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First report of the joint panel on oceanographic tables and standards

held at Copenhagen
5-6 October 1964
sponsored by
UNESCO, ICES, SCOR, IAPO

Unesco

UNESCO TECHNICAL PAPERS IN MARINE SCIENCE, No.1

FIRST REPORT OF THE JOINT PANEL ON OCEANOGRAPHIC TABLES AND STANDARDS

held at
Copenhagen, 5-6 October, 1964

jointly sponsored by the

United Nations Educational, Scientific and Cultural Organization
International Council for the Exploration of the Sea
Scientific Committee on Oceanic Research
International Association of Physical Oceanography

1965

The scientific views expressed here are those of experts participating in the work of the Panel and not necessarily those of Unesco or other sponsoring organizations.

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This report concerns a meeting held at Charlottenlund Slot, Denmark, on 5/6 October, 1964. The meeting was sponsored jointly by the Hydrographical Committee of ICES and Unesco, and was convened by Dr. R.A. Cox who took the Chair. Present were:

1. Members of the joint IAPO/SCOR/ICES/UNESCO panel on oceanographic tables and standards:

   D.E. Carritt (U.S.A.)
   R.A. Cox (U.K.)
   N.P. Fofonoff (U.S.A.)
   F. Hermann (Denmark)
   Y. Miyaki (Japan)
   O. Saelen (Norway)

   Apologies for absence were received from G. Dietrich (Germany) and G.N. Ivanoff-Frantzkevich (U.S.S.R.)

2. Participants in the meeting, in addition to the members of the panel included:

Argentina	-	A. Orlando
Denmark	-	S.F. Larsen, J. Smed
Finland	-	I. Hela, A. Voipio, F. Koroleff
Germany	-	K. Grasshof, G. Weichart
Iceland	-	S.A. Malmberg
Netherlands	-	R. Dorrestein
Norway	-	J. Eggvin, E. Føyn
Spain	-	N. Menendez
Sweden	-	B. Kullenberg, A. Svansson, S.H. Fonselius
U.K.	-	F. Culkin, D.P.D. Scott
UNESCO	-	K.N. Fedorov
U.S.A.	-	J. Lyman

First Session, Monday morning

In his introduction, the chairman, Dr. R.A. Cox, referred to the first and second reports of the joint panel on the equation of state of sea water and explained that on the disbanding of this committee in Berkeley in August, 1963, the members, with the addition of Dr. O. Saelen, were designated the joint panel on oceanographic tables and standards. He listed certain problems which would be considered by the meeting. Following is a summary of the chairman's remarks, as distributed before the meeting:-

The "Equation of State" of Sea Water

The "equation of state" of sea water is the mathematical expression to calculate density from measurements of temperature, pressure and salinity, or from other parameters dependent on these. In its most usual form the equation is expressed with density or specific volume as a function of temperature, pressure and salinity. Salinity, however, can be replaced by any of a large range of measured properties such as conductivity, refractive index or sound velocity. All these properties, however, are themselves dependent on both temperature and pressure; computing the density from temperature, pressure and conductivity, for example, is more difficult than from salinity,

Virtually all the computations of density of sea water made during the last 60 years have been based on measurements of density, chlorinity and salinity by Forch, Knudsen and Sörensen, published in 1902, and of compression by Amagat in 1893 and Ekman in 1908. All these measurements were of very high quality, and even today it is unlikely that we can greatly improve on them. However, there are several aspects of the problem which have recently attracted considerable attention, and it is now certain that we do not know enough about the basic relationships; in consequence the full precision of modern techniques of measurement cannot be used.

Among the points where we need further knowledge are these

1. "Density". We refer our densities as ratios to the density of "pure water, but nobody has defined the pure water. Density of water varies according to the source, e.g., rain water is lighter than distilled sea water.

2. "Absolute density". Physical oceanographers take specific gravity measurements, take the reciprocal (specific volume) and give it units of cm^3/g. This is quite wrong, and we do not know the conversion factor to make it right.

3. Nobody has measured salinity for 60 years. At present chlorinity, conductivity and refractive index measurements are all being converted to "salinity" by inadequate tables of often doubtful origin. All make assumptions regarding constancy of relative proportions of the various ions, which are doubtful and may be quite unjustified, to the precision of our modern measurements.

The "Standard sea water programme" at the National Institute of Oceanography has been run to try and answer some of these problems; similar work is underway in several laboratories. Among other subjects for discussion at this meeting will be the present state of this work; and the future prospects.

In addition delegates will no doubt wish to discuss the recommendations of the joint ICES/SCOR/IAPO/UNESCO committee on the equation of state of sea water, and in particular how those recommendations may need modification from recent work. The members of the Committee are anxious that discussion and criticism should be as general as possible.

We hope that, at this meeting, the delegates will be able to describe other work in progress, or projected, in this difficult but important field.

Another matter which should be discussed is the intention of the International Bureau of Weights and Measures to re-define the litre as a cubic decimetre. This has a bearing on oceanographic units, and it may be that this meeting will wish to make representations to the International Bureau on the subject.

The Standard Sea Water Service is intending to distribute standard sea water as soon as is practicable, certified in conductivity as well as, or as an alternative to, chlorinity. There are serious difficulties to be overcome before this can be done, and it may well be helpful to discuss these difficulties.

The meeting then discussed certain details of the first and second reports. Most important was the problem of the definition of salinity. The chairman referred to discussions between Dr. Saelen and himself on the problems of an absolute standard of density; these discussions led to the conclusion that it would be preferable to use conductivity as the reference parameter, since this would shortly be determinable in absolute terms. Moreover, it was intended that the standard sea water would then be calibrated in conductivity.

The N.I.O. had about 400 determinations of conductivity and chlorinity on natural sea water samples. A regression equation had been computed from these connecting chlorinity (or salinity defined as S‰ = 1.80655 cl ‰) with conductivity ratio, defined as the ratio of the conductivity to that of standard sea water batch P 31, chlorinity 19.374, both samples being at 15°C. Equations had been computed from these values up to the sixth order, but it was found that beyond the second order there was no significant improvement in fit to the data. The quadratic equation was hence used to compute a table connecting relative conductivity with salinity. A sheet from this table, covering the salinity range 34.91 - 35.11 was distributed to the meeting, and is included with this report. (Appendix A).

This equation could serve as the definition of salinity. However, there was a difficulty. Most of the samples with a salinity of about 35‰ were deep samples; many of these contained more calcium than surface water and hence had a fractionally higher conductivity than standard sea water, which is Atlantic surface water. Thus a conductivity ratio of 1.0 did not correspond to a salinity of 35‰, but with 34.994‰. This was a perfectly correct result, and reflected the fact that the standard water was not quite average. However, this result was potentially confusing, and would mean that Atlantic deep salinities, for example, computed from the new tables would not exactly correspond with older figures.

Various ways of resolving this discrepancy were discussed. These included:

1. Using deep water for preparing future standard sea water

2. Increasing the conductivity of the standard by adding, for example, sodium sulphate

3. Displacing the equation by adding a constant

4. Computing a new equation, using surface observations only

5. As 4, but if necessary adding a constant to the equation to make ratio 1.0 exactly correspond to salinity 35‰.

After a long discussion, the fifth course of action was adopted. The computing of the new equation, using surface observations only, is at present underway at the N.I.O. This equation will serve as the definition of salinity; at the moment it will be available only in terms of relative conductivity, but shortly it will be possible to give the definition also in terms of the ohm and centimetre. This salinity, so defined, will correspond with the chlorinity of surface sea water as nearly as is permitted by the natural scatter of the relationship. However, to compute the most probable chlorinity of a deep oceanic water from this salinity, a small depth correction will be necessary, reflecting the different average composition of deep water.

The next step will be to relate this salinity to density. The chairman explained that all we can do at the moment is to relate salinity to specific gravity; that is a ratio of density to the density of a defined pure water at 4°C. The intention was to prepare such a pure water by distillation of sea water. There was considerable discussion on the best location from which to take the water, but it was finally agreed that water from 2000 m down in the western basin of the Mediterranean Sea would be as good as any; several speakers emphasized that the distillation procedure should be defined as closely as possible, and the water so prepared should be characterised by isotopic analysis.

There was also general agreement that comparisons should be made with water from various sources, to see if significant variations in density were apparent.

To compute density in absolute units, in g/cm^3, the absolute density of the reference water must be determined. This determination is beyond the resources of the N.I.O., but the chairman reported that the National Physical Laboratory in England would be prepared to undertake this determination if the necessary funds were available. The order of cost was estimated at £30,000 ($100,000).

The meeting decided to write to the Bureau International des Poids et Mesures, asking their support in this work. A copy of the letter and that of the answer are appended. (Appendix B).

Mr. Hermann, on behalf of the Standard Sea-Water Service, reported that several requests had been received for standard water with high and low salinities, in addition to the normal 35‰. The meeting felt that there was no point in such alternative standards for chlorinity determination, and little point for low-range conductivity measurements because of the wide natural scatter usually found at low salinities. In the special case of the Mediterranean, however, there might be a call for a conductivity standard with a salinity of about 38.5‰. The use of such a standard should lead to a significant improvement in precision by greatly reducing transfer errors.

When the new conductivity apparatus is working a high-salinity standard could be prepared on the same basis as the present standard, given a supply of suitable water. Dr. Fedorov undertook to raise the matter at the forthcoming meeting of Mediterranean oceanographers, in Monaco.

Second Session, Monday afternoon

The chairman gave the meeting a description of the apparatus for determination of absolute conductivity, which is at present under construction at the N.I.O. It is hoped to start trials with this apparatus within the next month, and if the first results are satisfactory, to have the apparatus complete early next year.

The apparatus involves a fused silica cell of known physical dimensions, in which are mounted two platinum electrodes, one fixed and the other movable. The cell contains the solution under test in a thermostat at 15°C ± 0.0005°C. A transformer bridge compares the resistance of the solution with that of a standard resistor. The movable electrode is then moved a known distance, and the resistance again measured. The change in resistance should be independent of electrode effects, and a true measure of conductivity in absolute units.

The intention was firstly to use this apparatus to measure the absolute conductivity of standard water P 31 at 15°C. Measurements would also be made at 15°C and 25°C on other sea waters and sodium and potassium chloride solutions. These measurements should take only a few weeks, after which the apparatus would be available for the calibration of the standard sea water in conductivity, and for such studies as the change in conductivity with time under various storage conditions.

Mr. Hermann raised the question of maintenance of the apparatus, pointing out that the Standard Sea Water Service had no access to skilled electronic maintenance staff. He suggested it would be better that the apparatus be kept at the N.I.O., where such help was available. The chairman said the apparatus was being designed and built to reduce maintenance to a minimum, and in case of major difficulties the N.I.O. staff would be able to help. It was decided, on the chairman's suggestion, that Mr. Hermann should visit the N.I.O. during the final tests and measurements with the apparatus, and that the question of the final location of the apparatus should then be agreed between Mr. Hermann and Dr. Cox, who should then ask the committee to approve their decision.

The chairman gave a brief account of measurements of refractive index, which were underway at N.I.O. A Jamin interferometer had been borrowed from Oxford University, and was giving good results. It seemed that with a 10 cm path length it would be possible to determine differences in refractive index to a few units in the 7th decimal, which would compare well with the precision of conductivity salinometers. The determination of absolute refractive index was far more difficult, and probably not possible to this precision; this difficulty did not, however, affect the use of the method for salinity determination, using standard sea water as reference. Tables would be issued relating salinity to refractive index anomaly, using standard water as reference. The N.I.O. were using mercury green light (Wratten filter 77A, 5461A°). Dr. Rusby has found it necessary to use a low-power lamp and define the conditions, as high-power light sources cause frequency drift as they warm up. Basic measurements are to be at 20°, with certain additional measurements to see how much refractive index anomaly changed with temperature.

Third Session - Tuesday morning

The session started with the presentation of two papers:

1. Paper No.139. The bromide/chlorinity ratio of Baltic Waters, by F. Koroleff.

2. The sulphate content of Baltic Water and its relation to the chlorinity, by B. Kwiecinski, presented by S.H. Fonselius.

The discussion on these interesting papers raised the important question of the unique composition of Baltic Water. The chairman could not promise that the relationships computed at the N.I.O. would be valid for the Baltic; so far, only samples within the salinity range 30 - 42‰ had been used for the compurations. It might prove necessary to employ special tables for such areas. If the Baltic observations were included, all the evidence suggested that zero chlorinity and zero salinity would not agree. This disagreement presented problems when considering the dilution of sea water by pure water, such as rain or snow; it was not possible to provide a table applicable to both situations.

The committee undertook to bear in mind the special problem of the Baltic oceanographers, and to cooperate with them in the preparation of such tables as are appropriate for this important region.

The chairman and Dr. Culkin described certain problems which had arisen in the determination of chlorinity in the N.I.O. programme. Mr. Hermann had repeated a small number of chlorinities, and his results confirmed the suspicions of the N.I.O. that there were a few erroneous results in the series. In view of the importance attached to these results, and to our understanding of the causes of variations in chlorinity/conductivity ratio, it has been decided to repeat all the chlorinity determinations, also repeating the conductivity ratio on the same tube of water.

This work is to be shared between Liverpool University and N.I.O., and has already started. Of some 30 results so far available at N.I.O., the original chlorinity was confirmed within ± 0.002‰ in most cases, but in some 4 samples the new value was significantly nearer that computed from conductivity. On these 30 results alone, the root mean square deviation between each chlorinity and the mean line has been reduced from about 0.012‰ to 0.008‰. Mr. Crease, who was superintending the computer work on the results, thought the effect of these new values on the existing conductivity/chlorinity line would be quite negligible; however, by eliminating the small proportion of errors, the fit to the chemical analysis should be greatly improved.

The present chlorinity determinations are being made by Dr. Culkin and Dr. Orlando, at N.I.O., using a weight burette/volumetric method. An endpoint meter designed by Dr. Cox was used, in which dichlorofluorescein indicator caused a colour change observed by a photo-electric system. This system was reliable, but unfortunately not quite sensitive enough to judge the endpoint to within 0.001‰. Mr. Hermann strongly advocated a change to the electrode system which he favoured, where the reference electrode was a silver wire inside the burette jet, the tip of which was in the titrated solution. In discussion, several members agreed that this system was more reliable than the mercurous sulphate reference electrode favoured by Dr. Riley. Mr. Hermann offered to make a set of electrodes for the N.I.O., which offer was gratefully accepted.

Fourth Session, Tuesday afternoon

The agenda for this final session covered the details and distribution of new oceanographic tables. The chairman opened the discussion by presenting the sample sheet of tables, in this case relating relative conductivity to salinity (Appendix A). Members of the committee had discussed details with Dr. Fedorov, and proposed that:

1. The tables be issued as single sheets, suitable for binding in a loose-leaf file, as this would facilitate addition of further sheets as these became available, or replacement if necessary.

2. The sheet size should be 27 x 21 cm (10½ x 8 ins.).

3. When tables were prepared by computer, a direct photographic reproduction of the print-out should be used, to avoid type-setting errors.

4. The Office of Oceanography, UNESCO, would be responsible for publication and distribution of the tables.

A general discussion followed. The presentation and layout of the sample sheet received general approval, the chairman pointing out that to correspond with the proposed sheet size, a reduction of about 15% in the size of the computer's print-out would be necessary. The sheet which is given in Appendix A is somewhat smaller than the size proposed in (2) above. Besides, as follows from page 5, this sheet will have to be re-calculated. The issue of single sheets was criticised because of their tendency to tear. Lt. Cdr. Scott suggested it would be better to issue each table as a booklet, without stiff covers, and suitable for binding with others in a file cover. Others emphasized that whatever binding was adopted, the pages must open and lie flat when in use. Single sheets might be better if suitably reinforced. Dr. Fedorov undertook to consult with the UNESCO publishing department on these matters.

Dr. Fedorov agreed that it would be appropriate to provide each oceanographic institution with one free copy of the Tables. This would be a valuable step towards securing their general adoption. All additional copies would have to be paid for either through a system of subscription or by making it possible te purchase individual tables or sheets as replacements or for special purposes.

It was agreed that the conductivity ratio/salinity table at 15° should be distributed first, as it was urgently wanted to resolve problems of salinometer calibration. This should be available within a few weeks. Professor Kullenberg thought that expense could be reduced by printing one less decimal of conductivity, with an interpolation table for the last place; however, several users of salinometers disagreed strongly, and it was decided to proceed with the full table. There was discussion on the use of such a table with non-thermostat salinometers, such as the Auto-Lab and Hytech instruments, for which the present tables are computed to be correct at 22.5°. The chairman said there would be no difficulty in computing tables of conductivity ratio to salinity applicable to any desired temperature. However, it was doubtful if this was strictly necessary. Whatever tables were used with a non-thermostat meter, second-order corrections would be necessary if the samples varied much in temperature, unless the salinity was very close to 35‰. These corrections were, however, minimised by computing the table for the mean working temperature. 22.5° was too high for most European laboratories, but was a compromise between temperate and tropical ranges. The 15° tables was perfectly valid for use with such salinometers, providing the appropriate corrections were made for operating temperature, and a suitable correction table would be computed. The corrections would, however, be about four times greater when working at 25° than with the present tables. Some workers in warm regions had found that they could legitimately disregard these small corrections, but with a 15° table this might no longer be possible. If there was a sufficient demand for a "tropical" table, the committee would consider providing it.

Probably the next most important tables are those for computing density. The meeting favoured a table for computing σ_t (specific gravity anomaly) from temperature and salinity. The form of this table, and of tables for specific volume anomaly, was not decided; it was suggested that sample sheets of existing tables should be circulated, and comments requested from oceanographers. A selection of such sample sheets is appended (Appendix C).

Tables so far suggested for the series are listed below:

1a. Conductivity ratio/salinity at 15°.
1b. Conductivity ratio, variation with temperature and salinity.
1c. Conductivity variation with pressure (depth).
2a. Specific gravity anomaly (σ_t) from T and S.
2b. Specific volume anomaly variation with pressure.

(The details of group 2 to be decided after further discussion).

3a. Refractive index anomaly at 20°, 5461A°, to salinity.
3b. Refractive index anomaly, variation with temperature and salinity.
4. Velocity of sound, from T, S, P.
5. Adiabatic expansion correction, for insulated water bottles.
6. Potential temperature, from T, P, S.
7. Specific heat, from T, S.

The Committee would welcome suggestions for additions or modifications to this list, as well as suggestions on the most convenient format of the various tables, in particular the specific gravity and specific volume tables. Suggestions can be sent to any member of the Committee, or to the Director, Office of Oceanography, UNESCO, As work on the tables will start very soon, suggestions should be made as early as possible.

Prepared by
Roland A. Cox.

Appendix A. Sample sheet of proposed new tables.

Relative Conductivity —Salinity 34·91–35·11 ‰

			0	1	2	3	4	5	6	7	8	9
0.99	80	34.	915	916	916	917	917	917	918	918	919	919
	81		919	920	920	921	921	921	922	922	922	923
	82		923	924	924	924	925	925	926	926	926	927
	83		927	928	928	928	929	929	930	930	930	931
	84		931	932	932	932	933	933	933	934	934	935
	85		935	935	936	936	937	937	937	938	938	939
	86		939	939	940	940	941	941	941	942	942	942
	87		943	943	944	944	944	945	945	946	946	946
	88		947	947	948	948	948	949	949	950	950	950
	89		951	951	951	952	952	953	953	953	954	954
0.99	90		955	955	955	956	956	957	957	957	958	958
	91		959	959	959	960	960	961	961	961	962	962
	92		962	963	963	964	964	964	965	965	966	966
	93		966	967	967	968	968	968	969	969	970	970
	94		970	971	971	971	972	972	973	973	973	974
	95		974	975	975	975	976	976	977	977	977	978
	96		978	979	979	979	980	980	981	981	981	982
	97		982	982	983	983	984	984	984	985	985	986
	98		986	986	987	987	988	988	988	989	989	990
	99		990	990	991	991	991	992	992	993	993	993
1.00	00		994	994	995	995	995	996	996	997	997	997
	01		998	998	999	999	999	000	000	001	001	001
	02	35.	002	002	002	003	003	004	004	004	005	005
	03		006	006	006	007	007	008	008	008	009	009
	04		010	010	010	011	011	011	012	012	013	013
	05		013	014	014	015	015	015	016	016	017	017
	06		017	018	018	019	019	019	020	020	021	021
	07		021	022	022	022	023	023	024	024	024	025
	08		025	026	026	026	027	027	028	028	028	029
	09		029	030	030	030	031	031	031	032	032	033
1.00	10		033	033	034	034	035	035	035	036	036	037
	11		037	037	038	038	039	039	039	040	040	041
	12		041	041	042	042	042	043	043	044	044	044
	13		045	045	046	046	046	047	047	048	048	048
	14		049	049	050	050	050	051	051	051	052	052
	15		053	053	053	054	054	055	055	055	056	056
	16		057	057	057	058	058	059	059	059	060	060
	17		061	061	061	062	062	062	063	063	064	064
	18		064	065	065	066	066	066	067	067	068	068
	19		068	069	069	070	070	070	071	071	072	072
1.00	20		072	073	073	073	074	074	075	075	075	076
	21		076	077	077	077	078	078	079	079	079	080
	22		080	081	081	081	082	082	082	083	083	084
	23		084	084	085	085	086	086	086	087	087	088
	24		088	088	089	089	090	090	090	091	091	092
	25		092	092	093	093	093	094	094	095	095	095
	26		096	096	097	097	097	098	098	099	099	099
	27		100	100	101	101	101	102	102	102	103	103
	28		104	104	104	105	105	106	106	106	107	107
	29		108	108	108	109	109	110	110	110	111	111

Appendix B

Copy of letter from the Committee on Oceanographic Tables and Standards to the International Bureau of Weights and Measures, and of the reply received from the Director of the Bureau.

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AVS/9/114B 8 October 1964

Dear Sir,

The joint committee of experts on oceanographic tables and standards (which is appointed jointly by UNESCO, ICES, SCOR and IAPO)* has been considering the problems inherent in the determination of the density of sea water. This is normally computed from measurements of temperature, salinity and pressure, and is today commonly reported to a precision of 1 in 10^6.

The oceanographic tables are based on measurements of specific gravity referred to an undefined "pure water". As you are, of course, aware, the density of pure water varies somewhat, depending on its isotopic composition, which varies both with source and treatment.

Oceanographers would like to report their density values in terms of the gram and centimetre and I am sure the Bureau would wish us to do this. Before this can be done, however, we would need reference water of known density. In order that this standard could be reproduced, its isotopic composition should also be defined.

We should be grateful if the Bureau would advise us on any work, either in progress or contemplated, which would assist us in this aim. This Committee would be happy to cooperate with any international or national organisation which is working in this field.

./..

Mr. Jean Terrien
Director,
International Bureau of Weights & Measures
Pavillon de Breteuil
SEVRES (Seine et Oise)

* ICES = International Council for the Exploration of the Sea
SCOR = Scientific Committee on Oceanic Research
IAPO = International Association of Physical Oceanography

Dr. Fedorov, Director of the Office of Oceanography, Unesco, would be happy to provide further information on our problems, should the Bureau so wish, and could serve as a liaison between the Bureau and our Committee.

On behalf of the Committee,

(Sgd.) K.N. Fedorov
Director
Office of Oceanography, Unesco

cc: Prof. D.E. Carritt, IAPO
Dr. R.A. Cox, ICES
Prof.Dr. G. Dietrich, SCOR
Dr. N.P. Fofonoff, IAPO
Dr. G.N. Ivanov-Frantzkevich, UNESCO
Dr. Y. Miyake, SCOR
Dr. F. Hermann, ICES
Dr. O. Saelen, ICES

"

BUREAU INTERNATIONAL
DES
POIDS & MESURES

Jb/Co

Pavillon de Breteuil
Sèvres (S. & O.) France

21 octobre 1964

Monsieur K.N. Fedorov
Directeur
Bureau d8Océanographie
U.N.E.S.C.O.
Place de Fontenoy
PARIS (7e)

Monsieur,

Nous avons pris connaissance de votre lettre AVS/9/114B du 8 octobre 1964, relative à la masse volumique de l'eau de mer.

La détermination préalable de la masse volumique d'une eau pure de composition isotopique connue n'a pas été faite et n'est pas en cours ni au Bureau International des Poids et Mesures, ni ailleurs à notre connaissance. Si une étude aussi importante était entreprise par un organisme possédant tout ou partie des moyens nécessaires, il est possible que le Comité International des Poids et Mesures autorise l'exécution totale ou partielle des travaux au B.I.P.M.

Je vous signale, pour le cas où vous ne le sauriez pas, que Mr. MENACHE, à l'Institut Océanographique (MED 34-46), s'est déjà beaucoup occupé de questions analogues.

Veuillez agréer, Monsieur, l'expression de ma considération distinguée.

Le Directeur

(Signé) J. Terrien "

SAMPLES OF TABLES FOR SPECIFIC GRAVITY AND SPECIFIC VOLUME

Following are sample sheets from seven sets of tables for deriving sigma-t from salinity and temperature, in some cases through an intermediate stage of sigma-0 or rho-17.5. There is also one example of a reverse table (salinity from sigma-t) and three samples of specific volume tables from salinity temperature and pressure.

We would like potential users of such tables to consider seriously which type of tables they would prefer, and if appropriate suggest compromises or modifications of the format given here.

In the headings to each sample an estimate is given of the number of sheets of figures which would be needed to cover the salinity range 30 to $42^{o}/_{oo}$. This does not necessarily imply that we should not include tables for lower or higher salinities, but this is the range of greatest interest to most oceanographers, and initially it is proposed to concentrate on this range.

Comments or suggestions regarding these or other tables should be sent to any member of the committee on oceanographic tables and standards, or to the Office of Oceanography, UNESCO.

The Editors apologise for the rather pool quality of reproduction of the sample tables in this annex as double copying was involved in its process. The Editors hope, however, that it will not create inconvenience since these sample tables are not meant for actual use.

Knudsen's hydrographical tables. Two stages, salinity to sigma-0, sigma-0 and temperature to sigma-t.

8 sheets + 4 sheets

Cl	S	σ₀	ρ17.5	Cl	S	σ₀	ρ17.5
19.00	34.33	27.58	26.22	19.50	35.23	28.31	26.91
.01	.34	.60	.23	.51	.25	.32	.92
02	.36	.61	.24	.52	.26	.34	.94
3	.38	.63	.26	.53	.28	.35	.95
	.40	.64	.27	.54	.30	.37	.96
	.42	.65	.29	.55	.32	.38	.98
	.43	.67	.30	.56	.34	.40	.99
	5	.68	.31	.57	.35	.41	27.01
		.70	.33	.58	.37	.43	.02
		.71	.34	.59	.39	.44	.03
		7.73	26.36	19.60	35.41	28.46	27.05
		4	.37	.61	.43	.47	.06
			.38	.62	.44	.48	.07
			.40	.63	.46	.50	.09
			.41	.64	.48	.51	.10
			42	.65	.50	.53	.12
				.66	.52	.54	.13
				.67	.53	.56	.14
				.68	.55	.57	.16
				69	.57	.59	.17
					35.59	28.60	27.19
					.61	.62	.20
					.62	.63	.21
					.64	.64	.23
					6	.66	.24
						.67	.25
						.69	.27
						.70	.28
						72	.30
						3	.31
							27.32
							.34
							.35
							36

$\sigma_t = \sigma_0 - D$

	σ_0 =9·00	σ_0 =9·10	σ_0 =9·20	σ_0 =9·30	σ_0 =9·40	σ_0 =9·50	σ_0 =9·60	σ_0 =9·70	σ_0 =9·80	σ_0 =9·90	σ_0 =10·0				
t =	D =	D =	D =	D =	D =	D =	D =	D =	D =	D =	D =				
−2°	0·09	0·08	0·08	0·08	0·08	0·08	0·08	0·08	0·08	0·08	0·08	0·08			
−1°	03	03	03	03	03	03	03	03	03	03	03	03			
0°	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·0		
1°	− 02	− 02	− 02	− 02	− 02	− 02	− 01	− 01	− 01	− 01	− 01	− 01	− 01		
2°	− 02	− 02	− 02	− 02	− 02	− 01	− 01	− 01	− 01	− 01	− 01	− 01	− 01		
3°	− 01	00	00	00	00	00	00	00	00	01	01	01	01	0.	
4°	02	03	03	03	03	03	03	04	04	04	04	04	.04	05	
5°	0·07	0·07	0·07	0·07	0·08	0·08	0·08	0·08	0·08	0·09	0·09	0·09	0·09	0·09	0·1
6°	13	13	13	13	13	14	14	14	14	15	15	15	15	16	16
7°	20	20	20	20	21	21	21	22	22	22	22	23	23	23	23
8°	28	28	29	29	29	30	30	30	31	31	31	31	32	32	32
9°	38	38	39	39	39	40	40	40	41	41	41	42	42	42	43

Zhubov & Czihirin. Oceanological Tables. Moscow, 1940

Salinity to rho-17.5. (see last sheet- identical with Knudsen's tables)
Rho-17.5 and temperature to sigma-t.

8 sheets + 17 sheets.

T. 10. Correction E for the conditional density

$\sigma_t = \rho_{17.5} - K$

$\rho_{17.5}$ \ $t°$	20.0	20.2	20.4	20.6	20.8	21.0	21.2	21.4	21.6	21.8	22.0
0.00	1.77	1.83	1.87	1.91	1.94	1.98	2.02	2.07	2.11	2.16	2.20
1.00	.78	.83	.87	.91	.95	.99	.04	.08	.13	.17	.22
2.00	.79	.83	.87	.92	.96	2.00	.05	.09	.14	.18	.23
3.00	.79	.84	.88	.92	.97	.01	.06	.10	.15	.20	.24
4.00	.80	.85	.89	.93	.98	.02	.07	.11	.16	.21	.25
5.00	.81	.85	.90	.94	.99	.03	.08	.13	.17	.22	.26
6.00	.82	.86	.91	.95	2.00	.04	.09	.14	.18	.23	.28
7.00	.82	.87	.92	.96	.01	.05	.10	.15	.19	.24	.29
8.00	.83	.88	.92	.97	.01	.06	.11	.16	.20	.25	.30
9.00	.84	.88	.93	.98	.02	.07	.12	.16	.21	.26	.31
10.00	1.84	1.89	1.94	1.99	2.03	2.08	2.13	2.17	2.22	2.27	2.32
11.00	.85	.90	.95	.99	.04	.09	.13	.18	.23	.28	.33
12.00	.86	.90	.95	2.00	.05	.09	.14	.19	.24	.29	.34
13.00	.86	.91	.96	.01	.06	.10	.15	.20	.25	.30	.35
14.00	.87	.92	.97	.01	.06	.11	.16	.21	.26	.31	.36
15.00	.88	.93	.97	.02	.07	.12	.17	.22	.27	.32	.37
16.00	.88	.93	.98	.03	.08	.13	[illegible]	.23	.28	.33	.38
17.00	.89	.94	.99	.04	.09	.14	.19	.24	.29	.34	.39
18.00	.89	.94	.99	.04	.09	.15	.20	.25	.30	.35	.40
19.00	.90	.95	2.00	.05	.10	.15	.21	.26	.31	.36	.42
20.00	1.91	1.96	2.01	2.06	2.11	2.16	2.21	2.27	2.32	2.37	2.43
21.00	.91	.97	.02	.07	.12	.17	.22	.28	.33	.38	.44
22.00	.92	.97	.02	.07	.12	.18	.23	.29	.34	.39	.45
23.00	.93	.98	.03	.08	.13	.19	.24	.29	.35	.40	.46
24.00	.93	.99	.04	.09	.14	.20	.25	.30	.36	.41	.47
25.00	.94	.99	.05	.10	.15	.20	.26	.31	.37	.42	.48
26.00	.95	2.00	.05	.11	.16	.21	[illegible]	.32	.38	.43	.49
27.00	.95	.01	.06	.12	.17	.22	.28	.33	.39	.44	.50
28.00	.96	.02	.07	.12	.18	.23	.29	.34	.40	.45	.51
29.00	.97	.02	.08	.13	.19	.24	.30	.35	.41	.46	.52

United States Hydrographic Office publication 619

Temperature plus a linear correction from salinity to sigma-t. Precision limited to about 0.02. 6 sheets

Thus: Given 15.70°C and 36.47‰ S.

From table for Salinity 30.00 to 39.99‰, enter column one at lower limit of temperature interval (15.69)

obtain base value in column two	+	(f-factor of column three	x	last three digits of given S.)	=
22.00		.7680		6.47	

26.968960 (round to two decimal places) ANSWER 26.97

DENSITY (σ_t)

Salinity 30.00°/oo to 39.99°/oo

T. °C.	σ_t	f
25.65	19.40	
.68	.39	
.71	.38	
.75	.37	
.78	.36	
.81	.35	.7540
.85	.34	
.88	.33	
.91	.32	
.94	.31	
.98	.30	
26.01	19.29	
.04	.28	
.08	.27	
.11	.26	
.14	.25	
.17	.24	
.21	.23	
.24	.22	.7530
.27	.21	

T. °C.	σ_t	f
27.01	18.98	
.04	.97	
.07	.96	
.11	.95	
.14	.94	
.17	.93	
.20	.92	
.23	.91	
.26	.90	.7520
.30	.89	
.33	.88	
.36	.87	
.39	.86	
.42	.85	
.45	.84	
.48	.83	
27.52	18.82	
.55	.81	
.58	.80	
.61	.79	

T. °C.	σ_t	f
28.32	18.56	
.36	.55	
.39	.54	
.42	.53	.7510
.45	.52	
.48	.51	
28.51	18.50	
.54	.49	
.57	.48	
.60	.47	
.63	.46	
.66	.45	
.69	.44	
.72	.43	
.75	.42	.7510
.78	.41	
.81	.40	
.85	.39	
.88	.38	
.91	.37	

Kalle & Thorade. Tabellen und Tafeln für die Dichte des Seewassers. (Hamburg, 1940)

Sigma-t from temperature and either salinity or chlorinity, with interpolation tables.

About 36 sheets

Dichte = 1 + 0,001 σ_t.

S ‰ \ t°	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°	30°	Cl ‰
	25,				24,			23,			22,	
36,00	54	27	00	71	42	12	81	49	17	84	50	19,928
1	55	28	01	72	43	13	82	50	18	85	51	934
2	56	29	01	72	43	13	82	51	18	85	51	939
3	57	30	02	73	44	14	83	52	19	86	52	945
4	57	30	02	73	44	14	83	52	19	86	52	950
5	58	31	03	74	45	15	84	53	20	87	53	956
6	59	32	04	75	46	16	85	54	21	88	54	961
7	60	33	05	76	47	17	86	55	22	89	55	967
8	61	34	06	77	48	18	87	56	23	90	56	972
9	62	35	07	78	49	19	88	57	24	91	57	978
10	62	35	07	78	49	19	88	57	24	91	57	983
1	63	36	08	79	50	20	89	58	25	92	58	[illegible]
2	64	37	09	80	51	21	90	59	26	93	59	
3	65	[illegible]	10	81	[illegible]	22	91	60	27	94	[illegible]	
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	92	60	27			
5	65	38	11	82	53	22	92	[illegible]				
6	66	39	12	83	54	23	93					
7	67	40	13	84	55	[illegible]						
8	68	41	14	85								
9	69	42	15	[illegible]								
20	69	[illegible]										
1	[illegible]											
2												

Einschalttafeln

	2	3	4	5	6	7	8	9	10
1	0	0	0	1	1	1	1	1	1
2	0	1	1	1	1	1	2	2	2
3	1	1	1	2	2	2	2	3	[illegible]
4	1	1	2	2	2	3	3	[illegible]	
5	1	2	2	3	3	4	4		
6	1	2	2	3	4	4			
7	1	2	3	4	4				
8	2	2	3	4					
9	2	3	4	[illegible]					

	11
1	

Beispiel:
Gegeben S = 36,12 ‰; t = 18,64 °C; gesucht σ_t.

Auflösung:
Haupttafel: 36,12 ‰; 18° 26,15
Diff. f. 1° .... −25; Einschalttafel { −15, −1 }
σ_t = 25,99

Matthews, I.C.E.S. 1932. Sigma-t from sigma-O and temperature. An extended version of Knudsen's tables (see sheet A).

Salinity to sigma-O, 8 sheets
Sigma-O and temperature to sigma-t, 18 sheets.

INSTRUCTIONS FOR USING THE TABLES

These tables are not to be used to calculate D for temperatures lower than —2°.00 C or higher than 33°.00 C.

1) If σ_0 is exactly 0.00 or 28.00 the value of D can be taken from one of the left hand pages 1, 3, 5 ... opposite a right hand page in which these values of σ_0 are found.

Example: σ_0 = 0.00, t = 11°.23. By the tables on pages 11, 13, 17 or 23 D is 0.27. This value is accurate to two decimal places for all temperatures from 11°.23 to 11°.32, but not for 11°.33.

Example: σ_0 = 28.00, t = 15°.46. By the tables on pages 33, 39, 49, or 53, D = 2.23 to two decimal places.

2) If σ_0 is not exactly 0.00 or 28.00, take out the appropriate adjustment from one of the right hand tables, add it to the temperature and then find D from the left hand table opposite.

Example: σ_0 = 7.00, t = 12°.00. The adjustment is 2.40 by the table on page 20, the adjusted temperature is 14°.40 and D is 0.66 by the table on page 19 opposite.

Example: σ_0 = 7.08, t = 12°.63. Interpolation is necessary for σ_0 and for t. Exact interpolation gives 2.38 as the adjustment and D is 0.75.

t°	D
—0.98	0.07
—0.86	0.06
—0.74	0.05
—0.61	0.04
—0.48	0.03
—0.35	0.02
—0.21	0.01
—0.07	0.00
0.08	—0.01
0.23	—0.02
0.40	—0.03
0.57	—0.04
0.75	—0.05
0.94	—0.06
1.15	—0.07
1.37	—0.08
1.62	—0.09
1.89	—0.10
2.20	—0.11
2.60	—0.12
3.16	—0.13

Example: σ_0 = 13.62
observed temperature = 2°.13
adjustment = —2°.45
adjusted temperature = —0°.32

σ_0: 0.0 to 16.0
t: 1°.6 to 2°.8

	1°.6	1°.7	1°.8	1°.9	2°.0	2°.1	2°.2	2°.3	2°.4	2°.5	2°.6	2°.7	2°.8
0.0	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
1.0	—0.2	—0.2	—0.2	—0.2	—0.3	—0.3	—0.3	—0.4	—0.4	—0.4	—0.5	—0.5	—0.5
1.5	.2	.3	.3	.3	.4	.4	.5	.5	.5	.6	.6	.7	.7
2.0	.3	.4	.4	.4	.5	.5	.6	.6	.7	.7	.8	—0.9	—0.9
2.5	.4	.5	.5	.5	.6	.6	.7	.8	—0.8	—0.9	—0.9	—1.0	—1.0
3.0	.6	.5	.6	.6	.7	.8	.8	—0.9	—1.0	—1.0	—1.1	.2	.3
3.5	.6	.6	.7	.7	.8	—0.9	—0.9	—1.0	.1	.1	.2	.3	.4
4.0	.7	.7	.8	.8	—0.9	—1.0	—1.0	.1	.2	.3	.3	.4	.5
4.5	.8	.8	.8	—0.9	—1.0	.1	.1	.2	.3	.4	.5	.6	.7
5.0	**—0.8**	**—0.9**	**—0.9**	**—1.0**	**—1.1**	**—1.2**	**—1.2**	**—1.3**	**—1.4**	**—1.5**	**—1.6**	**—1.7**	**—1.8**
5.5	—0.9	—0.9	—1.0	1	.2	.3	.3	.4	.5	.6	.7	.8	—1.9
6.0	—1.0	—1.0	.1	.2	.3	.3	.4	.5	.6	.7	.8	—1.9	—2.1
6.5	.1	.0	.2	.2	.3	.4	.5	.6	.7	.8	—1.9	—2.1	.3
7.0	.1	.1	.2	.3	.4	.4	.6	.7	.8	—1.9	—2.0	.2	.3
7.5	.2	.2	.3	.4	.5	.5	.7	.8	—1.9	—2.0	.1	.3	.4
8.0	.2	.3	.4	.5	.6	.6	.8	—1.9	—2.0	.1	.2	.4	.5
8.5	.2	.3	.4	.5	.6	.7	.9	—2.0	.1	.2	.3	.5	.6
9.0	.3	.4	.5	.6	.7	.8	—1.9	.1	.2	.3	.4	.5	.7
9.5	.3	.4	.5	.7	.8	.9	—2.0	.1	.2	.4	.5	.6	.8
10.0	**—1.4**	**—1.5**	**—1.6**	**—1.7**	**—1.8**	**—1.95**	**—2.05**	**—2.20**	**—2.30**	**—2.45**	**—2.55**	**—2.70**	**—2.85**
10.5	.4	.5	.7	.7	—1.9	—2.00	.15	.25	.40	.50	.65	.80	—2.90
11.0	.5	.6	.7	.8	—2.0	.10	.20	.35	.45	.60	.75	.85	—3.00
11.5	.6	.7	.8	—1.9	.0	.15	.30	.40	.55	.70	.80	—2.95	.10
12.0	.6	.7	.8	—2.0	.1	.20	.35	.50	.60	.75	.90	—3.00	.15
12.5	.7	.8	—1.9	.0	.2	.25	.40	.55	.70	.80	—2.95	.10	.25
13.0	.7	.8	—2.0	.1	.2	.30	.50	.60	.75	.90	—3.05	.20	.30
13.5	.8	.9	.0	.1	.3	.40	.55	.70	.80	—2.95	.10	.25	.40
14.0	.8	—1.9	.1	.2	.3	.45	.60	.75	.90	—3.05	.15	.30	.45
14.5	.8	—2.0	.2	.2	.4	.50	.65	.80	—2.95	.10	.25	.40	.55
15.0	**—1.9**	**—2.0**	**—2.2**	**—2.3**	**—2.4**	**—2.60**	**—2.70**	**—2.85**	**—3.00**	**—3.15**	**—3.30**	**—3.45**	**—3.60**
15.5	—1.9	.0	.2	.3	.5	.65	.75	.90	.05	.20	.35	.50	.65
16.0	—2.0	.1	.2	.4	.5	.70	.80	.95	.10	.30	.45	.60	.75

United States Hydrographic Office publication615. Sigma-t from temperature and salinity. The most detailed tables available, but very bulky. About 60 sheets.

T°C \ S‰	11	12	13	14	15	16	17	18	19	20
16 50	340	103	865	628	390	151	913	675	436	198
16 51	339	101	864	626	388	149	911	673	434	196
16 52	337	099	862	624	386	147	909	671	432	194
16 53	335	097	860	622	384	145	907	669	430	192
16 54	333	095	858	620	382	143	905	667	428	190
16 55	331	093	856	618	380	141	903	665	426	188
16 56	329	092	854	616	378	139	901	663	424	186
16 57	327	090	852	614	376	137	899	661	422	184
16 58	325	088	850	612	374	135	897	659	420	182
16 59	323	086	848	610	372	133	895	657	418	180
16 60	321	084	846	608	370	131	893	655	416	177
16 61	320	082	844	606	368	129	891	652	414	175
16 62	318	080	842	604	366	127	889	650	412	173
16 63	316	078	840	602	364	125	887	648	410	171
16 64	314	076	838	600	362	123	885	646	408	169
16 65	312	074	836	598	360	121	883	644	406	167
16 66	310	072	834	596	358	119	881	642	404	165
16 67	308	070	832	594	356	117	879	640	401	163
16 68	306	068	830	592	354	115	877	638	399	161
16 69	304	067	829	590	352	113	875	636	397	159
16 70	302	065	827	588	350	111	873	634	395	157
16 71	300	063	825	586	348	109	871	632	393	155
16 72	298	061	823	584	346	107	869	630	391	152
16 73	297	059	821	582	344	105	867	628	389	150
16 74	295	057	819	580	342	103	865	626	387	148
16 75	293	055	817	578	340	101	863	624	385	146
16 76	291	053	815	576	338	099	861	622	383	144
16 77	289	051	813	575	336	097	859	620	381	142
16 78	287	049	811	573	334	095	857	618	379	140
16 79	285	047	809	571	332	093	854	616	377	138
16 80	283	045	807	569	330	091	852	614	375	136
16 81	281	043	805	567	328	089	850	612	373	134
16 82	279	041	803	565	326	087	848	609	371	132
16 83	277	039	801	563	324	085	846	607	368	129
16 84	275	037	799	561	322	083	844	605	366	127
16 85	273	035	797	559	320	081	842	603	364	125
16 86	272	033	795	557	318	079	840	601	362	123
16 87	270	032	793	555	316	077	838	599	360	121
16 88	268	030	791	553	314	075	836	597	358	119
16 89	266	028	789	551	312	073	834	595	356	117
16 90	264	026	787	549	310	071	832	593	354	115
16 91	262	024	785	547	308	069	830	591	352	113
16 92	260	022	783	545	306	067	828	589	350	111
16 93	258	020	781	543	304	065	826	587	348	108
16 94	256	018	779	541	302	063	824	585	346	106
16 95	254	016	777	539	300	061	822	583	343	104
16 96	252	014	775	537	298	059	820	581	341	102
16 97	250	012	773	535	296	057	818	578	339	100
16 98	248	010	771	533	294	055	816	576	337	098
16 99	246	008	769	531	292	053	814	574	335	096
ΔS	762	762	762	762	761	762	761	761	761	761

United States Hydrographic Office publication 614.

Similar to previous sheet, but given to one less decimal of temperature, so that interpolation is needed in both variables.

7 sheets.

TABLE X.—SIGMA-T FOR VALUES OF TEMPERATURE AND SALINITY—Continued

Temperature, ° C.	Salinity, °/₀₀								
	30	31	32	33	34	35	36	37	38
7.0	23. 512	24. 297	25. 082	25. 867	26. 653	27. 439	28. 226	29. 014	29. 802
7.1	23. 499	24. 284	25. 068	25. 853	26. 639	27. 425	28. 212	28. 999	29. 788
7.2	23. 486	24. 270	25. 055	25. 840	26. 625	27. 411	28. 198	28. 985	29. 773
7.3	23. 473	24. 257	25. 041	25. 826	26. 611	27. 397	28. 183	28. 970	29. 758
7.4	23. 460	24. 244	25. 028	25. 812	26. 597	27. 383	28. 169	28. 955	29. 743
7.5	23. 447	24. 230	25. 014	25. 798	26. 583	27. 368	28. 154	28. 940	29. 727
7.6	23. 434	24. 217	25. 000	25. 784	26. 569	27. 353	28. 139	28. 925	29. 712
7.7	23. 420	24. 203	24. 986	25. 770	26. 554	27. 339	28. 124	28. 910	29. 697
7.8	23. 406	24. 189	24. 972	25. 756	26. 539	27. 324	28. 109	28. 895	29. 681
7.9	23. 393	24. 175	24. 958	25. 741	26. 525	27. 309	28. 094	28. 879	29. 665
8.0	23. 379	24. 161	24. 944	25. 727	26. 510	27. 294	28. 079	28. 864	29. 650
8.1	23. 365	24. 147	24. 929	25. 712	26. 495	27. 279	28. 063	28. 848	29. 634
8.2	23. 351	24. 133	24. 915	25. 697	26. 480	27. 264	28. 048	28. 832	29. 618
8.3	23. 337	24. 118	24. 900	25. 682	26. 465	27. 248	28. 032	28. 817	29. 602
8.4	23. 323	24. 104	24. 885	25. 667	26. 450	27. 233	28. 016	28. 801	29. 586
8.5	23. 308	24. 089	24. 870	25. 652	26. 434	27. 217	28. 001	28. 785	29. 569
8.6	23. 294	24. 074	24. 855	25. 637	26. 419	27. 202	27. 985	28. 769	29. 553
8.7	23. 279	24. 060	24. 840	25. 622	26. 403	27. 186	27. 969	28. 752	29. 537
8.8	23. 264	24. 045	24. 825	25. 606	26. 388	27. 170	27. 953	28. 736	29. 520
8.9	23. 250	24. 030	24. 810	25. 591	26. 372	27. 154	27. 936	28. 720	29. 503
9.0	23. 235	24. 014	24. 795	25. 575	26. 356	27. 138	27. 920	28. 703	29. 487
9.1	23. 220	23. 999	24. 779	25. 559	26. 340	27. 122	27. 904	28. 686	29. 470
9.2	23. 204	23. 984	24. 763	25. 544	26. 324	27. 105	27. 887	28. 670	29. 453
9.3	23. 189	23. 968	24. 748	25. 528	26. 308	27. 089	27. 871	28. 653	29. 436
9.4	23. 174	23. 953	24. 732	25. 512	26. 292	27. 072	27. 854	28. 636	29. 418
9.5	23. 158	23. 937	24. 716	25. 495	26. 275	27. 056	27. 837	28. 619	29. 401
9.6	23. 143	23. 921	24. 700	25. 479	26. 259	27. 039	27. 820	28. 602	29. 384
9.7	23. 127	23. 905	24. 684	25. 463	26. 242	27. 022	27. 803	28. 584	29. 366
9.8	23. 111	23. 889	24. 668	25. 446	26. 226	27. 005	27. 786	28. 567	29. 349
9.9	23. 096	23. 873	24. 651	25. 430	26. 209	26. 988	27. 769	28. 549	29. 331

Fleming, in J. Marine Res. (1939) 2 9-11.

Reverse table of salinity from sigma-t. Useful for entering sigma-t curves on S-T diagrams.

2 sheets.

TABLE I

Tables for σ_t

Values of the salinity (°/₀₀) corresponding to unit values of σ_t and temperature

Temp. σ_t	18.00	19.00	20.00	21.00	22.00	23.00	24.00	25.00	26.00	27.00	28.00	29.00	30.00
−2° C.	22.40	23.66	24.88	26.11	27.35	28.59	29.82	31.06	32.29	33.52	34.75	35.98	37.21
−1	22.40	23.64	24.88	26.12	27.36	28.60	29.84	31.08	32.31	33.55	34.78	36.02	37.26
0	22.41	23.66	24.90	26.14	27.39	28.63	29.87	31.11	32.36	33.60	34.85	36.09	37.33
1	22.43	23.69	24.94	26.18	27.43	28.68	29.93	31.18	32.43	33.68	34.92	36.16	37.41
2	22.48	23.73	24.99	26.24	27.50	28.76	30.01	31.26	32.51	33.76	35.01	36.26	37.51
3	22.55	23.80	25.06	26.31	27.57	28.83	30.09	31.35	32.61	33.87	35.12	36.37	37.62
4	22.62	23.88	25.15	26.41	27.67	28.93	30.19	31.46	32.72	33.99	35.25	36.50	37.75
5	22.72	23.98	25.25	26.52	27.78	29.05	30.32	31.59	32.86	34.13	35.39	36.65	37.91
6	22.83	24.10	25.38	26.65	27.92	29.19	30.47	31.74	33.01	34.27	35.53	36.80	38.06
7	22.97	24.24	25.52	26.79	28.07	29.35	30.62	31.90	33.17	34.44	35.71	36.98	38.25
8	23.12	24.40	25.67	26.95	28.23	29.52	30.79	32.07	33.35	34.63	35.90	37.18	38.45
9	23.28	24.57	25.86	27.14	28.42	29.70	30.98	32.26	33.54	34.82	36.10	37.38	38.66
10	23.46	24.75	26.04	27.32	28.61	29.90	31.18	32.47	33.75	35.04	36.32	37.60	38.88
11	23.66	24.95	26.24	27.53	28.82	30.11	31.40	32.69	33.97	35.26	36.55	37.83	39.11
12	23.86	25.16	26.46	27.75	29.04	30.34	31.63	32.92	34.22	35.50	36.79	38.08	39.36
13	24.09	25.39	26.69	27.99	29.29	30.59	31.88	33.18	34.47	35.76	37.05	38.34	39.62
14	24.33	25.63	26.94	28.24	29.54	30.84	32.14	33.44	34.74	36.04	37.33	38.62	39.91
15	24.59	25.89	27.20	28.50	29.80	31.10	32.41	33.71	35.01	36.31	37.61	38.90	40.19
16	24.85	26.16	27.47	28.78	30.08	31.39	32.70	34.00	35.30	36.60	37.91	39.21	40.50
17	25.14	26.45	27.75	29.06	30.38	31.69	32.99	34.30	35.61	36.92	38.22	39.52	40.81
18	25.43	26.75	28.06	29.38	30.69	32.00	33.31	34.62	35.93	37.23	38.54	39.85	41.15
19	25.75	27.07	28.38	29.69	31.01	32.32	33.64	34.95	36.26	37.57	38.87	40.18	41.48
20	26.07	27.39	28.71	30.03	31.35	32.66	33.97	35.29	36.60	37.91	39.22	40.53	
21	26.40	27.72	29.04	30.37	31.69	33.01	34.33	35.64	36.95	38.26	39.58	40.89	
22	26.75	28.07	29.40	30.72	32.05	33.37	34.69	36.00	37.32	38.64	39.95	41.26	

TABLE II

Interpolation Table for Fractional Values of σ_t

Salinity difference	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1.22 °/₀₀	0.12 °/₀₀	0.24 °/₀₀	0.37 °/₀₀	0.49 °/₀₀	0.61 °/₀₀	0.73 °/₀₀	0.85 °/₀₀	0.98 °/₀₀	1.10 °/₀₀
1.23	.12	.25	.37	.49	.62	.74	.86	.98	1.11
1.24	.12	.25	.37	.50	.62	.74	.87	.99	1.12
1.25	.12	.25	.38	.50	.62	.75	.88	1.00	1.12
1.26	.13	.25	.38	.50	.63	.76	.88	1.01	1.13
1.27	.13	.25	.38	.51	.64	.76	.89	1.02	1.14
1.28	.13	.26	.38	.51	.64	.77	.90	1.02	1.15
1.29	.13	.26	.39	.52	.64	.77	.90	1.03	1.16
1.30	.13	.26	.39	.52	.65	.78	.91	1.04	1.17
1.31	.13	.26	.39	.52	.66	.79	.92	1.05	1.18
1.32	.13	.26	.40	.53	.66	.79	.92	1.06	1.19
1.33	.13	.27	.40	.53	.66	.80	.93	1.06	1.20
1.34	.13	.27	.40	.54	.67	.80	.94	1.07	1.21
1.35	.14	.27	.40	.54	.68	.81	.94	1.08	1.22

Bjerknes, Hydrographic tables. Specific volume from Salinity, Pressure and Temperature.
Basic table of specific volume - pressure, plus six correction tables for salinity , temperature and pressure combinations.
About 12 large sheets. On our page size, perhaps 20 sheets.

Table 8 H (continued from p. 7A).—$10^5 a_{35,0,p}$ ($a_{35,0,p}$ = *specific volume of sea-water of 35 ‰ salinity and 0° C. at standard pressure, expressed in* m^3/*tons*).

Sea-pressure (decibars).	0	10	20	30	40	50	60	70	80	90
5000	95173	95169	95165	95161	95157	95154	95150	95146	95142	951[illegible]
5100	95134	95130	95127	95123	95119	95115	95111	95107	95103	951[illegible]
5200	95096	95092	95088	95084	95080	95077	95073	95069	95065	95061
5300	95057	95054	95050	95046	95042	95038	95034	95031	95027	95023
5400	95019	95015	95011	95008	95004	95000	94996	94992	94988	94985
5500	94981	94977	94973	94969	94966	94962	94958	94954	94950	94947
5600	94943	94939	94935	94931	94928	94924	94920	94916	94912	94909
5700	94905	94901	94897	94893	94890	94886	94882	94878	94874	94871
5800	94867	94863	94859	94856	94852	94848	94844	94840	94837	94833
5900	94829	94825	94822	94818	94814	94810	94807	94803	94799	94795
6000	94791	94788	94784	94780	94776	94773	94769	94765	94761	94758
6100	94754	94750	94746	94743	94739	94735	94731	94728	94724	94720

Basic table

Table 13 H.—$10^5 \cdot \delta_{\tau p}$ ($\delta_{\tau p}$ = *combined temperature-pressure correction in* m^3/*ton to the specific volume of sea-water*).

Sea-pressure (decibars).	Temperature (° C.).																															
	−2	−1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	−1	0	0	0	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4
200	−1	−1	0	1	1	1	2	2	3	3	4	4	4	5	5	5	5	6	6	6	6	7	7	7	7	7	8	8	8	8	8	8	8
300	−2	−1	0	1	2	2	3	4	4	5	5	6	7	7	8	8	8	9	9	9	10	10	10	11	11	11	11	12	12	12	12	12	13
400	−2	−1	0	1	2	3	4	5	6	6	7	8	9	9	10	11	11	12	12	13	13	14	14	14	15	15	15	16	16	16	16	17	17
500	−3	−1	0	1	3	4	5	6	7	8	9	10	11	12	12	13	14	15	15	16	16	17	17	18	18	19	19	19	20	20	21	21	21
600	−3	−2	0	2	3	5	6	7	8	10	11	12	13	14	15	16	17	17	18	19	20	20	21	21	22	22	23	23	24	24	24	25	25
700	−4	−2	0	2	4	5	7	8	10	11	13	14	15	16	17	18	19	20	21	22	23	23	24	25	25	26	26	27	27	28	28	29	29
800	−4	−2	0	2	4	6	8	10	11	13	14	16	17	18	20	21	22	23	24	25	26	27	27	28	29	30	30	31	31	32	32	33	33
900	−5	−2	0	2	5	7	9	11	13	14	16	18	19	21	22	23	25	26	27	28	29	30	31	32	32	33	34	35	35	36	36	37	37

One of the correction tables

Zubov & Czihirin. Oceanological Tables, Moscow 1940

Specific volume from temperature, salinity and pressure. Basic table from salinity and temperature, with four correction tables. Precision similar to Bjerknes' table, but needs more interpolation in the pressure corrections. Probably easier to read.

Basic table 8 sheets. Given at closer spacing in the deep water range, but do not cover Mediterranean or Red Sea. Correction tables 6 sheets. Would fit onto our format with only slight reduction.

T. 14. Conditional specific volume of ocean waters

35.0	35.1	35.2	35.3	35.4	35.5	35.6	35.7	35.8	35.9	36.0	S / t°
72.57	72.49	72.41	72.33	72.26	72.19	72.11	72.03	71.95	71.87	71.80	−2.0
.57	.50	.42	.33	.26	.19	.11	.03	.95	.88	.81	−1.9
.57	.50	.42	.34	.27	.20	.11	.03	.95	.88	.81	.8
.57	.50	.42	.34	.27	.20	.12	.04	.95	.88	.81	.7
.58	.51	.42	.34	.27	.20	.12	.04	.96	.89	.82	.6
.58	.51	.43	.35	.28	.20	.12	.04	.96	.89	.82	.5
.58	.51	.43	.35	.28	.21	.13	.05	.96	.89	.82	.4
.59	.52	.43	.35	.28	.21	.13	.05	.97	.90	.83	.3
.59	.52	.44	.36	.29	.21	.13	.05	.97	.90	.83	.2
.59	.52	.44	.36	.29	.22	.14	.06	.98	.90	.83	.1
72.60	72.52	72.45	72.36	72.29	72.22	72.14	72.06	71.98	71.91	71.84	−1.0
.60	.52	.45	.37	.30	.23	.15	.06	.98	.91	.84	−0.9

Basic Table

T. 18. Correction (δ$_{tp}$) to specific volume for temperature and pressure

$$v_{pts} = v_t + \delta_p + \delta_{tp} + \delta_{sp} + \delta_{tsp}$$

10	12	14	16	18	20	22	24	26	28	30	t° / p
0	0	0	0	0	0	0	0	0	0	0	0
0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	100
.04	.05	.05	.06	.06	.07	.07	.08	.08	.08	.08	200
.07	.08	.08	.09	.10	.10	.11	.11	.12	.12	.13	300
.09	.10	.11	.12	.13	.14	.15	.15	.16	.16	.17	400
0.11	0.12	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.20	0.21	500
.13	.15	.17	.18	.20	.21	.22	.23	.24	.24	.25	600
.15	.17	.19	.21	.23	.24	.25	.26	.27	.28	.29	700
.17	.20	.22	.24	.26	.27	.29	.30	.31	.32	.33	800
.19	.22	.25	.27	.29	.31	.32	.34	.35	.36	.37	900

Sample of correction table

Fofonoff & Froese, Tables of Physical Properties of Sea Water. (Fisheries Res. Bd. of Canada Manuscript report No. 24, 1958)

Specific volume at fairly wide intervals of temperature, salinity and pressure, with derivatives for interpolation. Designed for use with electronic computer, rather than for the occasional individual observation. 25 large sheets, probably 40 on our format.

units in every case are:

temperature	t° C <u>or</u> T° Absolute
Salinity	S ‰
pressure	p decibars.

In Table 1, the specific volume α is tabulated as well as the derivatives $\alpha_t = \frac{\partial \alpha}{\partial t}$, $\alpha_s = \frac{\partial \alpha}{\partial S}$, $\alpha_{tt} = \frac{\partial^2 \alpha}{\partial t^2}$, $\alpha_{ss} = \frac{\partial^2 \alpha}{\partial S^2}$, and $\alpha_{st} = \frac{\partial^2 \alpha}{\partial S \partial t}$. The temperatures t and salinities S have been scaled by 10^2, the α's by 10^9, and all derivatives by 10^{10}. The truncation errors in α_t are ~ 2 in the fifth figure; in α_s , ~ 2 in the sixth figure; the last two figures in the second derivatives are not significant.

Table 1 (cont'd). Specific volume, α , and derivatives of α .

S = 3400 P = 03000

t	α	α_t	α_s	α_{tt}	α_{ss}	α_{st}
-0200	0960200547	1006023	-7250746	111497	006780	023241
0000	0960423455	1219604	-7205940	102333	006072	021574
0200	0960687331	1416252	-7164403	094585	005513	019981
0400	0960989068	1598661	-7126005	088065	004954	018440
0600	0961326053	1769131	-7090643	082552	004433	016940
0800	0961696105	1929681	-7058205	078082	004023	015506
1000	0962097414	2082050	-7028584	074375	003706	014114

S = 3500 P = 03000

t	α	α_t	α_s	α_{tt}	α_{ss}	α_{st}
-0200	0959475808	1029074	-7244148	110678	006388	022868
0000	0959703160	1241019	-7200045	101495	005699	021252
0200	[illegible]	1436085	[illegible]	093784	005103	019683