Kara Sea was found almost free from ice, with the aforesaid exception of the middle part of the sea between Novaya Zemlya and the Yalmal penninsula. From the 1th of August until the 9th September Captain Johannesen [2] cruised in the northern parts of the sea without meeting with any hinderance from the ice.

»Bis zur nordöstlichen Küste von Nowaja Semlä hatte das Meer eine braune und grüne Farbe bewahrt, hier wurde es blau. Am Lande [3] fanden sich einzelne kleine Eisstreifen,

[1] Although a special hydrographic survey of the Kara- and the Barentz Sea would give most useful and interesting results, I think, that frequently repeated deep-soundings in the course of a series of years ought to give a still more valuable and generalized account of the hydrographic conformation of this part of the ocean, as we might thereby perhaps get a cue to the *periodic variations* in the state of this sea. As there is no hope of getting a special expedition started every year for scientific purposes, I think the best thing for the present would be to entrust an isolating deep-water-bottle of Ekman's model, with the necessary instructions for use, to the care of the captain or navigating officer of every commercial steamer bound for the Yenisei, who is willing to take the trouble. The price of the instrument is moderate (£ 10 or there-abouts), it requires no special arrangements and performs admirably.

Kapitän Johannesen's Umfahrung von Nowaja Semlä in Sept. 1870. Geogr. Mitth. 1871.

[3] North, east part of Novaya Zemlya, between Cape Mauritius and Cape Vlissingher.

welche warscheinlich von den nordöstlichen und nördlichen Winden, die den ganzen August hindurch geweht hatten, herbeigeführt sein mochten.»

The following extract from the meteorological journal of the Nordenskiöld expedition in 1875 will give an idea of the prevailing direction of the winds in August that year, which was, as is well remembered, uncommonly favorable for navigation.

In calculating the following results I have left out of consideration all observations, wherein the force of the wind is denoted by the numbers 1, 2 & 3 of the scale, because I consider such winds to be too feeble to exert any remarkable influence upon ocean-currents.

From the 1th August until the 3rd Sept., the wind blew:

from	NW	during	8	hours	with	an	average	strength	of 8
»	N	»	36	»	»	»	»	»	» 7
»	NNE	»	40	»	»	»	»	»	» 5
»	NE	»	4	»	»	»	»	»	» 4
»	SW	»	12	»	»	»	»	»	» 6
»	SSW	»	8	»	»	»	»	»	» 6
»	WSW	»	4	»	»	»	»	»	» 5
»	SE	»	8	»	»	»	»	»	» 5.

The following transumt is taken from the observations of the Vega-expedition, 1st to 19th Aug., 1878.

wind	from	N	during	24	hours	with	an	average	strength of 5
»	»	NNE	»	4	»	»	»	»	» 5
»	»	NE	»	4	»	»	»	»	» 5
»	»	ENE	»	16	»	»	»	»	» 5
»	»	NW	»	8	»	»	»	»	» 5
»	»	E	»	»	»	»	»	»	» 8.

Still there is a remarkable item to the above rule in the following circumstance. The aforesaid winds from N and NE, although highly effective in clearing the *main part* of the Kara Sea from ice, may still be a hindrance to navigation by drifting the remainder of the ice towards the shore of Waigatch and thereby closing the Kara- and the Yugor strait until late in summer. Nordenskiöld ascribes[1] the delay caused by the ice, on his second voyage to the Yenisei in 1876 with the Ymer, to the cold weather and the prevailing unfavorable winds from E and NE. But we can on the other side ascribe

[1] Vegas färd kring Asien och Europa, Swedish Edition, page 15.

to the influence of the same winds from N and NE the fact, that the Ymer, on her return from the Yenisei the 1st September, crossed the whole Kara Sea from Port Dickson to the Matotchkin Shar and even made a long detour to the North up to 75° 30′ Lat. without meeting with any obstruction from the ice.[1]

In the following table are registered all observations concerning the temperature, saltness and spec. gravity of the sea-water at various depths, which were made during the traverse of the Kara Sea from the 1st to the 20th of August, 1878. Of the chlorine titrations one part is made on board the Vega by various members of the expedition. The numbers thus obtained are signed »V». Another part (denoted by »P») is made by the author on water-samples from the collections of the expedition. On the hydrographic maps [plates 24, 25, 26] the results of the investigation is graphically represented by means of the sections I—XI. These sections, which show the depth of the sea and the conformation of its deeper water-strata, correspond exactly to the track of the Vega represented by the black line on the map. Neither the tables nor the maps need any further explanation. Every date, which is necessary in order to initiate the reader into the hydrographic state of the sea, can easily be found either in the tables I, II, III & IV or by a comparison of the map and the sections. My sole object has been to arrange the matter in a manner adapted to study and inspection. The graphic illustrations as well as the description on the foregoing pages apply strictly to the actual state of things at the time of observation i. e. August & September, 1878. I am well aware, that the conditions of all parts of the Siberian ocean and the Kara Sea most of all are liable to great variations from one year to another. This is especially the case with the conformation of the upper strata, therefore the temperatures and sp. weights observed in the water at the surface are of far less importance than the observations from the deeper layers.

[1] . . . Nous gouvernâmes alors, comme l'année passée, au Cap Middendorff. La mer était d'abord entièrement exempte de glace; ce ne fut qu'en arrivant tout près de la côte orientale de la Nouvelle-Zemble, par 75° 30′ Lat. N. que nous aperçûmes un banc de glace rongée, qui s'étendait le long de la côte vers le Matotchkin. . . . Si en quittant le port Dickson, nous étions allés directement au Matotchkin en doublant l'île Blanche, nous n'aurions certainement pas rencontré un seul glaçon. [Expéditions Suédoises de 1876 au Yéniséi]. Rapport de M. le professeur Nordenskiöld à M.M. Oscar Dickson et Alexandre Sibiriakoff.

Table 2.

Hydrographic observations during the second part of the voyage, from the Yugor Shar [1st Aug. 1878] to Cape Tcheljuskin [20th Aug. 1878]. See the map, plate 24, sections I, II, III & IV.

Date 1878.	Time of the day.	Lat.	Long. E. G.	Depth in metres.	Temperature t° C.	Spec. gravity observed.	Spec. gravity reduced to $\frac{t^\circ}{+4^\circ}$ C or $\frac{0^\circ}{+4^\circ}$ C.	Percent of Cl in 100 gr. water.	Salt in percent.
Aug. 1	0 a. m.	Chabarova		0	+ 4°.7	1.0260	1.0265		3.28
	4 a. m.	»		0	+ 4°.6	1.0260	1.0265		3.28
	8 a. m.	»		0	+ 4°.7	1.0255	1.0260		3.21
	noon	69° 56′	60° 42′	0	+ 5°.9	1.0250	1.0255		3.15
	4 p. m.	70° 14′	61° 21′	0	+ 4°.3	1.0220	1.0225		2.78
	8 p. m.	70° 23′	61° 42′	0	+ 5°.2	1.0230	1.0235	1.55 V.	2.90
				10	+ 0°.4	1.0234	1.0239		2.96
				50	— 1°.5	1.0275	1.0280	1.90 V.	3.46
» 2	0 a. m.	70° 33′	62° 18′	0	+ 5°.9	1.0226	1.0231		2.85
	4 a. m.	70° 50′	63° 10′	0	+ 5°.7	1.0230	1.0235		2.91
	8 a. m.	71° 6′	63° 59′	0	+ 4°.1	1.0240	1.0245		3.03
				10	+ 4°.0	1.0243	1.0248		3.07
				50	— 1°.0*	1.0274	1.0279		3.45
				115	— 0°.9*	1.0277	1.0282		3.49
	noon	71° 23′	64° 32′	0	+ 3°.6	1.0245	1.0250		3.10
				10	+ 2°.1	1.0248	1.0253		3.13
				25	— 0°.2	1.0261	1.0266	1.80 V.	3.27
				50	— 2°.4	1.0270	1.0275		3.40
				122	— 2°.0	1.0277	1.0282		3.49
	4 p. m.	71° 41′	65° 16′	0	+ 3°.7	1.0240	1.0245		3.03
	8 p. m.	72° 6′	66° 10′	0	+ 3°.5	1.0240	1.0245		3.03
				25	— 2°.2	1.0270	1.0275		3.40
				50	— 2°.4	1.0274	1.0279		3.44
				150	— 2°.3	1.0277	1.0282		3.49
» 3	0 a. m.	72° 19′	66° 37′	0	+ 2°.4	1.0220	1.0225		2.78
	4 a. m.	72° 32′	67° 30′	0	+ 2°.0	1.0260	1.0265		3.28
	8 a. m.	72° 42′	68° 02′	0	+ 2°.9	1.0234	1.0239		2.95
				15	+ 1°.3	1.0237	1.0242		2.99
				30	+ 1°.2	1.0240	1.0245		3.03
	noon	73°	68° 14′	0	+ 2°.5	1.0201	1.0206		2.54
				10	+ 0°.8	1.0242	1.0247		3.06
				22	— 2°.0	1.0273	1.0278		3.44
	4 p. m.	73° 23′	68° 32′	0	+ 1°.8	1.0180	1.0183		2.26
	8 p. m.	73° 28′	68° 18′	0	+ 1°.0	1.0140	1.0143	1.01 V.	1.77
				10	— 0°.4	1.0210	1.0215	1.47 V.	2.66
				20	— 1°.8	1.0270	1.0275	1.84 V.	3.40
» 4	0 a. m.	73° 42′	68° 50′	0	+ 2°.1	1.0148	1.0150		1.85
	4 a. m.	73° 57′	68° 39′	0	+ 2°.5	—	—		—

Date 1878.	Time of the day.	Lat.	Long. E. G.	Depth in metres.	Temperature t° C.	Spec. gravity observed.	Spec. gravity reduced to t° C or +4° C.	Percent of Cl in 100 gr. water.	Salt in percent.
Aug. 4	8 a. m.	73° 50′	70° 12′	0	+ 4°.7	1.0101	1.0101		1.25
				10	— 0°.4	1.0220	1.0225		2.78
				20	— 0°.8	1.0235	1.0240		2.97
	noon	74° 9′	70° 41′	0	+ 3°.5	—	—		—
	4 p. m.	74° 4′	72° 0′	0	+ 5°.2	—	—		—
	8 p. m.	74° 0′	73° 14′	0	+ 5°.2	—	—		—
» 5	0 a. m.	73° 57′	74° 26′	0	+ 6°.2	1.0087	1.0087		1.07
	4 a. m.	74° 3′	73° 58′	0	+ 6°.4	—	—		—
	8 a. m.	74° 9′	73° 56′	0	+ 5°.9	1.0089	1.0089		1.10
	noon	74° 9′	75° 15′	0	+ 6°.8	1.0098	1.0098		1.20
	4 p. m.	73° 59′	76° 36′	0	+ 5°.4	1.0081	1.0081		1.09
	8 p. m.	73° 52′	77° 42′	0	+ 7°.6	1.0084	1.0084		1.04
» 6	0 a. m.	73° 43′	78° 50′	0	+ 8°.2	1.0044	1.0044		0.54
	4 a. m.	73° 36′	79° 42′	0	+ 6°.6	1.0040	1.0040		0.49
	8 a. m.	73° 29′	80° 36′	0	+ 8°.2	1.0033	1.0033		0.40
	noon	Port Dickson		0	+ 9°.4	1.0035	1.0035		0.43
	4 p. m.	»		0	+ 9°.4	1.0015	1.0015		0.18
	8 p. m.	»		0	+ 8°.6	1.0026	1.0026		0.32
» 7	0 a. m.	»		0	+ 8°.3	1.0027	1.0027		0.33
	4 a. m.	»		0	+ 8°.8	1.0026	1.0026		0.32
	8 a. m.	»		0	+ 8°.6	1.0036	1.0036		0.44
	noon	»		0	+ 8°.8	1.0033	1.0033		0.40
	4 p. m.	»		0	+ 9°.2	1.0035	1.0035		0.43
	8 p. m.	»		0	+ 8°.8	1.0027	1.0027		0.33
	0 a. m.	»		0	+ 8°.0	1.0029	1.0029		0.36
	4 a. m.	»		0	+ 7°.4	1.0027	1.0027		0.33
	8 a. m.	»		0	+ 8°.8	1.0034	1.0034		0.42
	noon	»		0	+ 9°.0	1.0031	1.0031		0.38
	4 p. m.	»		0	+ 8°.6	1.0026	1.0026		0.32
	8 p. m.	»		0	+ 8°.8	1.0028	1.0028		0.35
» 9	0 a. m.	»		0	+ 8°.9	1.0026	1.0026		0.32
	4 a. m.	»		0	+ 9°.0	1.0021	1.0021		0.25
	8 a. m.	»		0	+ 9°.0	1.0024	1.0024		0.30
	noon	»		0	+ 9°.4	1.0038	1.0038		0.47
	4 p. m.	»		0	+ 9°.1	1.0031	1.0031		0.38
	8 p. m.	»		0	+ 9°.3	1.0021	1.0021		0.25
		»		9	+ 9°.0	1.0025	1.0025		0.31
» 10	0 a. m.	»		0	+ 10°.0	1.0023	1.0023		0.28
	4 a. m.	»		0	+ 10°.0	1.0023	1.0023		0.28
	8 a. m.	»		0	+ 8°.8	1.0047	1.0047		0.58
	?	73° 52′	81° 40′	0	+ 6°.5	1.0075	1.0075	0.51 V.	0.92
				15	+ 1°.7	1.0195	1.0199		2.44
				35	— 1°.0	1.0260	1.0265	1.83 V.	3.28
	noon	73° 48′	82° 7′	0	+ 8°.7	1.0080	1.0080		0.98
	4 p. m.	74° 5′	82° 29′	0	+ 7°.9	1.0085	1.0085		1.04
	?	74° 8′	82° 12′	0	+ 8°.0	1.0096	1.0095	0.58 V.	1.17

Date 1878.	Time of the day.	Lat.	Long. E. G.	Depth in metres.	Temperature t° C.	Spec. gravity observed.	Spec. gravity reduced to t° C or + 4° C.	Percent of Cl.	Salt in percent.
Aug. 10				15	+ 1°.2	1.0205	1.0210	1.42 V.	2.60
				35	— 1°.0	1.0266	1.0271		3.35
	8 p. m.	74° 18′	82° 30′	0	+ 8°.0	1.0080	1.0080	0.56 V.	0.99
				20	— 0°.5	1.0233	1.0238	1.60 V.	2.94
				40	— 1°.4	1.0261	1.0266	1.81 V.	3.29
» 11	0 a. m.	74° 32′	83° 52′	0	+ 8°.2	1.0086	1.0086		1.06
	4 a. m.	74° 44′	84° 52′	0	+ 8°.0	1.0079	1.0079		0.98
	8 a m.	74° 51′	85° 03′	0	+ 8°.2	1.0092	1.0092		1.13
				10	+ 1°.0	1.0133	1.0135		1.67
	noon	»	»	0	+ 8°.2	1.0091	1.0091		1.12
	4 p. m.	»	»	0	+ 7°.2	1.0093	1.0093		1.15
	8 p. m.	75° 6′	85° 52′	0	+ 6°.0	1.0109	1.0110	0.75 V.	1.36
				10	+ 5°.5	1.0119	1.0121		1.49
				18	— 0°.5	1.0240	1.0245	1.67 V.	3.03
» 12	0 a. m.	75° 21′	86° 0′	0	+ 5°.4	1.0123	1.0125		1.54
	4 a. m.	75° 40′	86° 18′	0	+ 3°.6	1.0131	1.0133		1.65
	8 a. m.	75° 45′	87° 46′	0	+ 3°.2	1.0182	1.0186	1.26 V.	2.30
				10	— 0°.4	1.0224	1.0230	1.44 V.	2.84
	noon	75° 57′	88° 40′	0	+ 3°.6	1.0193	1.0197		2.44
	4 p. m.	76° 7′	90° 20′	0	+ 1°.2	1.0180	1.0184		2.27
				15	+ 0°.2	1.0234	1.0239	1.63 V.	2.96
				30	— 1°.1	1.0261	1.0266	1.82 V.	3.29
	8 p. m.	75° 56′	91° 0′	0	+ 0°.8	1.0110	1.0110		1.36
» 13	0 a. m.	75° 55′	91° 35′	0	+ 2°.2	1.0185	1.0189		2.34
	4 a. m.	76° 7′	92° 20′	0	+ 2°.2	1.0170	1.0174		2.15
	8 a. m.	76° 2′	94° 30′	0	+ 2°.1	1.0197	1.0201	1.36 V.	2.49
				38	— 1°.0	1.0263	1.0268		3.31
	noon	76° 18′	94° 3′	0	+ 2°.0	1.0197	1.0201		2.49
	4 p. m.	76° 19′	94° 10′	0	+ 0°.7	1.0165	1.0169		2.09
	8 p. m.	»	»	0	+ 1°.2	1.0060	1.0060		0.76
» 14	0 a. m.			0	+ 0°.8	1.0070	1.0070		0.86
	4 a. m.			0	+ 0°.4	1.0065	1.0065		0.80
	8 a. m.	76° 8′	94° 58′	0	+ 0°.6	1.0078	1.0078		0.97
				30	— 1°.3	1.0258	1.0263	1.81 V.	3.25
				70	— 1°.4	1.0261	1.0266	1.84 V.	3.29
	10 a. m.	76° 18′	95° 35′	0	+ 0°.9	1.0094	1.0094		1.16
				5	+ 0°.1	1.0120	1.0122		1.50
				10	— 1°.07	1.0182	1.0186		2.30
				15	— 1°.30	1.0239	1.0244		3.02
				20	— 1°.38	1.0249	1.0254		3.14
				25	— 1°.38	1.0259	1.0264		3.26
				30	— 1°.40	1.0262	1.0267		3.30
				35	— 1°.40	1.0264	1.0269		3.33
				40	— 1°.40	1.0269	1.0274		3.39
				45	— 1°.45	1.0265	1.0270		3.34
				50	— 1°.45	1.0270	1.0275		3.40

Date 1878.	Time of the day.	Lat.	Long. E G.	Depth in metres.	Temperature t° C.	Spec. gravity observed.	Spec. gravity reduced to $\frac{t^\circ}{+4^\circ}$ C or $\frac{0^\circ}{+4^\circ}$ C.	Percent of Cl.	Salt in percent.
Aug. 14				55	— 1°.45	1.0268	1.0273		3.38
				60	— 1°.45	1.0267	1.0272		3.36
	noon	76° 19′	95° 48′	0	+ 1°.0	1.0087	1.0087		1.06
	4 p. m.	Actinia bay		0	+ 2°.1	1.0134	1.0136		1.68
	8 p. m.	»		0	+ 1°.2	1.0176	1.0179		2.21
» 15	0 a. m.	»		0	+ 1°.0	1.0171	1.0174		2.15
	4 a. m.	»		0	+ 1°.0	1.0186	1.0190		2.35
	8 a. m.	»		0	+ 1°.2	1.0165	1.0168		2.08
	noon	»		0	+ 0°.9	1.0155	1.0158		1.93
	4 p. m.	»		0	+ 1°.4	1.0186	1.0190		2.35
	8 p. m.	»		0	+ 0°.4	1.0199	1.0203		2.51
» 16	0 a. m.	»		0	+ 1°.0	1.0191	1.0195		2.41
	4 a. m.	»		0	+ 0°.2	1.0205	1.0210		2.60
	8 a. m.	»		0	+ 1°.1	1.0178	1.0181		2.24
	noon	»		0	+ 1°.8	1.0161	1.0164		2.03
	4 p. m.	»		0	+ 1°.6	1.0162	1.0165		2.04
	8 p. m.	»		0	+ 1°.6	1.0161	1.0164		2.03
» 17	0 a. m.	»		0	+ 1°.4	1.0162	1.0165		2.04
	4 a. m.	»		0	+ 1°.4	1.0162	1.0165		2.04
	8 a. m.	»		0	+ 1°.4	1.0163	1.0166		2.05
	noon	»		0	+ 1°.8	1.0162	1.0165		2.04
	4 p. m.	»		0	+ 1°.8	1.0164	1.0167		2.06
	5 p. m.	»		0	+ 1°.3	1.0191	1.0195		2.41
		»		1	— 0°.30	1.0222	1.0226		2.79
		»		3	— 0°.20	1.0222	1.0226		2.79
		»		5	— 0°.35	1.0227	1.0232		2.87
		»		7	— 0°.5	1.0231	1.0236		2.92
		»		9	— 0°.6	1.0235	1.0240		2.97
		»		11	— 0°.6	1.0234	1.0239		2.96
	8 p. m.	»		0	+ 0°.8	1.0200	1.0205		2.54
» 18	0 a. m.	»		0	0	1.0200	1.0205		2.54
	4 a. m.	»		0	+ 0°.2	1.0161	1.0164		2.03
	8 a. m.	»		0	+ 0°.8	1.0157	1.0160		1.98
	noon	76° 23′	96° 0′	0	+ 1°.2	1.0134	1.0136		1.68
	4 p. m.	76° 32′	97° 10′	0	+ 3°.0	1.0125	1.0127		1.56
	8 p. m.	76° 42′	98° 35′	0	+ 2°.6	1.0082	1.0082		1.01
» 19	0 a. m.	76° 50′	100° 0′	0	+ 1°.6	1.0098	1.0098		1.20
	4 a. m.	77° 0′	101° 5′	0	+ 0°.4	1.0183	1.0187		2.26
	8 a. m.	77° 14′	101° 32′	0	+ 0°.4	1.0193	1.0197		2.44
				10	— 1°.2	1.0216	1.0221		2.73
				22	— 1°.5	1.0250	1.0225	1.73 V.	3.15
	noon	77° 24′	102° 10′	0	— 0°.3	1.0209	1.0214		2.65
				10	— 1°.0	1.0219	1.0224		2.77
				20	— 1°.4	1.0253	1.0258		3.19
				35	— 1°.6	1.0262	1.0267		3.30
	4 p. m.	77° 33′	102° 40′	0	— 0°.1	1.0221	1.0226		2.79

Date 1878.	Time of the day.	Lat.	Long. E. G.	Depth in metres.	Temperature t° C.	Spec. gravity observed.	Spec. gravity reduced to t° C or +4° C.	Percent of Cl.	Salt in percent.
Aug. 19	8 p. m.	77° 36′	103° 25′	0	— 0°.1	1.0224	1.0229		2.83
» 20	0 a. m.	Cape Tcheljuskin		0	— 0°.6	1.0225	1.0230		2.84
	4 a. m.	»		0	— 0°.2	1.0228	1.0233		2.88
	8 a. m.	»		0	— 0°.2	1.0226	1.0231		2.86
	noon	»		0	0	1.0226	1.0231		2.86
	4 p. m.	77° 44′	104° 7′	0	— 0°.4	1.0232	1.0237		2.93
	8 p. m.	77° 39′	105° 7′	0	+ 0°.0	1.0225	1.0230		2.84
				0	— 1°.4	1.0259	1.0264	1.87 V.	3.26
				128	— 1°.2	1.0274	1.0279	1.92 P.	3.45

The temperatures found at the deep-sounding, Aug. 2nd, 8 o'clock a. m., [= — 1°.0 C at 50 m. and — 0°.9 C at 115 m. below the surface] are very remarkable, especially if compared with the results obtained 4 hours later at similar depths [= — 2°.4 C at 50 m. and — 2°.0 C at 122 m.]. It is indeed very strange, that the temperature *at the bottom* should change so much within so short a distance, although the chemical and physical properties of the water, represented by its saltness and spec. gravity, remains almost identically the same. It has occurred to me, that this anomaly *may* be explained as an error of annotation and that the real numbers ought to be — 2°.0 C (instead of — 1°.0 C) and — 1°.9 C (instead of — 0°.9 C) since this seems to be the normal temperature of the Kara Sea so deep below the surface. We can see from the following that the spec. weights 1.0279 — 1.0282 (saltness 3.45 & 3.49 p. c.) has never been observed in the Siberian Sea except in water of the temperature — 1°.4 C to — 2°.4 C. It must be observed, however, that there is no ambiguousness in the ciphers of the manuscript journal, which warrants my supposition.

The Siberian Sea.

The whole distance from the Taimur peninsula to Long's strait was before the voyage of the Vega almost a *mare incognitum* to hydrography. In want of reliable facts, from which we might judge of the real condition of this sea, we are wont to attach a great deal of hypothetical assumption to the subject.

Thus f. ex. the question, whether the Gulf-stream pene-

trates into the Kara and Siberian Sea or not, has been much debated. Petermann and Middendorff[1] are prone to assert that the warm water of the Gulf-stream is spread beyond Novaya Zemlya and the Taimur peninsula to the longitudes of Cape Yakan and even to Behring strait. The remarkably mild climate even in winter of the northern parts of these countries compared to the rest of the North-Asiatic continent makes this hypothesis by no means unacceptable.

Hedenström[2] during his voyage to the Siberian Islands, and Wrangel,[2] on his sledging expeditions on the frozen sea found, that the sea-ice became thinner and more corroded, the more they proceeded northward, until it finally gave way to open water »the polynia» extending northward beyond eyesight. — Although a similar phenomenon has been observed occasionally almost everywhere along the coast of the arctic sea in winter [f. ex. in Smith's Sound, in Austria Sound at Franz Joseph Land, at Spitzbergen, Novaya Zemlya etc...] and has ordinarily been found to be limited to short spaces of the ocean, the »polynia» is often regarded as the southern part of a polar sea, unfrozen even in winter, which is kept open[3] by a branch of the Gulf-stream undermining the arctic drift-ice current etc...

Lately Lieutenant Hovgaard, one of the members of the Vega-expedition, has propounded the hypothesis of the existence of two polar continents north of Siberia, separated from each other by a sound at the longitude of Cape Tcheljuskin, opening from the Siberian Sea straightway into the polar basin.

I fear that the results of the Vega-expedition will not contribute much to solve the mystery of these questions. We can not reasonably expect, that the observations of a single expedition will reveal to us all the secrets of the immense ocean, which borders on the Siberian coast.

As for the polar continents north of Siberia, there is scarcely to be found anything in the hydrographic observations of the Vega, which could tend to corroborate the hypothesis of Mr. Hovgaard. According to his theory the Franz Joseph archipelago would extend eastward to the longitude of Cape Tcheljuskin and be connected with the Taimur and Yalmal peninsulæ by a submarine plateau. Consequently the

[1] Middendorff: Der Golfstrom östlich vom Nordkap. Geogr. Mitth. 1871.

[2] Wrangel: Reise längs der Nordküste von Sibirien see also: Erman's »Russisches Archiv», vol. XXIV, 1865.

[3] Petermann: Der Golfstrom, Geogr. Mitth. 1870, page 229—230.

deep basin in the western part of the Kara Sea along the coast of Novaya Zemlya ought to be entirely *separated from the deep sea east of Cape Tcheljuskin,* from which a deep channel is supposed to extend between the aforesaid continents to the vicinity of the north pole. It is true, that the depth of the sea increases abruptly immediately east of Cape Tcheljuskin, but we can see from section V (plate 24) that a little more to the east it decreases again to about 60 metres, the same depth, which was found at the Taimur coast a few miles north-west of Actinia Bay [see section IV]. Moreover, the temperature and the saltness of the water at the bottom of the sea east of Cape Tcheljuskin [t = — 1°.4 C or — 1°.2 C, saltness = 3.45 p. c.] is almost identical with that of the deeper strata of the western basin of the Kara Sea [t = — 1°.8 C, saltness = 3.49 p. c.]. We could as well fancy the bottom of the shallow sea north of the Obi and Yenisei to be formed by the deposits from these rivers as to be a submarine plateau connecting the northern part of Asia with an unknown continent.

But, if there is very little in the Vega observations to strengthen the hypothesis of Mr. Hovgaard, there is on the other hand nothing, which is absolutely contradictory to it, so we must be content to hope, that this question will be settled soon in a satisfactory manner by the Dijmphna-expedition.

The opinion, that the »polynia» of the Siberian Sea is a branch of an open arctic ocean, unfrozen even in winter, has received an irreparable shock by the experiences of the Jeannette-expedition. Still there is full evidence from the Vega observations of the fact, first observed by Wrangel, that the ice of the Siberian Sea breaks up partly on several occasions in the course of every winter. The 31st December, 1878, Lieutenant Bove[1] made an excursion to a large clearing in the ice, which had formed in the course of the previous day. He found the temperature of the water to be — 2° C, which proves that the open water was not due to any melting

[1] »In altre sei o sette occasioni e semprechè spirarono tempeste dal sud-est o dal sud-ovest, aprironsi bacini al nord della posizione della *Vega.*» .... »Era un vastissimo bacino che si perdeva verso l'est e verso il nord, mentrechè all'ovest era limitato da alto catene di *hummocks*» .... »Montammo su di una collina di ghiaccio per avere una più chiara idea del bacino d'acqua che avevamo in cospetto; ma anche dall'allto di quell'osservatorio non potemmo vedere i limiti di quella piccola *Polynià*» .... »Trovammo la temperatura dell'acqua a — 2° e diversi scandagli ci diedero 'un 'altezza di fondo di 24 a 25 metri.

Giacomo Bove: Spedizione Artica Svedese 1878—79.

of the ice caused by a warm under-current etc. . , but solely to the mechanical force of a violent tempest from the south which had blown during 10 or 11 hours the day before.

The only point on the route of the Vega, where we could expect to trace the influence of the Gulf-stream — if there really should exist anything worthy of that name in the Siberian ocean — undisturbed by the effluvia from the rivers, is the sea north and east of Cape Tcheljuskin. The observations on the 19, 20, 21, 22nd August (see section V on plate 24) are somewhat scanty, but will nevertheless furnish a reply to the question, *as far as regards the actual conditions of the sea at that season of the year.*

We are wont to attach the idea of a relatively warm and salt surface-current of clear bluish coloured water with the name of the Gulf-stream. None of these characteristics are applicable to the sea, which borders on the northest point of Asia. Its maximum saltness at the surface was 2.93 p. c. Its temperature varied from + 0°.8 C to — 0°.8 C and the colour of its water was green. Now it is a well-proved truth, that the last out-parts of the warm Atlantic water to the north must not always be sought for *at the surface.* In very high latitudes the isotherms of the warm water often take the shape of closed curves, showing that the warm surface stream has been partially inundated by arctic water, which contains less of salt and therefore, notwithstanding its lower temperature, can be lighter than the Atlantic water between certain limits of temperature. Thus, to cite one example of many, Professor Mohn, the leader of the Norwegian North-Atlantic expedition, discovered an isolated warm spot in the sea west of Spitzbergen at about 79°—80° Lat. N. But the results of the deep-soundings on the 21st and 22nd August [section V] convinces us, that there exists no such phenomenon here.

From a few metres below the surface and unto the bottom the temperature of the water was — 1°.2 to — 1°.4 C. But if there is no trace to be found of a warm current of Atlantic water north of Cape Tcheljuskin in summer, it *may* still be possible, that such a current exists there in winter. [1]

[1] See the last page of the preceding paper. Petermann has tried to find a connection between the direction of the ocean-currents in winter along the north-eastern coast of Siberia and that of the Gulf-stream. »Der Golfstrom» Mitth. 1870. »Bemerkenswerth ist eine Thatsache in den Strömungs-Beobachtungen Wrangels in Nordost-Sibirien. Bekanntlich gehen dort die Strömungen im Frühjahr und Sommer nach Westen, im Herbst und Winter nach Osten, *in der Richtung des Golfstromes*».

The numbers [pointed with blue] in sections IV, V & VI, which represent the saltness in p. c. of the surface-water, reveal to us another very important fact, viz. *that the great fresh-water current of the Kara Sea, derived from the Obi and Yenisei rivers, does not reach farther eastward than Cape Tcheljuskin.* The diluted water at the surface, north of the Taimur peninsula, is of course due to an admixture of river-water, but this water does not belong to the Obi and Yenisei, but to the great Siberian river-system east of the Taimur land. For in case the fresh-water current from the Kara Sea reached beyond the Taimur peninsula, we ought to find the saltness of its water *continually increasing* along its whole course. Instead, it *reaches its maximum at Cape Tcheljuskin.* The following series is the result of the regular observations of the saltness of the water at the surface between Port Actinia and the Chatanga Bay (see sections IV, V, VI on plate 24 & 25)

1.98 p. c.; *1.54* p. c.; *1.01* p. c.; *1.20* p. c.; *2.26* p. c.; *2.44* p. c.;
Actinia Bay. Taimur Bay.

2.65 p. c.; *2.79* p. c.; *2.88* p. c.; ***2.93*** p. c.; *2.84* p. c.; *2.83* p. c.;
Cape Tcheljuskin.

2.73 p. c.; *2.76* p. c.; *2.71* p. c.; *2.80* p. c.; *2.82* p. c.; *2.78* p. c.;

2.81 p. c.; *2.77* p. c.; *2.73* p. c.; *2.74* p. c.; *2.73* p. c.; *2.75* p. c.;
East point of the Taimur Land.

2.73 p. c.; *2.64* p. c.; *2.40* p. c.; *2.31* p. c.; *1.43* p. c.; *1.36* p. c.
Chatanga Bay.

etc. . .

This fact is the more remarkable as we might rather anticipate the contrary. It can be seen most unmistakably from the sections VII, VIII, IX that the currents from the rivers Chatanga, Olonek, Anabara, Lena, Indigirka, Kolyma etc. . . are always deviating to the east; consequently we should expect that the upper-current of the Kara Sea, after rounding the northern and eastern capes of the Taimur coast, would penetrate into the Siberian Sea. From the other side there is no current of river-water along the east side of the Taimur land, which could directly neutralize the former. From section VI we see, that the outflow from the Chatanga bay takes an easterly and southerly direction. Towards the north it is limited by a »wall» of relatively cold and salt water. I think the problem can be explained as follows: The *average* niveau of the Siberian Sea, east of the Taimur peninsula, is raised by

the abundant supply of fresh water from the rivers in summer almost as much as that of the Kara Sea; consequently there is no tendency on either side to encroach upon the other.

The sections VI—IX on plate 25, which represent the conformation of the sea along the course of the Vega, also give a transverse section of the fresh-water currents from the rivers outside the river-mouths.

A closer inspection of the temperature, the saltness and likewise of the change of colour in the water shows that the main mass of the river-water is invariably found at a considerable distance to the east of the mouth of the river, from which it originates. If we choose for example the section VII, which represents the state of the sea outside the mouths of the Anabara, the Lena and the Jana rivers, we find that the head mass of the fresh water from the Lena flows between the 130th and the 136th degree Long. E. G., i. e. 3 longitudinal degrees *east* of the embouchure of the river. Here the saltness at the surface sunk to only 0.49 or 0.91 p. c. and the water was clay-coloured. A similar remark is due also to the waters emerging from the Anabara and Jana-rivers.

At some distance to the *west* of the warm and fresh river-water there will invariably also be found a layer of cold salt water at the bottom of the sea. This is, as already mentioned, an indraught of arctic water from the north, caused by the mechanic reaction of the outflow of the rivers.

The same influence of the earths rotation, which forces the upper-current to take an easterly direction, also directs the under-current to the west. The existence of such an under-current of salt water, cooled unto its freezing-point, explains to us the strange phenomenon, that the expedition very often had to struggle with pack-ice or foundered ice-floes in the immediate vicinity of the warm river-water, as for ex. east of the Chatanga bay and the Lena delta. In such places vast masses of drifting ice-floes or massive foundered iceblocks were found in the midst of almost fresh flowing river-water of relatively high temperature. The warm water could only attack the superficial layers of the ice, which as a rule were found to be much corroded, while its bulk was protected from melting by the cold water at the base. Lieutenant Bove[1]

[1] »*Lingua di ghiaccio.* — La corrente del Katanga aveva accumulato, lungo il suo margine, una longa e compatta lingua di vecchi ghiacci tra i quali passammo con qualche difficoltà e con gravi pericoli per il timone e l'elica.» — — —

has drawn special attention to the frequent occurence of ice masses in those parts of the sea, which we should expect to be most free of ice, although he seems not to have appreciated the real cause of the phenomenon.

Another remarkable phenomenon, which certainly must be due to the influence of the cold water-stratum below, was observed on the evening of the 30th August. Nordenskiöld writes:

»The temperature of the water *near the surface* varied between + 1° and + 1°.6 C, the temperature of the air was found + 1°.5 to + 1°.8 C. Notwithstanding both air and water had a temperature higher than 0°, ice began to appear at the surface of the sea (which was quite calm and unruffled) in the shape of needles or a thin film of frozen water. Several times before I had witnessed the formation of ice in the arctic sea, when the temperature of the air was above zero. In this case, when the temperature of the upper water-stratum was also above zero, the formation of the ice clearly must depend upon a radiation of heat either upwards to the air or downwards to the cool water-stratum at the bottom.»

I think the most plausible explanation of the phenomenon is: that the undermost layer of the fresh-water at the surface of the sea, being cooled below its freezing point [= — 0°.76 C corresponding to the spec. weight = 1.0110], gave up ice, which on account of its higher spec. volume rose to the surface of the calm sea and thus made the impression upon the spectators of a spontaneous formation of ice-crystals from the surface-

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Very interesting is the description of the encounter of the Vega with ice in the midst of the waters of the Lena river in the afternoon of the 28th August. From the map (plate 25) and the section VII the reader will get an idea of the situation.

»*Incontro di nuovo ghiaccio.* — Fummo anche costretti a farlo dall' apparire di alcuni pezzi di ghiaccio che per la loro natura indicavano che non si erano staccati da molto tempo dal banco principale. Ed in fatti verso le 2, il ghiaccio cominciò a spesseggiare, ed alle 4 pom. divenne tanto denso, da obbligarci ad avanzare lentamente e con continuo maneggio di timone.»

»*In presenza del ghiaccio nessun sensibile cambiamento avviene nella temperatura e colore delle acque.* — Contrariamento a quanto ci era sin qui accaduto, l'approssimarsi del ghiaccio non fu annunciato da alcun sensibile cambiamento di temperatura e di scoloramento dell' acqua; la temperatura dell' acqua alla superficie ed a qualche metro di profondità si mantenne al disopra de' + 3° ed il colore continuò ad essere di un giallo terreo, le quali cose indicavano che non eravamo ancora usciti dall' estuario della Lena» ...

[Spedizione artica Svedese, G. Bove.]

water. Unhappily there exists, as may be seen from the table, no deepsounding from this place.

From Cape Irkaipij [on the 12th Sept.] to the arrival at Pitlekaj [on the 28th Sept.] the temperature of the sea was found to be at its freezing point and the progress of the expedition was accompanied with a continual struggle against the ice. The deep-soundings from this part of the voyage are represented on diagram X.

The depths of the sea are not expressly mentioned in the tables 1—4, because the necessary information can be got most easily from the hydrographic maps. The nature of the sea-bottom [2] is registered in Dr. Stuxberg's paper: »Evertebratfaunan i Sibiriens ishaf», Vega-expeditionens vetenskapliga iakttagelser, I. Some minor discrepancies between the annotations in the meteorologic and the hydrographic journal regarding the localities, from which the samples were taken, the spec. gravity of the sea-water at the surface, the depths and the occurrence of ice etc. . . I have tried to remove by comparison with the log-book of the ship, the reports of Prof. Nordenskiöld, the Italian description of the Vega-voyage by Mr. Bove etc. . .

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[1] Vegas färd kring Asien och Europa, page 405 (Swedish edition).

[2] Regarding the colour of the water of the Siberian Sea I wish to call attention to an important investigation entitled: »La couleur des eaux», recently published by Professor W. Spring, from which I borrow the following lines, which will be found to have a direct application on the observations of the Vega-expedition (see the maps, plate 24 & 25).

»On sait que l'argile ou le silicate d'aluminium, sans être soluble dans l'eau, dans l'acception propre du mot, forme cependant avec elle une pseudo-solution: de l'eau d'un fleuve, roulant sur un limon gras, argileux, ne devient jamais complétement limpide par le repos. L'argile, sans être dissoute, est comme emulsionnée dans le liquide. Mais si l'on vient à ajouter à l'eau une solution d'un sel, du chlorure de sodium, par exemple, alors le silicate d'aluminium se précipitera rapidement. On observe ce fait, sur une échelle énorme à l'embouchure des grands fleuves . . . . . Le sel hâte la précipitation du silicate d'aluminium, dont la présence dans l'eau, sous la forme de precipité naissant, contribue *au développement de la couleur verte des eaux.*»

Table 3.

Hydrographic observations during the third part of the voyage, from Cape Tcheljuskin (21st Aug.) to Pitlekaj (29—30 Sept. 1878) see the map, plate 25, sections V—X.

Date 1878.	Time of the day.	Lat.	Long. E. G.	Depth in metres.	Temperature t° C.	Spec. gravity observed.	Spec. gravity reduced to $\frac{t^\circ C}{+4^\circ C}$ or $\frac{0^\circ}{+4^\circ C}$.	Percent of Cl.	Salt in percent.
Aug. 21	0 a. m.	77° 35′	106° 12′	0	— 0°.8	1.0229	1.0234		2.89
	4 a. m.	77° 32′	107° 24′	0	+ 0°.2	1.0216	1.0221		2.73
	8 a. m.	77° 24′	108° 20′	0	+ 0°.5	1.0218	1.0223		2.76
				50	— 1°.2	1.0269	1.0274		3.39
				100	— 1°.4	1.0270	1.0275		3.40
	noon	77° 25′	109° 13′	0	+ 0°.8	1.0214	1.0219		2.71
	4 p. m.	77° 20′	110° 12′	0	— 0°.2	1.0222	1.0227		2.80
	8 p. m.	77° 15′	111° 43′	0	— 0°.2	1.0223	1.0228		2.82
» 22	0 a. m.	77° 10′	113° 10′	0	+ 0°.2	1.0220	1.0225		2.78
	4 a. m.	77° 6′	114° 40′	0	+ 0°.2	1.0222	1.0227		2.81
	8 a m.	76° 55′	115° 15′	0	— 0°.1	1.0219	1.0224		2.77
	noon	76° 54′	116° 9′	0	— 0°.2	1.0216	1.0221		2.73
	4 p. m.	76° 50′	115° 58′	0	— 0°.5	1.0216	1.0221		2.73
	6 p. m.	76° 4′	116° 9′	0	— 0°.6	1.0217	1.0222		2.74
				10	— 1°.0	1.0223	1.0228		2.82
				20	— 1°.1	1.0236	1 0241		2.98
				30	— 1°.3	1.0253	1.0258		3.19
				40	— 1°.3	1.0266	1.0271	1.87 P.	3.35
				50	— 1°.4	1.0267	1.0272	1.87 P.	3.36
				59	— 1°.4	1.0273	1.0278		3.44
	8 p. m.	76° 45′	115° 52′	0	— 0°.4	1.0219	1.0224		2.77
				30	— 1°.4	1.0249	1.0254		3.14
				59	— 1°.4	1 0266	1.0271		3.77
» 23	0 a. m.	76° 35′	115° 45′	0	— 0°.8	1.0220	1.0225		2.78
	4 a. m.	76° 32′	115° 38′	0	— 1°.0	1.0218	1 0223		2.76
	8 a. m.	76° 40′	115° 28′	0	— 0°.6	1.0218	1.0223		2.76
				30	— 1°.4	1.0262	1.0267	1.73 V.	3.30
				60	— 1°.6	1.0275	1.0280		3.46
	noon	76° 48′	115° 0′	0	+ 0°.4	1.0216	1.0221		2.30
	4 p. m.	76° 47′	113° 55′	0	— 0°.5	1.0216	1.0221		2.73
	8 p. m.	76° 23′	113° 40′	0	— 0°.4	1.0212	1.0217		2.68
» 24	0 a. m.	75° 58′	114° 22′	0	+ 0°.8	1.0208	1.0213		2.64
	4 a. m.	75° 40′	114° 37′	0	+ 0°.2	1.0190	1.0194		2.40
	8 a. m.	75° 17′	114° 7′	0	+ 1°.4	1.0183	1.0187		2.31
	noon	75° 0′	113° 33′	0	+ 4°.0	1.0114	1.0116		1.43
				20	+ 1°.8	1.0190	1.0194	1.32 V.	2.40
				40	— 0°.8	1.0238	1.0243	1.68 V.	3.01
	4 p. m.	74° 49′	113° 16′	0	+ 4°.6	1.0120	1.0122		1.50
	8 p. m.	74° 44′	113° 10′	0	+ 4°.5	1.0121	1.0123		1.52
» 25	0 a. m.	74° 37′	113° 7′	0	+ 4°.2	1.0108	1.0110		1 36
	4 a. m.	74° 18′	113° 17′	0	+ 4°.4	1.0104	1.0106		1.31

Date 1878.	Time of the day.	Lat.	Long. E. G.	Depth in metres.	Temperature t° C.	Spec. gravity observed.	Spec. gravity reduced to t° C or +4° C.	Percent of Cl.	Salt in percent.
Aug. 25	8 a. m.	73° 58′	113° 13′	0	+ 4°.1	1.0133	1.0135		1.67
				5	+ 3°.9	1.0120	1.0122		1.50
				14	+ 2°.4	1.0146	1.0149	1.03 P.	1.84
	noon	73° 44′	113° 53′	0	+ 5°.8	1.0104	1.0105		1.28
	4 p. m.	73° 41′	114° 56′	0	+ 5°.0	1.0120	1.0122		1.50
				5	+ 4°.8	1.0119	1.0121	0.84 V.	1.49
				11	+ 2°.6	1.0151	1.0154	1.06 P.	1.90
	8 p. m.	73° 46′	115° 40′	0	+ 3°.0	1.0144	1.0147		1.80
» 26	0 a. m.	73° 48′	116° 38′	0	+ 3°.2	1.0139	1.0141		1.72
	4 a. m.	73° 48′	118° 1′	0	+ 3°.6	1.0090	1.0090		1.10
	8 a. m.	73° 47′	119° 13′	0	+ 2°.6	1.0072	1.0072		0.88
				6	0	1.0178	1.0181		2.24
				13	— 1°.0	1.0205	1.0210		2.60
	noon	73° 45′	120° 22′	0	+ 1°.2	1.0091	1.0091		1.11
	4 p. m.	73° 45′	121° 27′	0	+ 1°.2	1.0098	1.0098		1.19
	8 p. m.	73° 40′	122° 15′	0	+ 1°.8	1.0110	1.0112		1.38
				5	+ 1°.6	1.0104	1.0104	0.71 P.	1.28
				9	+ 0°.4	1.0115	1.0117	0.82 P.	1.45
» 27	0 a. m.	73° 40′	123° 10′	0	+ 3°.8	1.0080	1.0080		0.75
	4 a. m.	73° 29′	123° 5′	0	+ 3°.2	1.0092	1.0092		1.12
	8 a. m.	73° 39′	122° 54′	0	+ 3°.1	1.0095	1.0095		1.16
	noon	73° 47′	123° 26′	0	+ 2°.6	1.0107	1.0109		1.31
	4 p. m.	73° 49′	124° 50′	0	+ 3°.2	1.0120	1.0122		1.48
	7 p. m.	73° 50′	126° 0′	0	+ 2°.8	1.0139	1.0141		1.74
				10	+ 0°.5	1.0179	1.0182		2.25
				20	— 1°.2	1.0226	1.0231		2.86
	8 p. m.	73° 50′	126° 7′	0	+ 2°.6	1.0134	1.0136		1.66
» 28	0 a. m.	73° 44′	127° 37′	0	+ 2°.4	1.0100	1.0100		1.23
	4 a. m.	73° 49′	128° 50′	0	+ 4°.2	1.0058	1.0058		0.74
	8 a. m.	74° 9′	130° 20′	0	+ 4°.4	1.0040	1.0040		0.49
				10	+ 4°.4	1.0040	1.0040		0.49
				22	+ 3°.8	1.0050	1.0050	0.39 V.	0.62
	noon	74° 15′	132° 0′	0	+ 3°.2	1.0041	1.0041		0.50
	4 p. m.	74° 0′	133° 32′	0	+ 2°.0	1.0042	1.0042		0.52
	8 p. m.	73° 53′	134° 47′	0	+ 1°.4	1.0046	1.0046		0.57
» 29	0 a. m.	73° 53′	135° 20′	0	+ 0°.4	1.0060	1.0060		0.76
	4 a. m.	73° 46′	134° 46′	0	+ 0°.2	1.0060	1.0060		0.76
	8 a. m.	74° 3′	135° 35′	0	+ 1°.2	1.0074	1.0074		0.91
				12	0	1.0118	1.0120	0.86 V.	1.48
				24	— 0°.4	1.0128	1.0130	1.38 V.	1.61
	noon	74° 5′	136° 18′	0	+ 1°.4	1.0112	1.0114		1.38
	4 p. m.	73° 54′	137° 28′	0	+ 0°.7	1.0128	1.0130		1.58
	6 p. m.	73° 53′	138° 0′	0	+ 1°.4	1.0116	1.0118		1.46
				10	+ 1°.2	1.0117	1.0119	0.81 V.	1.47
				20	— 0°.4	1.0165	1.0168		2.08
	8 p. m.	73° 49′	138° 30′	0	+ 1°.0	1.0110	1.0112		1.36

Date 1878.	Time of the day.	Lat.	Long. E. G.	Depth in metres.	Temperature t° C.	Spec. gravity observed.	Spec. gravity reduced to $\frac{t^\circ}{+4^\circ}$ C or $\frac{0^\circ}{+4^\circ}$ C.	Percent of Cl.	Salt in percent.
Aug. 30	0 a. m.	73° 43′	139° 35′	0	+ 1°.6	1.0112	1.0114		1.38
	4 a. m.	73° 42′	139° 57′	0	+ 2°.0	1.0110	1.0110		1.36
	8 a. m.	73° 43′	140° 41′	0	+ 2°.6	1.0118	1.0120		1.48
				4	+ 2°.6	1.0119	1.0121		1.49
				8	+ 2°.6	1.0120	1.0122	0.84 V.	1.50
	noon	73° 40′	140° 16′	0	+ 2°.6	1.0116	1.0118		1.43
	4 p. m.	73° 22′	139° 32′	0	+ 1°.0	1.0110	1.0112		1.36
	8 p. m.	73° 2′	139° 40′	0	+ 1°.6	1.0110	1.0112		1.36
» 31	0 a. m.	72° 57′	140° 37′	0	+ 2°.6	1.0140	1.0142		1.72
	4 a m.	72° 59′	141° 26′	0	+ 1°.0	1.0108	1.0110		1.34
	8 a. m.	73° 4′	142° 40′	0	+ 0°.8	1.0121	1.0123		1.52
				8	+ 0°.1	1.0140	1.0143		1.77
				16	0	1.0145	1.0148		1.83
	noon	73° 9′	143° 20′	0	+ 1°.2	1.0114	1.0116		1.41
	4 p. m.	73° 5′	144° 20′	0	+ 2°.6	1.0105	1.0107		1.33
				7	+ 1°.8	1.0110	1.0112	0.76 P.	1.38
				14	— 0°.4	1.0144	1.0146	1.00 V.	1.80
	8 p. m.	73° 0′	145° 40′	0	+ 3°.6	1.0105	1.0107		1.31
Sept. 1	0 a. m.	72° 55′	146° 43′	0	+ 3°.2	1.0083	1.0083		1.02
	4 a. m.	72° 55′	147° 35′	0	+ 3°.4	1.0082	1.0082		1.01
	8 a. m.	72° 40′	148° 40′	0	+ 3°.2	1.0092	1.0092		1.12
				6	0	1.0151	1.0153		1.89
				12	— 0°.8	1.0172	1.0175		2.16
	noon	72° 33′	150° 0′	0	+ 4°.0	1.0090	1.0090		1.10
	4 p. m.	72° 30′	152° 18′	0	+ 1°.4	1.0161	1.0164		2.04
	6 p. m.	72° 20′	153° 30′	0	+ 0°.6	1.0165	1.0168		2.07
				10	0	1.0195	1.0199		2.46
				20	— 0°.6	1.0202	1.0207		2.56
	8 p. m.	72° 15′	153° 18′	0	+ 1°.0	1.0165	1.0168		2.10
» 2	0 a. m.	72° 3′	154° 6′	0	+ 0°.8	1.0180	1.0184		2.29
	4 a. m.	71° 53′	155° 6′	0	+ 0°.6	1.0182	1.0186		2.31
	8 a. m.	71° 44′	156° 15′	0	+ 1°.6	1.0129	1.0131		1.59
	noon	71° 40′	157° 11′	0	+ 2°.0	1.0118	1.0120		1.48
	1 p. m.	71° 38′	157° 25′	0	+ 1°.8	1.0120	1.0122		1.50
				10	+ 1°.0	1.0125	1.0127		1.56
				20	— 1°.0	1.0198	1.0202		2.49
	4 p. m.	71° 33′	157° 55′	0	+ 1°.6	1.0130	1.0132		1.61
	8 p. m.	71° 22′	158° 48′	0	+ 1°.0	1.0134	1.0136		1.66
» 3	0 a. m.	71° 15′	159° 45′	0	+ 1°.6	1.0135	1.0137		1.67
	4 a. m.	71° 7′	160° 18′	0	— 0°.8	1.0142	1.0145		1.77
	8 a. m.	70° 52′	161° 0′	0	— 0°.2	1.0151	1.0153		1.87
	noon	70° 37′	161° 25′	0	+ 0°.1	1.0165	1.0168		2.09
	4 p. m.	70° 30′	162° 13′	0	0	1.0142	1.0144		1.76
	8 p. m.	70° 31′	163° 12′	0	— 0°.4	1.0142	1.0144		1.76
» 4	0 a. m.	70° 24′	163° 40′	0	— 1°.0	1.0142	1.0144		1.73
	4 a. m.	70° 22	163° 48′	0	— 1°.2	1.0163	1.0166		2.05

Date 1878.	Time of the day.	Lat.	Long. E. G.	Depth in metres.	Temperature t° C.	Spec. gravity observed.	Spec. gravity reduced to t° / +4° C or 0° / +4° C	Percent of Cl.	Salt in percent.
Sept. 4	8 a. m.	70° 27′	163° 59′	0	— 1°.0	1.0170	1.0174		2.15
	noon	70° 16′	163° 35′	0	— 0°.6	1.0165	1.0168		2.09
	4 p. m.	70° 2′	163° 16′	0	— 0°.6	1.0184	1.0188		2.34
	8 p. m.	69° 52′	163° 20′	0	+ 3°.5	1.0120	1.0122		1.48
» 5	0 a. m.	69° 45′	164° 21′	0	+ 3°.5	1.0099	1.0099		0.97
	4 a. m.	69° 42′	165° 15′	0	+ 1°.0	1.0122	1.0124		1.50
	8 a. m.	69° 38′	166° 20′	0	+ 2°.0	1.0153	1.0155		1.93
	noon	69° 40′	167° 17′	0	+ 1°.0	1.0200	1.0205		2.53
	4 p. m.	70° 4′	168° 10′	0	+ 0°.6	1.0210	1.0215		2.66
	8 p. m.	70° 12′	169° 30′	0	— 0°.4	1.0234	1.0239		2.95
» 6	0 a. m.	70° 14′	170° 17′	0	— 0°.9	1.0232	1.0237	1.61 P.	2.93
				12	— 1°.2	1.0238	1.0243	1.68 P.	3.01
				22	— 1°.2	1.0242	1.0247	1.69 P.	3.06
				32	— 1°.3	1.0252	1.0257	1.72 P.	3.18
	4 a. m.	70° 8′	170° 32′	0	— 0°.9	1.0232	1.0237		2.93
	8 a. m.	70° 5′	171° 20′	0	+ 2°.6	1.0181	1.0185		2.29
	noon	70° 5′	172° 7′	0	+ 2°.0	1.0192	1.0196		2.37
	4 p. m.	70° 1′	172° 48′	0	+ 1°.6	1.0207	1.0212		2.62
	8 p. m.	69° 58′	173° 22′	0	+ 1°.0	1.0220	1.0225		2.78
» 7	0 a. m.	69° 56′	174° 27′	0	— 1°.3	1.0241	1.0246	1.69 P.	3.04
				12	— 1°.0	1.0244	1.0249	1.70 P.	3.08
				25	— 0°.9	1.0250	1.0255	1.74 P.	3.15
	4 a. m.	69° 56′	174° 56′	0	+ 0°.6	1.0225	1.0230		2.84
	8 a. m.	69° 58′	175° 28′	0	— 0°.3	1.0235	1.0240		2.97
	noon	69° 56′	176° 10′	0	— 0°.8	1.0239	1.0244		3.02
	4 p. m.	69° 51′	176° 41′	0	+ 0°.2	1.0250	1.0255		3.15
	8 p. m.	69° 39′	177° 8′	0	— 0°.6	1.0246	1.0251		3.10
» 8	0 a. m.	69° 32′	177° 41′	0	— 1°.0	1.0250	1.0255		3.15
	4 a. m.	69° 30′	177° 26′	0	— 1°.2	1.0238	1.0243		3.01
	8 a. m.	69° 27′	177° 14′	0	— 1°.0	1.0242	1.0247		3.05
	noon	69° 25′	177° 20′	0	— 0°.8	1.0243	1.0248		3.07
	4 p. m.	69° 22′	177° 38′	0	— 0°.9	1.0238	1.0243		3.01
	8 p. m.	»	»	0	— 1°.4	1.0232	1.0237		2.93
				5	— 1°.3	1.0233	1.0238		2.94
				10	— 1°.2	1.0243	1.0248		3.07
» 9	0 a. m.	»	»	0	— 1°.4	1.0237	1.0242		3.00
	4 a. m.	»	»	0	— 1°.6	1.0243	1.0248		3.07
	8 a. m.	»	»	0	— 1°.8	1.0237	1.0242		3.00
	noon	»	»	0	— 1°.2	1.0237	1.0242		3.00
	4 p. m.	»	»	0	— 1°.5	1.0237	1.0242		3.00
	8 p. m.	»	»	0	— 1°.5	1.0236	1.0241		2.98
» 10	0 a. m.	»	»	0	— 1°.6	1.0230	1.0235		2.91
	4 a. m.	»	»	0	— 1°.6	1.0238	1.0243		3.01
	8 a. m.	»	»	0	— 1°.6	1.0237	1.0242		3.00
	noon	69° 26′	177° 30′	0	— 1°.4	1.0230	1.0235		2.91
	4 p. m.	69° 26′	177° 30′	0	— 1°.4	1.0232	1.0237		2.93

Date 1878	Time of the day.	Lat.	Long. E. G.	Depth in metres.	Temperature t° C.	Spec. gravity observed.	Spec. gravity reduced to $\frac{t^\circ}{+4^\circ}$ C or $\frac{0^\circ}{+4^\circ}$ C.	Percent of Cl.	Salt in percent.
Sept. 10	8 p. m.	69° 26′	177° 30′	0	— 1°.2	1.0241	1.0246		3.04
» 11	0 a. m.	»	»	0	— 1°.4	1.0242	1.0247		3.05
	4 a. m.	»	»	0	— 1°.6	1.0233	1.0238		2.94
	8 a. m.	69° 22′	178° 12′	0	— 1°.3	1.0245	1.0250		3.09
	noon	69° 10′	178° 58′	0	— 0°.8	1.0232	1 0237		2.93
	4 p. m.	69° 8′	178° 48′	0	— 0°.8	1.0230	1.0235		2.91
	8 p. m.	69° 3′	179° 28′	0	— 1°.3	1.0232	1.0237	1.63 P.	2.93
				5	— 1°.3	1.0232	1.0237	1.64 P.	2.93
				10	— 1°.2	1.0243	1.0248	1.66 P.	3.07
» 12	0 a. m.	69° 3′	179° 28′	0	— 1°.4	1.0232	1 0237		2.93
	4 a. m.	69° 3′	179° 28′	0	— 1°.4	1.0232	1.0237		2.93
	8 a. m.	69° 0′	180° 10′	0	— 1°.0	1.0225	1.0230		2.84
	noon	68° 55′	180° 52′	0	— 1°.2	1.0233	1.0238		2.94
	4 p. m.	68° 55′	180° 40′	0	— 1°.2	1.0229	1.0234		2.89
	8 p. m.	»	»	0	— 1°.0	1.0220	1.0225		2.78
» 13	0 a. m.	»	»	0	— 1°.0	1.0213	1.0218		2 70
	4 a. m.	»	»	0	— 1°.0	1.0225	1.0230		2.84
	8 a. m.	»	»	0	— 1°.2	1.0226	1.0231		2.85
	noon	»	»	0	— 1°.0	1.0229	1.0234		2.89
	4 p. m.	»	»	0	— 1°.2	1.0233	1.0238		2.94
	8 p. m.	»	»	0	— 1°.1	1.0230	1.0235		2.91
» 14	0 a. m.	»	»	0	— 1°.2	1.0230	1.0235		2.91
	4 a. m.	»	»	0	— 1°.3	1.0230	1.0235		2.91
	8 a. m.	»	»	0	— 1°.2	1.0230	1.0235		2.91
				2	— 1°.2	1.0230	1.0235		2.91
				4	— 1°.2	1.0229	1.0234		2.89
				6	— 1°.1	1.0230	1.0235		2.91
				8	— 1°.3	1.0234	1.0239		2 95
				10	— 1°.3	1.0236	1.0241		2.98
	noon	»	»	0	— 1° 2	1.0230	1 0235		2.91
	4 p. m.	»	»	0	— 1°.2	1.0230	1.0235		2.91
	8 p. m.	»	»	0	— 1°.2	1.0230	1.0235		2.91
» 15	0 a. m.	»	»	0	— 1°.4	1.0230	1.0235		2.91
	4 a. m.	»	»	0	— 1° 4	1.0230	1.0235		2.91
	8 a. m.	»	»	0	— 1°.4	1.0230	1.0235		2.91
	noon	»	»	0	— 1°.4	1.0225	1.0230		2.84
	4 p. m.	»	»	0	— 1°.4	1.0230	1.0235		2 91
	8 p. m.	»	»	0	— 1°.3	1.0230	1.0235		2.91
» 16	0 a. m.	»	»	0	— 1°.0	1.0230	1.0235		2.91
	4 a. m.	»	»	0	— 1°.2	1.0230	1.0235		2.91
	8 a. m.	»	»	0	— 1°.2	1.0233	1.0237		2.93
				5	— 1°.2	1.0230	1.0235		2.96
				10	— 1°.3	1.0235	1.0240		2 97
	noon	»	»	0	— 1°.2	1.0230	1.0235		2.91
	4 p. m.	»	»	0	— 1°.2	1.0232	1.0237		2 93
	8 p. m.	»	»	0	— 1°.2	1.0232	1.0237		2.93

Date 1878.	Time of the day.	Lat.	Long. E. G.	Depth in metres.	Temperature t° C.	Spec. gravity observed.	Spec. gravity reduced to $\frac{t°}{+4°}$ C or $\frac{0°}{+4°}$ C.	Percent of Cl.	Salt in percent.
Sept. 17	0 a. m.	68° 55′	180° 40′	0	— 1°.2	1.0232	1.0237		2.93
	4 a. m.	»	»	0	— 1°.4	1.0225	1.0230		2.84
	8 a. m.	»	»	0	— 1°.2	1.0230	1.0235		2.91
	noon	»	»	0	— 0°.9	1.0225	1.0230		2.84
	4 p. m.	»	»	0	— 0°.9	1.0228	1.0233		2.88
	8 p. m.	»	»	0	— 1°.2	1.0228	1.0233		2.88
» 18	0 a. m.	»	»	0	— 1°.4	1.0225	1.0230		2.84
	4 a. m.	»	»	0	— 1°.2	1.0226	1.0231		2.85
	8 a. m.	»	»	0	— 1°.2	1.0225	1.0230		2.84
	noon	»	»	0	— 1°.2	1.0226	1.0231		2.85
	8 p. m.	68° 55′	180° 35′	0	— 1°.2	1.0225	1.0230		2.84
				1	— 1°.2	1.0226	1.0231		2.85
				2	— 1°.2	1.0226	1.0231		2.85
				3	— 1°.2	1.0227	1.0232		2.86
				4	— 1°.2	1.0229	1.0234		2.89
				5	— 1°.2	1.0230	1.0235		2.91
				6	— 1°.1	1.0230	1.0235		2.91
				7	— 1°.2	1.0231	1.0236		2.92
				8	— 1°.3	1.0233	1.0238		2.94
				9	— 1°.3	1.0234	1.0239		2.95
				10	— 1°.3	1.0235	1.0240		2.97
» 19	0 a. m.	68° 45′	178° 45′	0	— 0°.6	1.0182	1.0186		2.31
	4 a. m.	68° 45′	178° 45′	0	0	1.0115	1.0118		2 45
	8 a. m.	68° 35′	178° 7′	0	+ 0°.4	1.0175	1.0179		2.21
	noon	68° 23′	177° 30′	0	— 0°.8	1.0210	1.0215		2.66
	4 p. m.	68° 19′	176° 58′	0	+ 0°.2	1.0154	1.0158		1.94
	8 p. m.	68° 12′	176° 43′	0	+ 0°.8	1.0120	1.0123		1.50
» 20	0 a. m.	68° 12′	176° 43′	0	+ 0°.8	1.0122	1.0125		1.51
	4 a. m.	68° 12′	176° 43′	0	+ 0°.1	1.0130	1.0133	0.92 P.	1.65
				4	— 0°.4	1.0141	1.0144	1.01 P.	1.78
				8	— 0°.7	1.0155	1.0158	1.09 P.	1.95
				12	— 1°.4	1.0215	1.0220	1.50 P.	2.66
				16	— 1°.6	1.0228	1.0233	1.58 P.	2.88
				20	— 1°.2	1.0233	1.0238	1.64 P.	2.94
	8 a. m.	68° 12′	176° 25′	0	— 0°.6	1.0138	1.0142		1.71
	noon	68° 12′	176° 32′	0	— 1°.0	1.0130	1.0133		1.65
				4	— 0°.4	1.0129	1.0132		1.63
				8	— 0°.6	1.0139	1.0142		1,76
				16	— 1°.1	1.0169	1.0172	1.14 P.	2.13
	4 p. m.	»	»	0	0	1.0107	1.0109		1.33
	8 p. m.	»	»	0	+ 0°.4	1.0100	1.0100		1.23
» 21	0 a. m.	»	»	0	+ 0°.2	1.0089	1.0089		1.10
	4 a. m.	»	»	0	+ 0°.4	1.0082	1.0082		1.00
	8 a. m.	»	»	0	0	1.0113	1.0115		1.43
	noon	»	»	0	0	1.0106	1.0107		1.29
	4 p. m.	»	»	0	+ 0°.2	1.0106	1.0107		1.29

Date 1878.	Time of the day.	Lat.	Long. E. G.	Depth in metres.	Temperature F. C.	Specific gravity observed.	Specific gravity reduced to + 4° C.	Content of Cl.	Cl in percent.
Sept. 21	8 p. m.	68° 12′	176° 32′	0	+ 0°.2	1.0102	1.0102		1.23
» 22	0 a. m.	»	»	0	0	1.0100	1.0100		1.22
	4 a. m.	»	»	0	+ 0°.3	1.0089	1.0089		1.10
	8 a. m.	»	»	0	+ 0°.6	1.0084	1.0084		1.04
	noon	»	»	0	+ 0°.8	1.0079	1.0079		0.98
	4 p. m.	»	»	0	+ 1°.0	1.0079	1.0079		0.98
	8 p. m.	»	»	0	+ 0°.7	1.0077	1.0077		0.95
» 23	0 a. m.	»	»	0	+ 0°.7	1.0066	1.0066		0.81
	4 a. m.	»	»	0	+ 0°.6	1.0065	1.0065		0.80
	8 a. m.	68° 11′	176° 27′	0	+ 0°.6	1.0027	1.0027		0.33
	noon	68° 10′	176° 22′	0	— 0°.2	1.0089	1.0089		1.10
	4 p. m.	68° 8′	176° 12′	0	— 0°.4	1.0143	1.0146		1.82
	8 p. m.	68° 0′	176° 6′	0	0	1.0090	1.0090		1.11
				5	— 0°.9	1.0142	1.0145		1.79
				10	— 1°.3	1.0210	1.0215		2.66
				15	— 1°.4	1.0225	1.0230		2.84
				20	— 1°.4	1.0237	1.0242		3.00
» 24	0 a. m.	68° 0′	176° 6′	0	— 0°.2	1.0089	1.0089		1.10
	4 a. m.	68° 0′	176° 6′	0	— 0°.4	1.0089	1.0089		1.10
	8 a. m.	67° 58′	176° 10′	0	0	1.0098	1.0098		1.20
	noon	67° 53′	176° 6′	0	0	1.0079	1.0079		0.98
	4 p. m.	»	»	0	0	1.0077	1.0077		0.95
	8 p. m.	»	»	0	— 0°.4	1.0078	1.0078		0.96
» 25	0 a. m.	»	»	0	— 0°.2	1.0077	1.0077		0.95
	4 a. m.	»	»	0	— 0°.4	1.0077	1.0077		0.95
	8 a. m.	»	»	0	0	1.0067	1.0067		0.82
	noon	»	»	0	+ 0°.8	1.0062	1.0062		0.78
» 26	0 a. m.	67° 47′	176° 0′	0	— 0°.2	1.0050	1.0052		0.64
	4 a. m.	67° 47′	176° 0′	0	0	1.0052	1.0052		0.64
	8 a. m.	67° 46′	175° 25′	0	+ 0°.8	1.0039	1.0039		0.48
	noon	67° 41′	174° 42′	0	+ 0°.8	1.0060	1.0060		0.76
	4 p. m.	67° 40′	174° 39′	0	0	1.0093	1.0093		1.15
	8 p. m.	67° 34′	174° 39′	0	— 0°.8	1.0152	1.0155		1.90
» 27	0 a. m.	»	»	0	— 1°.2	1.0150	1.0153		1.89
	4 a. m.	»	»	0	— 1°.2	1.0150	1.0153		1.89
	8 a. m.	67° 29′	174° 20′	0	— 0°.8	1.0163	1.0166		2.05
	noon	67° 16′	174° 12′	0	— 0°.2	1.0171	1.0174		1.15
	4 p. m.	67° 4′	173° 35′	0	0	1.0112	1.0114		1.39
	8 p. m.	67° 7′	173° 32′	0	— 0°.6	1.0116	1.0118		1.45
» 28	0 a. m.	»	»	0	— 0°.8	1.0110	1.0112		1.38
	4 a. m.	»	»	0	— 0°.8	1.0120	1.0122		1.49
	8 a. m.	67° 5′	173° 15′	0	— 0°.8	1.0108	1.0110		1.36
	noon	Pitlekaj		0	— 0°.2	1.0092	1.0092		1.13
	4 p. m.	»		0	— 0°.8	1.0080	1.0080		0.99
	8 p. m.	»		0	— 0°.4	1.0092	1.0092		1.13
» 29	0 a. m.	»		0	— 0°.4	1.0095	1.0095		1.17

Date 1878.	Time of the day.		Long. E. G.	Depth in metres	Temperature t° C.	Spec. gravity observed.	Spec. gravity reduced to t° C or +4° C.	Percent of Cl.	Salt in percent.
Sept. 29	4 a. m.	Pitlekaj		0	— 0°.4	1.0093	1.0093		1.14
	8 a. m.	»		0	— 0°.4	1.0097	1.0097		1.19
	noon	»		0	— 0°.0	1.0089	1 0089		1.10
	4 p. m.	»		0	— 0°.2	1.0091	1 0091		1.12
	8 p. m.	»		0	— 0°.2	1.0095	1 0095		1.17
» 30	0 a. m.	»		0	— 0°.8	1.0092	1.0092		1.13
	4 a. m.	»		0	— 0°.8	1.0095	1.0095		1.17
	8 a. m.	»		0	— 0°.8	1.0095	1.0095		1.17
	noon	»		0	— 0°.8	1.0095	1.0095		1.17
	4 p. m.	»		0	— 0°.8	1.0096	1.0096		1.18
	8 p. m.	»		0	— 0°.8	1.0096	1.0096		1.18

Winter-observations at Pitlekaj.

Some of these observations, which concern the saltness of the ice, the efflorescence of Rossol salt and the appearance of salt brines on the surface of the ice-floes are discussed in the foregoing paper. In the following table are enumerated some determinations of the temperature and spec. gravity of the sea-water beneath the ice.[1] The titrations were made on board the ship.

Depth.	Oct. 15. 11 a. m.	Nov. 1. 11 a. m.	Nov. 15. 10 a. m.	Dec. 1. 10 a. m.	Dec. 20. 11 a. m.	Jan. 10. 11 a. m.	Jan. 29. 4 p. m.	Febr. 10. noon.
0 m.	— 1°.4 C	— 1°.5 C	— 1°.5 C	— 1°.4 C	— 1°.5 C	— 1°.5 C	— 1°.9 C	— 1°.6 C
2 m.	— 1°.6 C	— 1°.5 C	— 1°.6 C	— 1°.6 C	— 1°.8 C	— 1°.8 C	— 1°.8 C	— 1°.7 C
5 m.	— 2°.0 C	— 1°.5 C	— 1°.8 C	— 2°.0 C	— 1°.8 C	— 1°.7 C	— 1°.9 C	— 1°.7 C
8 m.	— 1°.6 C	— 1°.7 C	— 1°.8 C	— 1°.7 C	— 1°.8 C	— 1°.9 C	— 2°.0 C	— 1°.8 C
10 m.	— 1°.8 C	— 1°.9 C	— 2°.1 C	— 1°.8 C	— 2°.0 C	— 1°.9 C	— 2°.2 C	— 2°.2 C

[1] The thickness of the ice was measured once or twice every month. The following transumt is taken from »Vegas färd kring Asien och Europa» (page 449, Swedish edition):

Dec.	1st	56 centimetres		May	1st	154	centimetres
Jan.	1st	92	»	»	15th	162	»
Febr.	1st	108	»	June	1st	154	»
»	15th	120	»	»	15th	151	»
March	1st	123	»	July	1st	104	»
April	1st	128	»	»	15th	67	»
»	15th	139	»	»	18th	—	»

From the 28th Febr. 1879 regular areometric determinations of the spec. gravity of the water-samples and titrations of Cl were made simultaneously with the temperature observations.

Date 1879.	Time of the day.	Depth in metres.	Temperature of the water C.	Spec. gravity observed.	Spec. gravity at ° C.	Grammes of Cl in 1000 cc. water.	P. c. of Cl.	P. c. of salt.
Febr. 28	noon	0	— 1°.5			16.6		
		2	— 1°.7					
		4.4				16.6		
		6	— 1°.8					
		8	— 1°.9					
		10	— 2°.3			16.8		
March 11	10 a. m.	0	— 1°.9					
		2	— 2°.0	1.0220	+ 8°.6	16.6	1.62	2.92
		4	— 2°.6	1.0221	+ 8°.6	17.0	1.67	3.01
		6	— 2°.4	1.0222	+ 9°.0	17.0	1.67	3.01
		8	— 2°.0	1.0228	+ 8°.6	17.4	1.70	3.06
		10	— 2°.0	1.0225	+ 9°.0	17.5	1.72	3.00
April 1	2 p. m.	0	— 1°.8					
		2	— 1°.8	1.0220	+ 10°.0	17.1	1.67	3.01
		4	— 2°.0	1.0221	+ 10°.6	17.1	1.67	3.01
		6	— 2°.0	1.0221	+ 10°.6	17.3	1.70	3.06
		8	— 2°.2	1.0223	+ 10°.4	17.3	1.70	3.06
		10	— 2°.0	1.0224	+ 10°.4	15.4	1.70	3.06
» 14	2 a. m.	0	— 2°.0					
		2	— 2°.8	1.0227	+ 7°.8	16.3	1.60	2.89
		4	— 3°.0	1.0217	+ 7°.2	15.5	1.51	2.72
		6	— 2°.4			16.8		
		8	— 2°.0			16.5		
		10	— 2°.4			14.7		
» 26	10 a. m.	0	— 1°.6	1.0208	+ 8°.2	15.5	1.51	2.72
		5	— 1°.8			16.6		
		10	— 1°.4	1.0225	+ 8°.2	16.6	1.63	2.93
May 3	9 a. m.	0	— 2°.0					
		4	— 2°.1	1.0226	+ 8°.5	16.6	1.63	2.93
		6	— 2°.3	1.0225	+ 8°.8	16.5	1.61	2.90
		8	— 2°.0	1.0229	+ 8°.3	16.7	1.64	2.94
		10	— 1°.8	1.0227	+ 8°.3	16.6	1.62	2.92
June 9		0	— 1°.0	1.0223	+ 11°.6	16.4	1.61	2.90
		3	— 1°.5	1.0223	+ 12°.0	16.6	1.62	2.92
		6	— 1°.4	1.0224	+ 12°.2	16.8	1.64	2.95
		10	— 1°.5	1.0226	+ 12°.4	16.9	1.65	2.96

The titrations, which were executed in the cabin by lamplight are of course only approximately exact. Still they bear out an important and unexpected result, viz. that the

water beneath the ice was for the most part cooled below its normal freezing point [— 1°.5 to — 1°.7 C]. From the increasing thickness of the ice-floes we must infer, that the sea-water below was constantly giving up ice. Consequently we ought to expect, that its temperature would remain precisely at the normal freezing-point during the whole time. Although I am acquainted with many similar observations from previous deep-soundings in arctic seas, I can find no plausible explanation for the strange fact, that water, which is in contact with ice, can be over-cooled at the same time. From a physical point of view such temperatures as f. ex. — 2°.8 C or — 3°.0 C in water, which does not contain more than 2.72 p. c. of salt and has a spec. weight of not more than 1.0217 — 1.0227 or thereabouts must be considered as abnormal.

The lowest temperatures hitherto observed in the ocean are those found in Baffin Bay [t = — 2°.8 C; depth = 1478 metres (Parry), and t = — 3°.7 C; depth = 1243 metres (Ross & Sabine) and west of Spitzbergen, 1873, by the Swedish expedition [t = — 3°.2 C; depth = 142 metres] and (in the same year) by Mr. Leigh Smith [t = — 5°.1 C; depth = 1005 metres]. The numbers in the above tables, taken from the observations in the winter 1878—79 at Pitlekaj, do not range among the lowest submarine temperatures ever observed, but are, however, still more remarkable by the circumstance, that the cold layer was found only a few metres below the surface. The low temperatures observed in the sea east and west of Greenland belonged to a stratum of water 140 to 1000 metres beneath the surface, which was exposed to an enormous pressure. The rate, at which the freezing point of salt water decreases under the influence of pressure, is at present totally unknown to us. It might therefore be possible that the water of — 5° C

[1] We ought by no means *a priori* to apply the formula found by J. Thomson (Transact. R. S. E. T. XVI) for the depression of the freezing-point of pure water also to sea-water. The mistakes, which have arisen from confounding the properties of sea-water and fresh water, or sea-ice with fresh-water-ice, are too numerous and flagrant not to impress the necessity of experimental investigation. In the same way, as the majority of hydrographers 30 or 40 years ago took for granted, that the maximum density of sea-water was at + 4° C, like that of fresh water, and that the sea from a thousand metres from the surface to the bottom had a constant temperature etc., science has hitherto tacitly supposed, that the dilatation, the chemical composition and the latent heat of sea-ice was equal or *almost equal* to that of fresh-water-ice. In the preceding paper I have tried to show up the fallacy of these assumptions.

was not over-cooled, but was kept liquid by the influence of the pressure, but in the case f. ex. of the observations from the 14th April 1879 at Pitlekaj we can not well resort to this explanation.

From the commencement of June the thickness of the ice began to diminish and the temperature of the sea-water increased. The following table contains the last deep-soundings made at Pitlekaj.

Depth.	June 21. 11 a. m.	June 25. 11 a. m.	July 1. 10 a. m.	July 7 (10 a. m.)		
				Temperature.	P. c. of Cl.	P. c. of salt.
0	+ 2°.5 C	+ 0°.9 C	+ 0°.2 C	+ 4°.1 C	0.026 p. c.	0.047 p. c.
5	——	— 0°.4 C	0 C	+ 0°.6 C	0.072 »	0.129 »
7	——	— 0°.9 C	— 0°.2 C	— 1°.0 C	1.27 »	2.28 »
10	— 1°.4 C	— 1°.4 C	— 1°.2 C	— 0°.6 C	1.65 »	2.97 »

Water-analyses.

I choose this opportunity to mention briefly the results of some quantitative analyses on samples of sea-water taken from various localities and from different depths of the Siberian Ocean. At my request Mr. Forsberg, assistant teacher of chemical analysis at the laboratory of the university of Stockholm, undertook these determinations. The experimental methods for the determination of the constituent parts of sea-water: sodium, potassium, lime, magnesium etc... are too well known to need any description here. Some practical precautions in the analytical operations have been recommended lately by experienced chemists and hydrographers, such as Prof. Ekman[1] and Mr. Schmelck.[2] Mr. Forsberg agreed with my opinion, that the experimental proceeding ought to be conducted strictly in accordance with these principles, in order to make the investigation of the Siberian Ocean conformable to the previous researches on the water of the North-Atlantic, the Kattegatt and the Baltic. Suffice it then to say, that the amount of

1) Lime was weighed[3] as CaO, obtained by calcination of

[1] Om hafsvattnet utmed Bohuslänska kusten. K. V. A:s H. Bd 9. N:o 4.

[2] Norwegian North-Atlant. exped. 1876—78. IX.

[3] According to my own opinion it would be far better to calculate the amount of Na, Ka, Mg, Ca, SO_4, Cl contained in 1000 cc. of the sea-water [at 0° C], but as the usual method is: to represent empirically the composi-

the oxalate after doubly repeated precipitation with oxalate of ammonium.

2) Magnesia was weighed as $Mg_2O_4P_2O_3$.

3) Sulphuric acid [calculated as SO_3] was determined as BaO_2SO_2.

4) Potassium [calculated as Ka_2O] was determined as $Ka_2Cl_4PtCl_2$.

5) Sodium [calculated as Na_2O] was determined as NaCl [from the difference between the sum of chlorides [KaCl + NaCl] and KaCl].

6) Chlorine + Bromine was determined by titration with silver nitrate [by the author].

Sea-waters (Siberian ocean).

Locality. Lat.	Locality. Long. E. G.	Depth. Metres.	Ka_2O in percent.	Na_2O in percent.	MgO in percent.	CaO in percent.	SO_3 in percent.	Cl + Br. in percent.
77° 39′	105° 0′	128	0.0493	1.4272	0.2155	0.0565	0.2228	1.920
70° 14′	170° 17′	22	0.0440	1.2440	0.1963	0.0510	0.1944	1 691
73° 59′	113° 12′	11	0.0265	0.7817	0.1236	0.0320	0.1248	1.065
73° 05′	144° 40′	7	0.0190	0.5680	0.0874	0.0240	0.0908	0.763
Salt brines and crystals found upon the ice.								
liquid intermingled with crystals of snow collected at — 32° C			0.1802	5.3812	1.9080	0.4323	0.1617	9.636
liquid inundating the ice at — 32° C (free from snow).			0.2787	8.2247	1.9168	0 4646	0.1508	13.198

The proportions of the constituents relatively to chlorine (= 100) are represented in the tables 1 & 2 in the 5th Chapter of the preceding paper. The chemical composition of the water from the different strata of the Siberian Ocean is —

tion of sea-water by its percentage of Ka_2O, Na_2O, MgO, CaO, Cl, SO_3, I felt bound to obey the general rule, of which I, however, can not approve, although it is supported by eminent authorities. On the other hand I have purposely abstained from the manner of *rational* computation usually adopted in water-analysis, viz. to groupe together the basic and acid or halogen radicals into definite saline compounds: NaCl, $MgSO_4$, etc... which depends upon hypothetical assumptions not sufficiently warranted by facts. I think that the discrepancies in the hydrographical measures and methods could best be removed by international agreement.

contrary to what might be expected — not more variable than in the Atlantic.

Sea-waters (Siberian ocean).

Lat.	Long. E. Green.	Depth. Metres.	Cl.	Ca 0.	Mg 0.	S 0_3.	Ka_2 0.	Na_2 0.
77° 40′	105° 10′	128	100	2.97	11.32	11.70	2.59	74.99
70° 14′	170° 17′	22	100	3.01	11.60	11.49	2.60	73.53
73° 59′	113° 13′	11	100	3.00	11.60	11.71	2.48	73.40
73° 05′	144° 40′	7	100	3.14	11.44	11.89	2.48	74.38
Brines.								
brine free from crystals (snow?)			100.	3.52	14.52	1.14	2.11	62.32
liquid brine with crystals, snow?			100	4.48	19.80	1.67	1.87	55.84

In the waters from the North-Atlantic Mr. Schmelck found the following proportions.

	Surface.	Intermed. depths.	Bottom.	Mean value.	Maximum.	Minimum.
Ca 0 : Cl (= 100)	2.98	2.98	3.01	2.99	3.08	2.79
Mg 0 : Cl (»)	11.42	11.37	11.42	11.40	11.77	10.90
S 0_3 : Cl (»)	11.46	11.49	11.42	11.46	11.64	11.14

The amount of SO_3 and CaO relatively to Cl in the upper layers of the Siberian sea is *greater* than in the Atlantic. The cause of this is twofold, viz. the admixture of river-water and the chemical phenomena accompanying the freezing and melting of sea-ice.

Hydrographic observations in the Behring Sea.

The following table contains the results of the deep-soundings in the Behring Sea. The results obtained during the voyage from Port Clarence on the American coast to Konyam Bay on the Asiatic side of the strait are graphically represented on section XII, plate 26.

Table 4.

Date 1879.	Time of the day.	Lat.	Long. V. G.	Depth.	Temperature C.	Spec. gravity observed.	Spec. gravity reduced to $\frac{+4^\circ}{0^\circ}$ C or $\frac{+4^\circ}{0^\circ}$ C.	Saltness in p. c.
July 24	noon	Port Clarence		0	+ 11°.8	1.0140	1.0143	1.77
				7	+ 6°.8	1.0194	1.0198	2.45
» 25	0 a. m.	»		0	+ 10°.2	1.0120	1.0122	1.50
				7	+ 6°.4			
» 26	8 p. m.	65° 13′	166° 43′	0	+ 11°.0	1.0190	1.0194	2.40
				4	+ 10°.9	1.0191	1.0195	2.41
				8	+ 8°.8	1.0206	1.0211	2.61
				12	+ 7°.4	1.0223	1.0228	2.82
» 27	0 a. m.	65° 8′	167° 59′	0	+ 6°.5	1.0244	1.0249	2.08
				13	+ 5°.8	1.0247	1.0252	3.11
				27	+ 2°.6	1.0248	1.0253	3.13
				40	+ 5°.2	1.0248	1.0253	3.13
	4 a. m.	65° 3′	168° 50′	0	+ 2°.8	1.0240	1.0245	3.03
				15	+ 2°.0	1.0239	1.0244	3.02
				30	+ 0°.8	1.0242	1.0246	3.04
				55	+ 1°.5	1.0238	1.0243	3.01
	8 a. m.	65° 12′	169° 7′	0	+ 3°.6	1.0255	1.0260	3.22
				59	+ 2°.2	1.0250	1.0255	3.15
	noon	65° 9′	169° 47′	0	+ 3°.3	1.0238	1.0243	3.01
				20	+ 1°.9	1.0240	1.0246	3.04
				40	+ 4°.8	1.0242	1.0246	3.04
				60	+ 1°.6			
	4 p. m.	65° 5′	170° 23′	0	+ 2°.7	1.0252	1.0257	3.18
				16	+ 2°.4	1.0253	1.0258	3 19
				32	+ 1°.9	1.0253	1.0258	3.19
				50	+ 2°.0	1.0253	1 0258	3.19
	8 p. m.	65° 1′	170° 58′	0	+ 2°.6	1.0252	1.0257	3.18
				16	+ 2°.0	1.0252	1.0257	3.18
				32	+ 2°.2	1.0252	1.0257	3.18
				52	+ 2°.3	1.0252	1.0257	3.18
» 28	0 a. m.	64° 57′	171° 35′	0	+ 3°.0	1.0216	1.0221	3.73
				12	0	1.0250	1.0255	3.15
				24	+ 0°.4	1.0250	1.0255	3.15
				36	+ 0°.8	1.0250	1.0255	3.15
» 29	8 a. m.	64° 49′ (Konyam bay)	172° 58′	0	+ 5°.0	1.0100	1.0100	1.23
				6	— 0°.3	1.0230	1.0235	2.91
				11	— 1°.4	1.0240	1.0245	3.03
				17	— 0°.6	1.0248	1.0253	3.13
» 30	8 p. m.	64° 49′	172° 37′	0	+ 6°.4	1.0130	1 0232	1.63
				30	— 0°.8	1.0234	1.0239	2.96
				60	— 0°.4	1.0235	1.0239	2.96
				88	— 0°.2	1.0238	1.0243	3.01
» 31	4 a. m.	64° 30′	171° 43′	0	+ 1°.2	1.0228	1.0233	2.88

Date 1879.	Time of the day.	Lat.	Long. V. G.	Depth.	Temperature C.	Spec. gravity observed.	Spec. gravity reduced to $\frac{+4^\circ}{0^\circ}$ C or $\frac{+4^\circ}{0^\circ}$ C.	Saltness in p. c.
				10	+ 0°.2	1.0240	1.0245	3.03
				21	+ 0°.6	1.0242	1.0247	3.05
				44	+ 1°.2	1.0243	1.0248	3.07
Aug. 1	8 a. m.	64° 48′ (St. Lawrence Isl.)	171° 25′	0	+ 5°.4	1.0236	1.0141	2.98
				5	+ 5°.4	1.0235	1.0240	2.97
				10	+ 5°.4	1.0236	1.0235	2.90
				16	+ 5°.4	1.0238	1.0243	3.01
» 4	4 p. m.	63° 16′	175° 2′	0	+ 6°.0	1.0243	1.0248	3.07
				30	— 0°.2	1.0244	1.0249	3.08
				60	— 0°.8	1.0249	1.0254	3.14
				90	+ 0°.8	1.0252	1.0247	3.18
» 5	4 p. m.	62° 37′	176° 39′	0	+ 6°.5	1.0244	1 0249	3.08
				65	+ 0°.4	1.0249	1.0254	3.14
				100	+ 1°.2	1.0259	1.0264	3.26
» 6	4 p. m.	61° 52′	179° 43′	0	+ 8°.2	1.0238	1.0245	3.03
				50	— 1°.2	1.0249	1.0254	3.14
				100	+ 1°.5	1.0251	1.0256	3.17
				153	+ 2°.5	1.0254	1.0259	3.20
» 7	4 p. m.	60° 20′	179° 32′	0	—			
				50	+ 2°.4	1.0254	1.0259	3.20
				100	+ 2°.0	1.0254	1.0259	3.20
				170	+ 2°.2	1 0254	1.0259	3.20

The most interesting observations are those from the 27th & 28th July 1879. The section XII on plate 26 represents the constitution of the sea a few miles south of Behring strait. In Mr. Bove's description of the Vega-expedition the reader will find a diagram representing the temperatures at different depths in this strait. They seem to bear out that a current of warm water from the Pacific flows into the Siberian Sea, along the American coast, while a cold current of arctic water passes in the contrary direction along the Asiatic side of the strait. The above table as well as section XII shows, that the temperature of the water is much higher at the American side, but neither the temperature nor the saltness of the water at the Asiatic side seems to warrant the conclusion, that it should belong to a *cold stream* from the *arctic* ocean. The sea-currents on both sides of the Behring strait are far from sufficiently explored yet, and the Vega-expedition could do very little to this purpose. Previous observations made by

Wrangel and by American officers bear out the fact, that the current in this strait and in the adjacent parts of the Siberian Sea changes its direction with the seasons. Dr. Stuxberg[1] asserts that, according to the statement of the aborigines, the water in autumn and winter flows from the arctic sea into the Pacific, in spring and summer in the contrary direction. The observations of the Vega-expedition, made on the 27th & 28th July, do not contradict this rule. The temperature and saltness of the water at the Asiatic coast can very well belong to a current of Pacific water flowing northward, whereof the warmer branch takes its way along the eastern coast of the Behring strait.

[1] »Evertebratfaunan i Sibiriens Ishaf.» Vega-expeditionens vetenskapliga iakttagelser, Bd I. Lately Mr. H. W. Dall has published some observations from the Behring Strait made on board the schooner Yukon. [American Journal of Sciences XXI, 1881] from which I cite the following lines: »The water is warmest toward the American side. The highest temperature (commencement of Sept.) is 48° F. and the lowest about 36° F. . . . The uniformity of the temperatures from top to bottom does away with the idea of a sub-surface current from the Arctic ocean carrying cold water southward.»