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INTRODUCTION

At a meeting held in Sidney, B.C., Canada, 1-5 September 1980, the UNESCO/ICES/SCOR/IAPSO Joint Panel on Oceanographic Tables and Standards (JPOTS) adopted a new practical salinity scale, and a new equation of state of seawater. All of the sponsoring agencies have since approved the work of JPOTS. In a communique recently addressed to the oceanographic community, the Director of the Division of Marine Sciences, UNESCO, and the Presidents of SCOR, ICES, and IAPSO recommend that, beginning 1 January, 1982, the Practical Salinity Scale, 1978 be used exclusively for the conversion of temperature and conductivity measurements to salinity, and that the International Equation of State of Seawater, 1980 be used for the computation of density of seawater from values of temperature, salinity and pressure. In the case of the computation of density, the salinity as defined by the Practical Salinity Scale, 1978 is to be used.

These new definitions of salinity and density are the result of some 15 years of effort by the JPOTS to arrive at a precise specification of salinity in terms of the electrical conductivity of seawater, and at a precise numerical statement of the equation of state of seawater.

The detailed arguments and data base for the development of the new salinity scale and the new equation of state of seawater are given in various numbers of the Unesco Technical Papers in Marine Science, and in recent published papers. A complete reference listing of the most important background papers is given at the end of this report. Here, some pertinent conclusions of the UNESCO/ICES/SCOR/IAPSO Joint Panel on Oceanographic Tables and Standard will be noted.

PRACTICAL SALINITY SCALE, 1978

During the course of the work of the JPOTS it became clear that there was a need for a reproducible electrical conductivity standard. A precisely specified solution of potassium chloride was chosen as this standard. A concentration of potassium chloride was taken that would yield a conductivity ratio of unity at 15 Deg C with respect to a North Atlantic seawater of a salinity of 35 ^{o}/oo on the old salinity scale (equivalent to a chlorinity of 19.3740 ^{o}/oo) so as to ensure continuity at that salinity with the previous scale. Whereas the existing salinity scale was based on a conductivity-chlorinity relation using natural seawater, the new scale is based on a conductivity-salinity relation in which the samples which were used in the development of the relation were obtained from standard seawater of salinity ca. 35 by weight dilution with distilled water or by weight evaporation. This procedure was followed to ensure the constancy of relative composition of the seawater samples over the salinity range of interest.

The salinities obtained on this new scale are referred to as practical salinities and are to be reported as dimensionless quantities. A value of 35 on the new scale corresponds exactly to 35 ^{o}/oo on the old scale. While not so stated in the JPOTS reports, it is evident that this decision to have the values of practical salinity reported without units serves to effectively void the recommendation made in 1979 by the IAPSO Working Group on Symbols, Units and Nomenclature in Physical Oceanography (SUN Report, IUGG Publication Office, Paris, 1979). As reported in Deep Sea Research, Vol. 28A, No. 4. p.i., 1981, the IAPSO Working Group recommended that the ^{o}/oo symbol to express chlorinity and salinity be abandoned and replaced by 10^{-3}. Under this recommendation a salinity of 35 ^{o}/oo on the old scale would have to be reported as $35*10^{-3}$. The practical salinity scale recommended by the JPOTS is certainly preferable. The omission of units also serves as a tacit recognition that salinity is not actually the weight concentration of the total dissolved solids, but is only some measure related to the total dissolved solids.

The basic experimental work and mathematical analysis on which the Practical Salinity Scale 1978 is based were carried out at five different laboratories in four countries. Not only was the precision of the individual data sets from each laboratory higher than had previously been attained, but also interlaboratory agreement of a very high order was achieved.

DEFINITION OF THE PRACTICAL SALINITY SCALE, 1978

1. Absolute salinity, symbol S_A, is defined as the ratio of the mass of dissolved material in seawater to the mass of seawater. In practice, this quantity cannot be measured directly and a practical salinity is defined for reporting oceanographic observations.

2. The practical salinity, symbol S, of a sample of seawater, is defined in terms of the ratio K_{15} of the electrical conductivity of the seawater sample at the temperature of 15 Deg C and the pressure of one standard atmosphere, to that of a potassium chloride (KCl) solution, in which the mass fraction of KCl is $32.4356*10^{-3}$, at the same temperature and pressure. The K_{15} value exactly equal to 1 corresponds, by definition, to a practical salinity exactly equal to 35. The practical salinity is defined in terms of the ratio K_{15} by the following equation:

$$S = a_0 + a_1K_{15}^{1/2} + a_2K_{15} + a_3K_{15}^{3/2} + a_4K_{15}^2 + a_5K_{15}^{5/2} \quad (1)$$

where:

$a_0 = 0.0080$	$a_3 = 14.0941$
$a_1 = -0.1692$	$a_4 = -7.0261$
$a_2 = 25.3851$	$a_5 = 2.7081$
$\text{SUM } a_i = 35.0000$	$2 <= S <= 42$

Supplementary Statement

As a consequence of this definition any oceanic water having a precisely known conductivity ratio near unity at 15 Deg C with the KCl solution is a secondary standard for routine calibration of oceanographic instruments. All seawaters having the same conductivity ratio have the same practical salinity. Chlorinity is to be regarded as a separate, independent variable in describing the properties of seawater.

As a practical matter, only a few laboratories will maintain and utilize the primary KCl standard. The conductivity ratio at 15 Deg C of standard seawater (S = ca 35) will be determined using the primary standard, and marked on every vial. Standard seawater thus becomes the secondary standard of choice for calibration of laboratory salinometers. Once calibrated, the laboratory salinometers can be used to determine the conductivity ratio at 15 Deg C of seawater used as tertiary standards for the calibration of in situ field salinometers.

The Algorithm for Practical Salinity 1978

If R_t is the ratio of the conductivity of seawater, at temperature t, to the conductivity of seawater of practical salinity 35 at the same temperature (both at a pressure of 1 standard atmosphere), then R_{15} will have the same value as K_{15} and may, therefore, be used to calculate practical salinity in equation (1). Since all practical salinity measurements are carried out in reference to the conductivity of standard seawater (corrected to S = 35), it is the quantity R_t which will be available for salinity calculations. R_t is normally obtained directly by laboratory salinometers. In situ measurements usually produce the quantity R (or a nominal conductivity reading which can be converted to this quantity), that is, the ratio of the in situ conductivity to the standard conductivity at S = 35, t = 15 Deg C, p = 0 (where p is the pressure above one standard atmosphere).

R is factored into three parts, i.e.,

$$R = R_p r_t R_t \qquad (2)$$

where R_p is the ratio of the in situ conductivity to the conductivity of the same sample at the same temperature but at p = 0; r_t is the ratio of the conductivity of reference seawater, having a practical salinity of 35, at $p = 0$, and at temperature t, to its conductivity at $t = 15$ Deg C. A knowledge of R_p and r_t allows the calculation of the R_t from the in situ measurements, i.e.,

$$R_t = R/(R_p r_t) \tag{3}$$

It has been found that R_p, r_t, and R_t can be expressed as functions of the numerical values of the in situ parameters R, t, and p. When t is expressed in Deg C and p in bars (10^5Pa), the relationships are as follows:

$$R_p = 1 + \frac{p(e_1 + e_2 p + e_3 p^2)}{1 + d_1 t + d_2 t^2 + (d_3 + d_4 t)R} \tag{4}$$

where

$e_1 = 2.070*10^{-4}$ $\quad$ $d_1 = 3.426*10^{-2}$
$e_2 = -6.370*10^{-8}$ $\quad$ $d_2 = 4.464*10^{-4}$
$e_3 = 3.989*10^{-12}$ $\quad$ $d_3 = 4.215*10^{-1}$
$d_4 = -3.107*10^{-3}$

and

$$r_t = c_0 + c_1 t + c_2 t^2 + c_3 t^3 + c_4 t^4 \tag{5}$$

where

$c_0 = 0.6766097$ $\quad$ $c_3 = -6.9698 * 10^{-7}$
$c_1 = 2.00564 * 10^{-2}$ $\quad$ $c_4 = 1.0031 * 10^{-9}$
$c_2 = 1.104259 * 10^{-4}$

The effect of the relative small difference between R_t and R_{15} at a given salinity can be accounted for by adding a correction, ΔS, to the practical salinity calculated by substitution of R_t for K_{15} in equation 1. The practical salinity, therefore, may be computed with the equation

$$S = a_0 + a_1 R_t^{1/2} + a_2 R_t + a_3 R_t^{3/2} + a_4 R_4^2 + a_5 R_t^{5/2} + \Delta S \tag{6}$$

where

$$\Delta S = \frac{(t-15)}{1+k(t-15)} (b_0 + b_1 R_t^{1/2} + b_2 R_t + b_3 R_t^{3/2} + b_4 R_t^2 + b_5 R_t^{5/2})$$

with the constants a_i defined above for equation 1 and

$b_0 = 0.0005$	$b_4 = 0.0636$
$b_1 = -0.0056$	$b_5 = -0.0144$
$b_2 = -0.0066$	SUM $b_i = 0.0000$
$b_3 = -0.0375$	$k = 0.0162$

THE INTERNATIONAL EQUATION OF STATE OF SEAWATER, 1980

The new equation of state of seawater to be used with the practical salinity scale is based on measurements made using samples of seawater (S = ca 35) diluted by distilled water or concentrated by evaporation. This equation is more precise than the currently used equations and covers a wider range of temperature and pressure. The UNESCO reports containing the pertinent background papers in the development of this new equation of state of seawater are listed at the end of this paper.

The recommended units for density are kg m^{-3}. This means that the nominal numerical value of density is on the order of 1000, rather than 1 as was the case using units of gr cm^{-3}.

The density (rho, kg m^{-3}) of seawater as a function of practical salinity (S), temperature (t, Deg C) and pressure (p, bars) is given by:

$$\text{rho}(S,t,p) = \text{rho}(S,t,0)/\{1 - p/K(S,t,p)\} \quad (7)$$

where K(S,t,p) is the secant bulk modulus. The density of seawater at one standard atmosphere (p = 0) can be determined from

$$\rho(S,t,0) = (\rho)_w + (b_0 + b_1 t + b_2 t^2 + b_3 t^3 + b_4 t^4)S + (c_0 + c_1 t + c_2 t^2)S^{3/2} + d_0 S^2 \quad (8)$$

where

$b_0 = 8.24493 * 10^{-1}$

$b_1 = -4.0899 * 10^{-3}$

$b_2 = 7.6438 * 10^{-5}$

$b_3 = -8.2467 * 10^{-7}$

$b_4 = 5.3875 * 10^{-9}$

$c_0 = -5.72466 * 10^{-3}$

$c_1 = 1.0227 * 10^{-4}$

$c_2 = -1.6546 * 10^{-6}$

$d_0 = 4.8314 * 10^{-4}$

The density of the reference pure water is given by:

$$(\rho)_w = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5 \quad (9)$$

where

$a_0 = 999.842594$

$a_1 = 6.793952 * 10^{-2}$

$a_2 = -9.095290 * 10^{-3}$

$a_3 = 1.001685 * 10^{-4}$

$a_4 = -1.120083 * 10^{-6}$

$a_5 = 6.536332 * 10^{-9}$

The secant bulk modulus (K) of seawater is given by

$$K(S,t,p) = K(S,t,0) + Ap + Bp^2 \quad (10)$$

where

$$K(S,t,0) = K_w + (f_0 + f_1 t + f_2 t^2 + f_3 t^3)S + (g_0 + g_1 t + g_2 t^2)S^{3/2} \quad (11)$$

$f_0 = 54.6746$

$f_1 = -0.603459$

$f_2 = 1.09987 * 10^{-2}$

$f_3 = -6.1670 * 10^{-5}$

$g_0 = 7.944 * 10^{-2}$

$g_1 = 1.6483 * 10^{-2}$

$g_2 = -5.3009 * 10^{-4}$

$$A = A_w + (i_0 + i_1 t + i_2 t^2)S + j_0 S^{3/2} \quad (12)$$

$i_0 = 2.2838 * 10^{-3}$

$i_1 = -1.0981 * 10^{-5}$

$i_2 = -1.6078 * 10^{-6}$

$j_0 = 1.91075 * 10^{-4}$

$$B = B_w + (m_0 + m_1 t + m_2 t^2)S \quad (13)$$

$m_0 = -9.9348 * 10^{-7}$

$m_1 = 2.0816 * 10^{-8}$

$m_2 = 9.1697 * 10^{-10}$

The pure water terms of the secant bulk modulus are given by

$$K_w = e_0 + e_1 t + e_2 t^2 + e_3 t^3 + e_4 t^4 \quad (14)$$

$e_0 = 19652.21$ $\quad$ $e_3 = 1.360477 * 10^{-2}$

$e_1 = 148.4206$ $\quad$ $e_4 = -5.155288 * 10^{-5}$

$e_2 = -2.327105$

$$A_w = h_0 + h_1 t + h_2 t^2 + h_3 t^3 \quad (15)$$

$h_0 = 3.239908$ $\quad$ $h_2 = 1.16092 * 10^{-4}$

$h_1 = 1.43713 * 10^{-3}$ $\quad$ $h_3 = -5.77905 * 10^{-7}$

$$B_w = k_0 + k_1 t + k_2 t^2 \quad (16)$$

$k_0 = 8.50935 * 10^{-5}$ $\quad$ $k_2 = 5.2787 * 10^{-8}$

$k_1 = -6.12293 * 10^{-6}$

SOME ADDITIONAL COMMENTS

An important aspect of the adoption of the Practical Salinity Scale 1978 is the affirmation that the conductivity ratio, rather than absolute conductivity, should be the primary measure used in the determination of salinity of seawater. For a number of years there was an effort to determine the absolute electric conductivity of seawater as a function of temperature and salinity. At one time a proposal to mark all vials of standard seawater with the absolute conductivity was close to being adopted, and many *in situ* instruments give readouts which are purported to be absolute conductivity, in units of mmhos/cm. It is now clear that the readout from these units should be considered simply as meter readings. These readings for a given *in situ* salinometer become meaningful only when divided by the meter reading of that instrument for standard seawater having a practical salinity of 35, at t = 15 Deg C and p = 0.

The calibration and computational procedures which should be used at MSRC so that we can be in compliance with the recommendations of the UNESCO/ICES/SCOR/IAPSO JPOTS will be contained in a following MSRC working report.

LIST OF BACKGROUND REPORTS

The following are all reports in the series "Unesco technical papers in marine science." At least one copy of each is in the MSRC library.

No.		Year
36	Tenth report of the joint panel on oceanographic Tables and Standards.	1981
37	Background papers and supporting data on the Practical Salinity Scale 1978.	1981
38	Background papers and supporting data on the International Equation of State of Seawater 1980.	1981
39	International Oceanographic Tables, Vol. 3.	1981

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