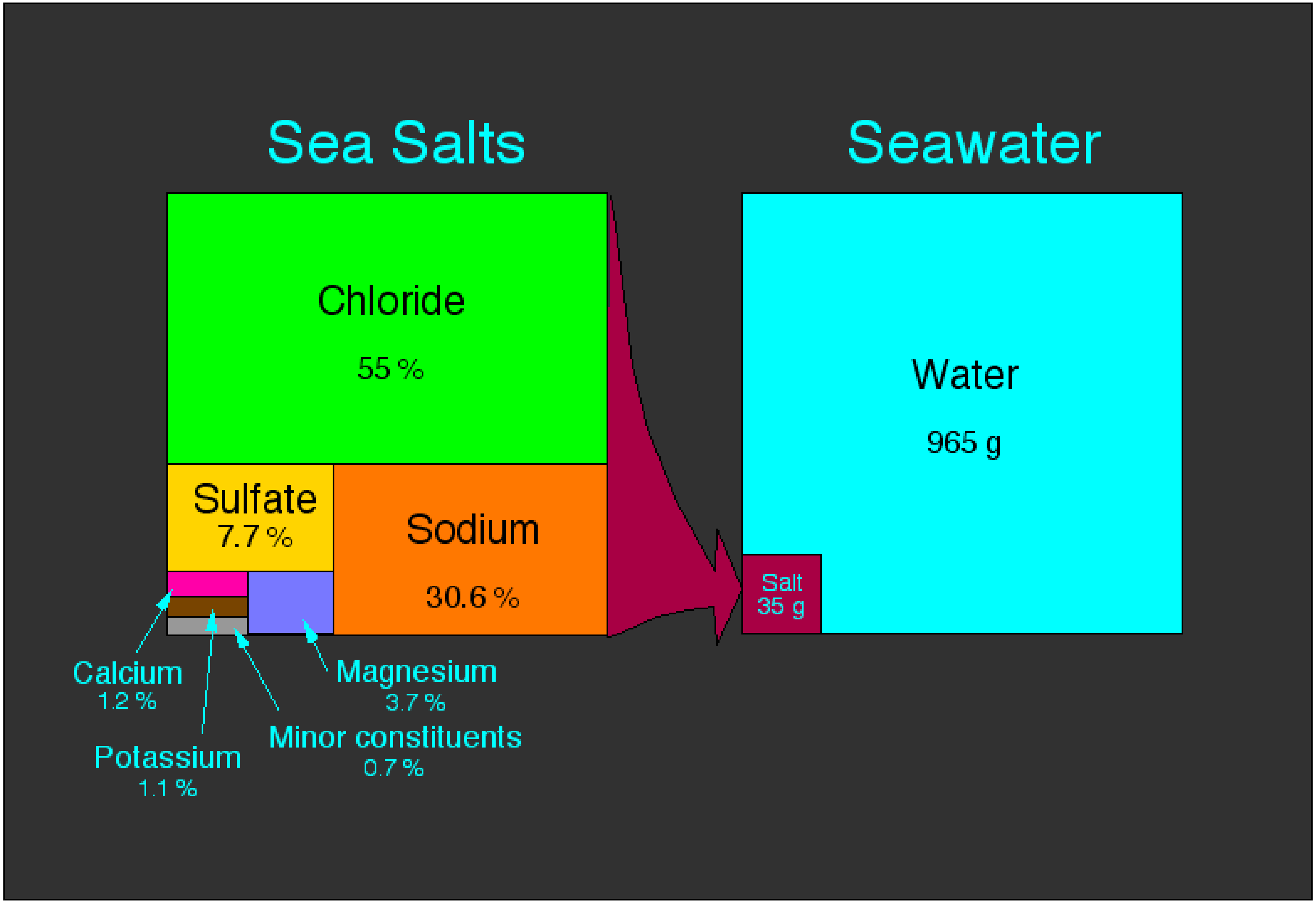
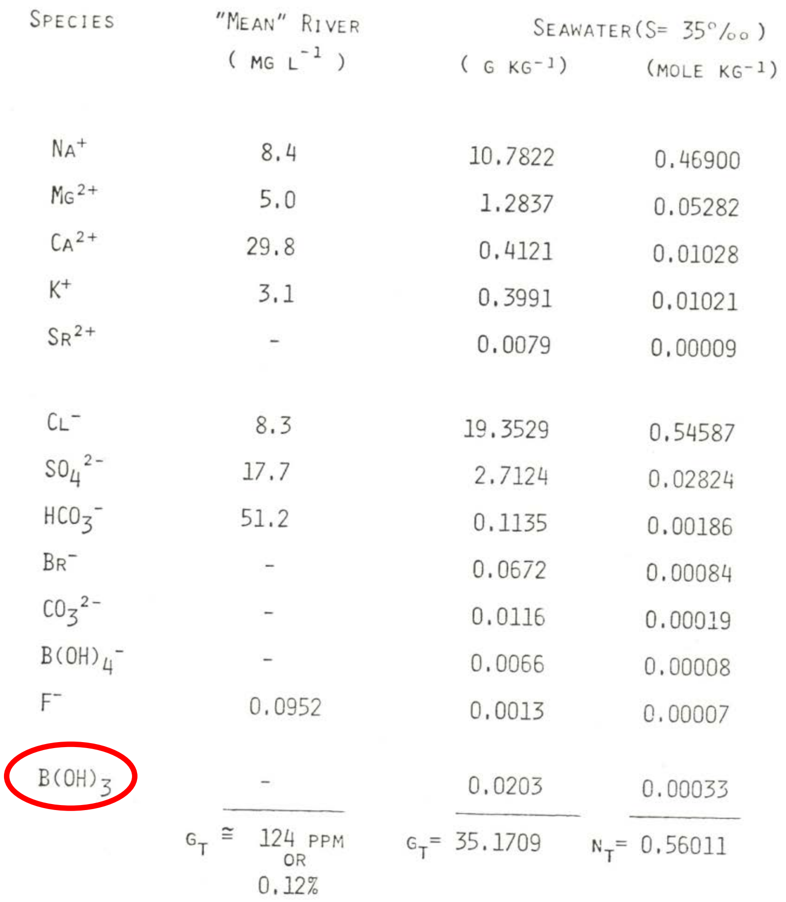
Seawater composition



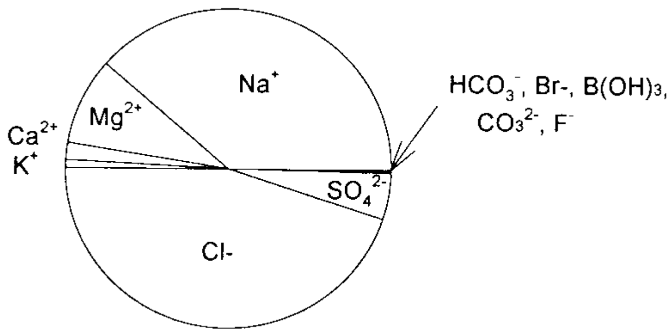
http://eps.mcgill.ca/~courses/c542/

Seawater composition

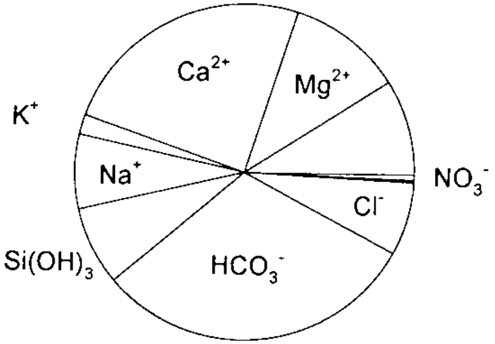


Species	"Mean" River (mg L^{-1})	Seawater (S= 35°/oo) (g kg^{-1})	(mole kg^{-1})
Na^+	8.4	10.7822	0.46900
Mg^{2+}	5.0	1.2837	0.05282
Ca^{2+}	29.8	0.4121	0.01028
K^+	3.1	0.3991	0.01021
Sr^{2+}	-	0.0079	0.00009
Cl^-	8.3	19.3529	0.54587
SO_4^{2-}	17.7	2.7124	0.02824
HCO_3^-	51.2	0.1135	0.00186
Br^-	-	0.0672	0.00084
CO_3^{2-}	-	0.0116	0.00019
$B(OH)_4^-$	-	0.0066	0.00008
F^-	0.0952	0.0013	0.00007
$B(OH)_3$	-	0.0203	0.00033
	$G_T \cong$ 124 ppm or 0.12%	$G_T =$ 35.1709	$N_T =$ 0.56011

Seawater

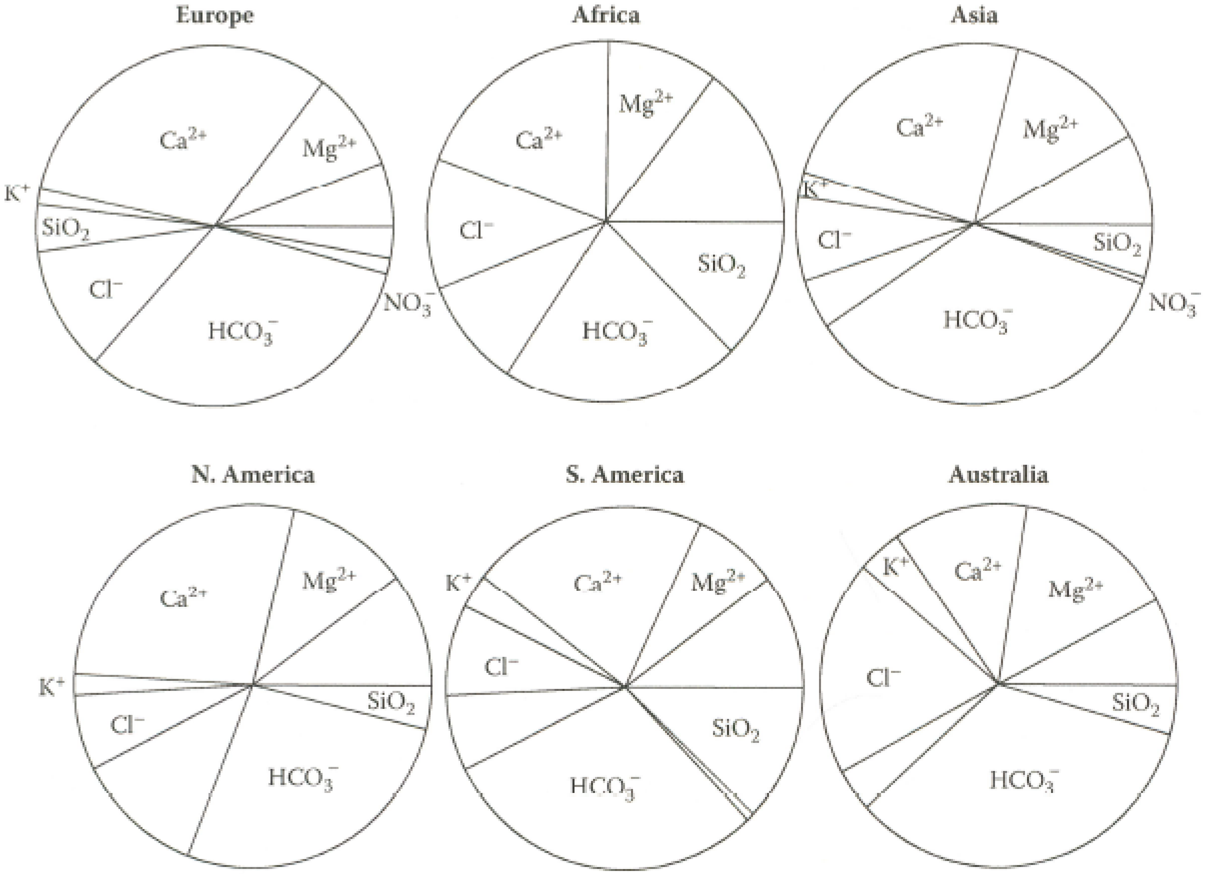


River Water

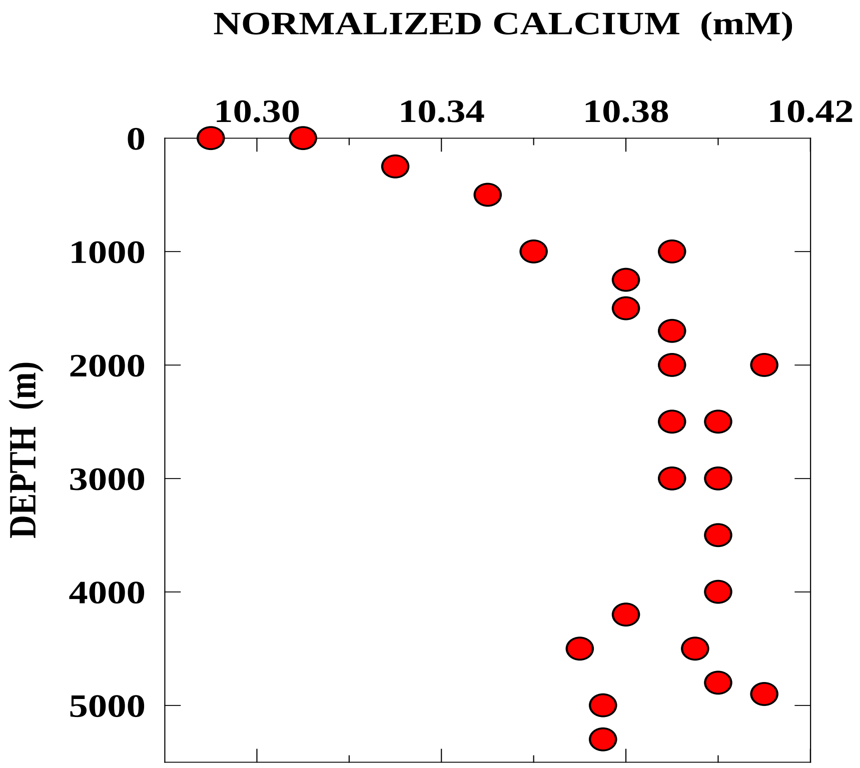


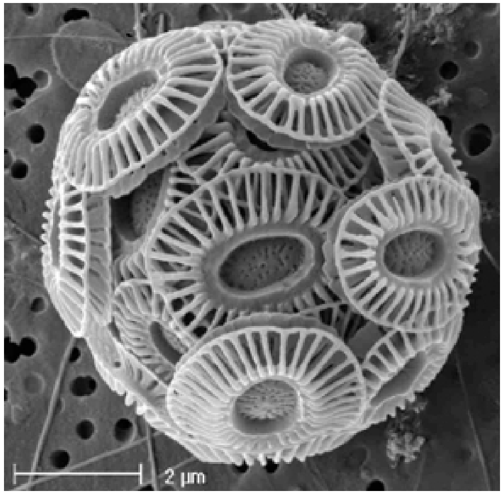
Law of constant relative proportions (Marcet's principle): the concentration ratio of major elements to each other or to the total salt content is a constant.

Major constituents of various rivers of the continents of the world

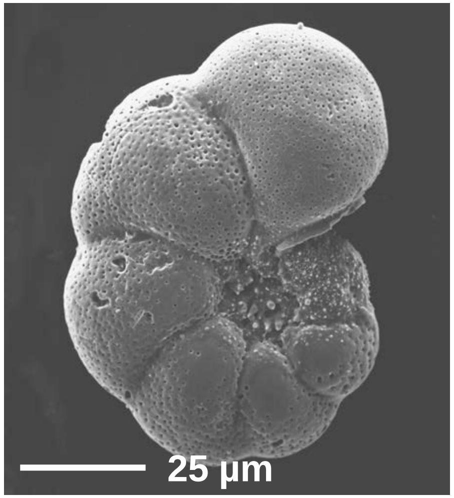


Seawater composition





Coccolithophores



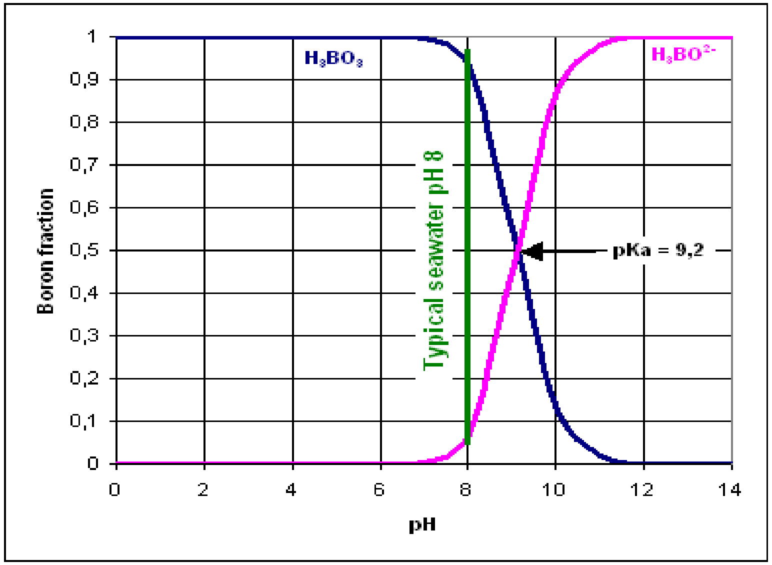
Foraminifera

$$CaCO_3 \longleftrightarrow Ca^{2+} + CO_3^{2-}$$

Seawater composition

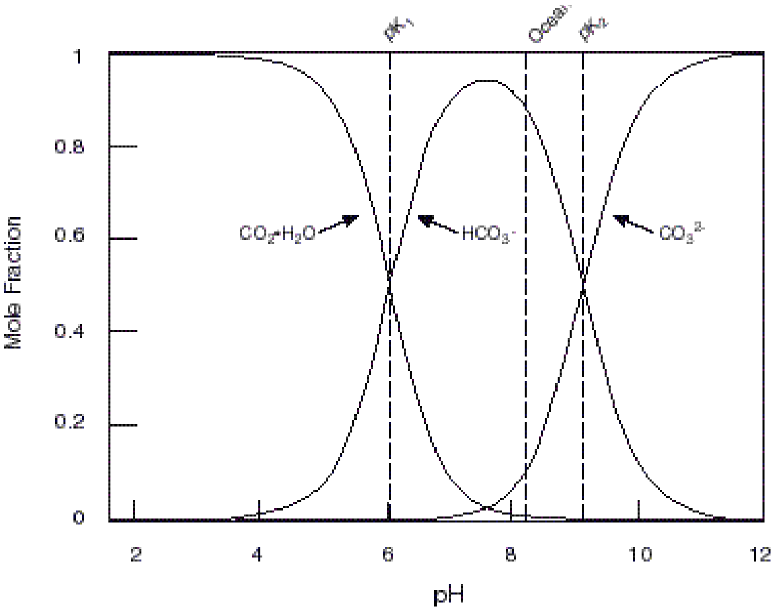
$B(OH)_3 + H_2O \leftrightarrow B(OH)_4^- + H^+$

$\Sigma B = [B(OH)_3] + [B(OH)_4^-]$
$= 0.0007826 * S_P$ (g/kg)
$= 1.230 \times 10^{-5} * S_P$ (mol/kg-H_2O)



$CO_{2(g)} + H_2O \leftrightarrow H_2CO_3$
$H_2CO_3 \leftrightarrow H^+ + HCO_3^-$
$HCO_3^- \leftrightarrow H^+ + CO_3^{2-}$

$\Sigma CO_2 = [H_2CO_3] + [HCO_3^-] + [CO_3^{2-}]$
$TA = 2\,[CO_3^{2-}] + [HCO_3^-] + [B(OH)_4^-]$
NTA = Normalized alkalinity = TA x $35/S_P$
SA = Specific alkalinity = TA/Cl



Seawater composition

Acantharians secrete celestite exoskeletons

$SrSO_4 \leftarrow\rightarrow Sr^{2+} + SO_4^{2-}$

celestite

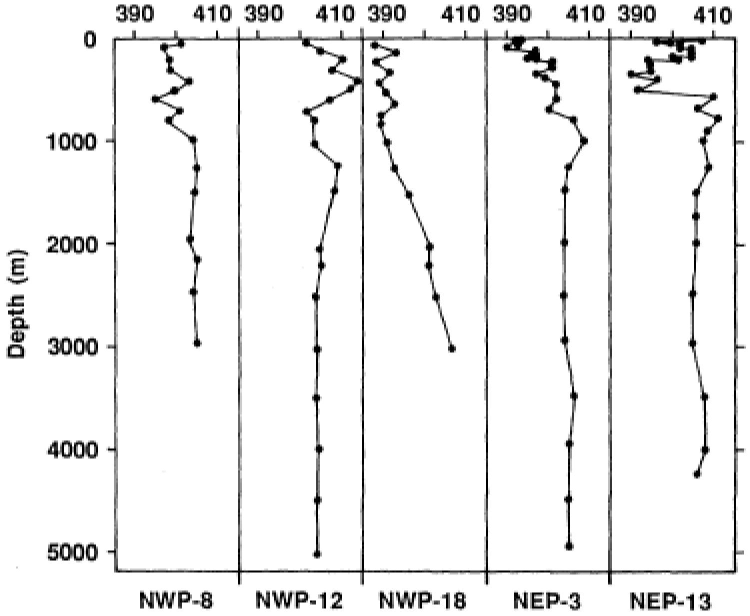
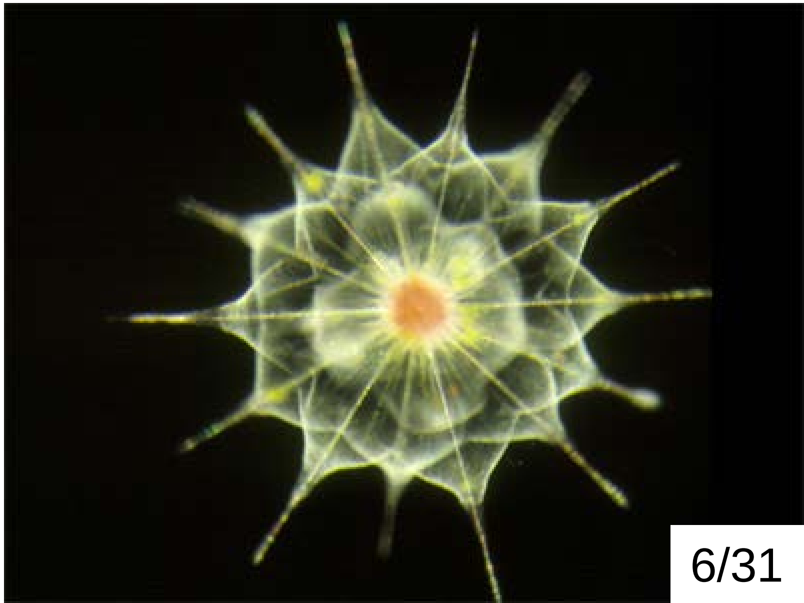


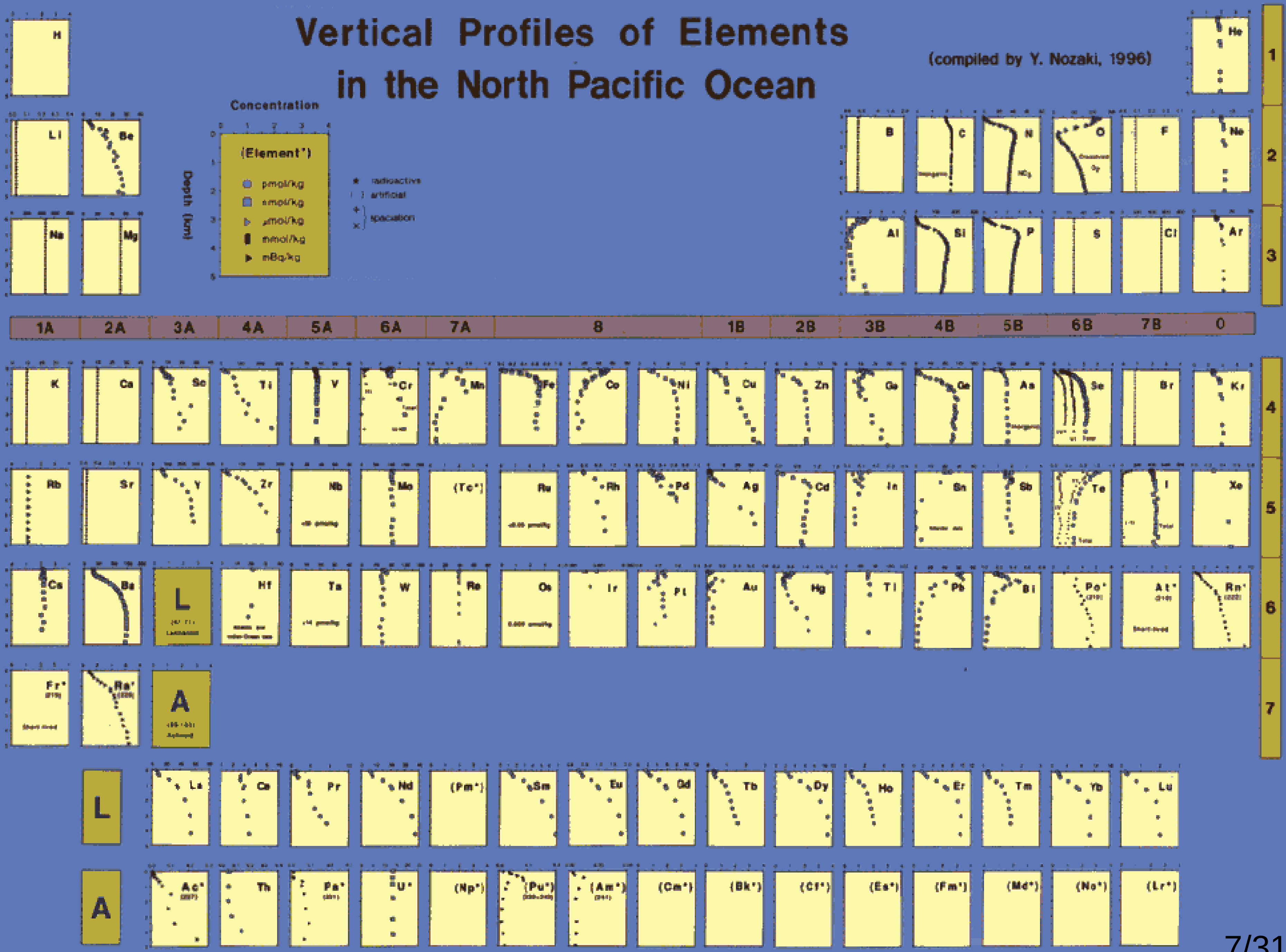
Fig. 5. Profiles of Sr/Cl for selected stations in the eastern and western North Pacific (Sr in micrograms per kilogram; Cl in grams per kilogram; Sr/Cl in micrograms per gram).

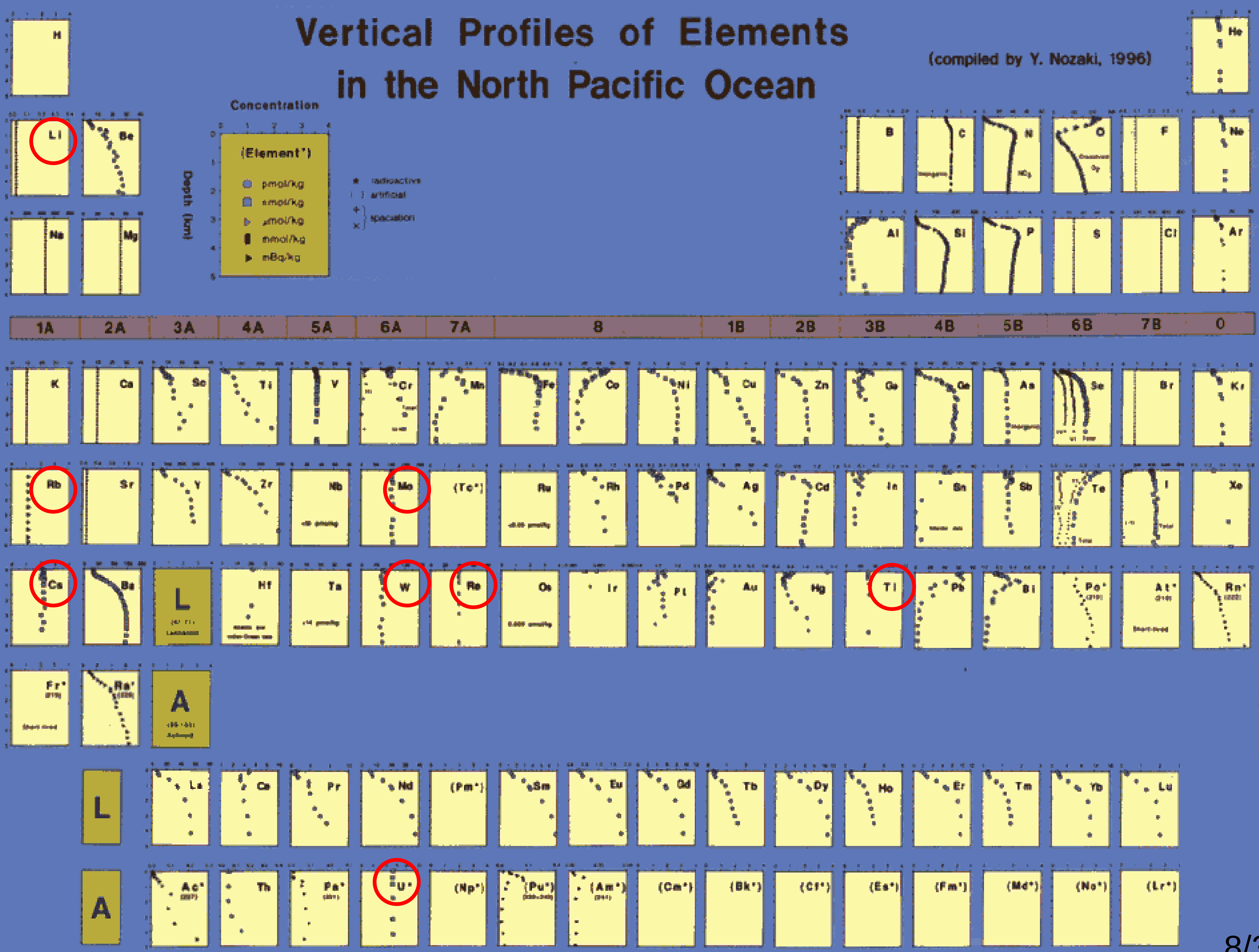


From: Bernstein et al. Science (237) 1987.

Vertical Profiles of Elements in the North Pacific Ocean

(compiled by Y. Nozaki, 1996)




Vertical Profiles of Elements in the North Pacific Ocean
(compiled by Y. Nozaki, 1996)
Concentration
Depth (km)
(Element*)
pmol/kg
nmol/kg
µmol/kg
mmol/kg
mBq/kg
* radioactive
( ) artificial
+ × } spallation
1A
2A
3A
4A
5A
6A
7A
8
1B
2B
3B
4B
5B
6B
7B
0
1
2
3
4
5
6
7
H
He
Li
Be
B
C
N
O
F
Ne
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
Kr
Rb
Sr
Y
Zr
Nb
Mo
(Tc*)
Ru
Rh
Pd
Ag
Cd
In
Sn
Sb
Te
I
Xe
Cs
Ba
L
Hf
Ta
W
Re
Os
Ir
Pt
Au
Hg
Tl
Pb
Bi
Po*
At*
Rn*
Fr*
Ra*
A
La
Ce
Pr
Nd
(Pm*)
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Ac*
Th
Pa*
U*
(Np*)
(Pu*)
(Am*)
(Cm*)
(Bk*)
(Cf*)
(Es*)
(Fm*)
(Md*)
(No*)
(Lr*)
Short-lived

Seawater composition

(minor elements)

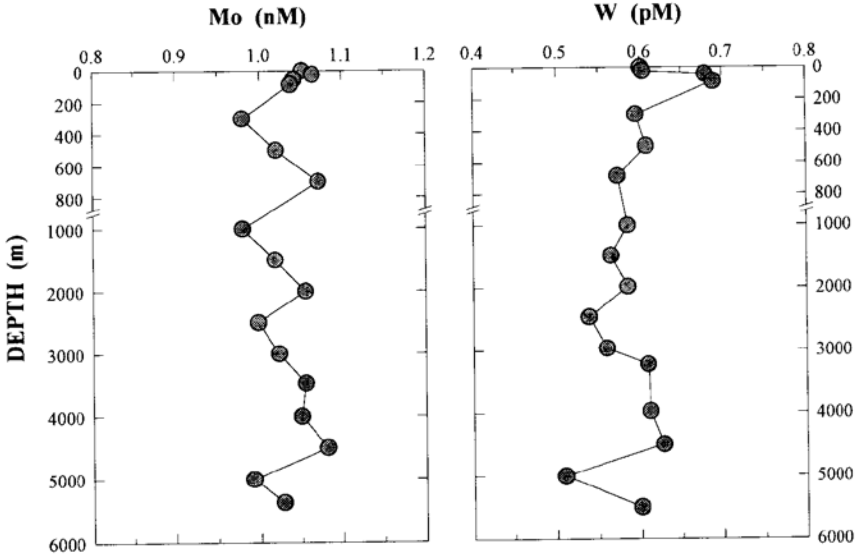


FIGURE 3.5. Profiles of molybdenum (Mo) and tungsten (W) in the Pacific Ocean.

Element	Speciation	Concentration at S_P = 35
Li	**Li^+**	**25 µmole kg^{-1}**
Rb	**Rb^+**	**1.4 µmole kg^{-1}**
Mo	**MoO_4^{2-}**	**0.11 µmole kg^{-1}**
Cs	**Cs^+**	**2.2 nmole kg^{-1}**
Tl	**$Tl^{+,}$ $TlCl^o$ or $Tl(OH)_3^o$**	**60 pmole kg^{-1}**

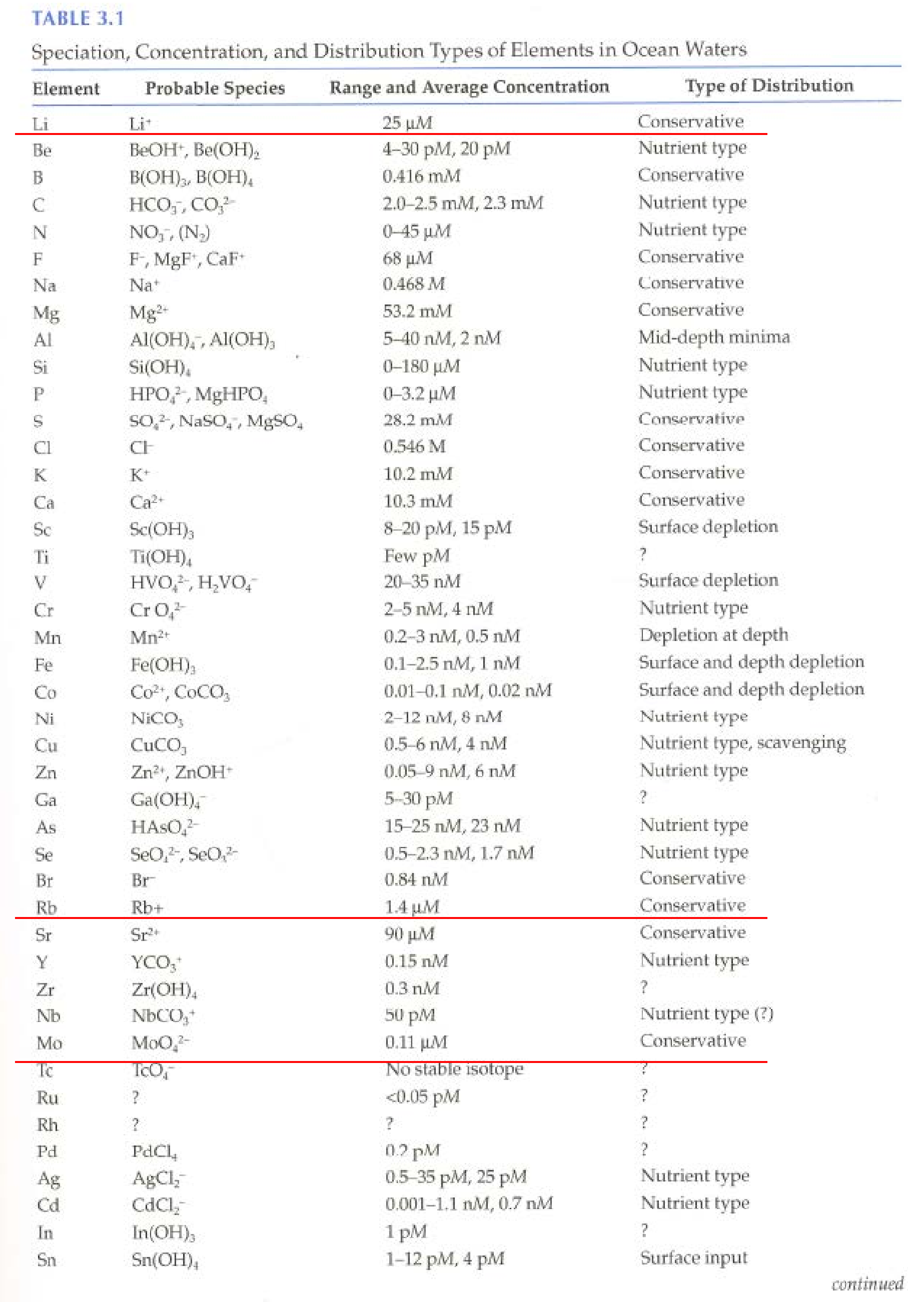


TABLE 3.1

Speciation, Concentration, and Distribution Types of Elements in Ocean Waters

Element	Probable Species	Range and Average Concentration	Type of Distribution
Li	Li^+	25 μM	Conservative
Be	$BeOH^+$, $Be(OH)_2$	4–30 pM, 20 pM	Nutrient type
B	$B(OH)_3$, $B(OH)_4$	0.416 mM	Conservative
C	HCO_3^-, CO_3^{2-}	2.0–2.5 mM, 2.3 mM	Nutrient type
N	NO_3^-, (N_2)	0–45 μM	Nutrient type
F	F^-, MgF^+, CaF^+	68 μM	Conservative
Na	Na^+	0.468 M	Conservative
Mg	Mg^{2+}	53.2 mM	Conservative
Al	$Al(OH)_4^-$, $Al(OH)_3$	5–40 nM, 2 nM	Mid-depth minima
Si	$Si(OH)_4$	0–180 μM	Nutrient type
P	HPO_4^{2-}, $MgHPO_4$	0–3.2 μM	Nutrient type
S	SO_4^{2-}, $NaSO_4^-$, $MgSO_4$	28.2 mM	Conservative
Cl	Cl^-	0.546 M	Conservative
K	K^+	10.2 mM	Conservative
Ca	Ca^{2+}	10.3 mM	Conservative
Sc	$Sc(OH)_3$	8–20 pM, 15 pM	Surface depletion
Ti	$Ti(OH)_4$	Few pM	?
V	HVO_4^{2-}, $H_2VO_4^-$	20–35 nM	Surface depletion
Cr	$Cr\ O_4^{2-}$	2–5 nM, 4 nM	Nutrient type
Mn	Mn^{2+}	0.2–3 nM, 0.5 nM	Depletion at depth
Fe	$Fe(OH)_3$	0.1–2.5 nM, 1 nM	Surface and depth depletion
Co	Co^{2+}, $CoCO_3$	0.01–0.1 nM, 0.02 nM	Surface and depth depletion
Ni	$NiCO_3$	2–12 nM, 8 nM	Nutrient type
Cu	$CuCO_3$	0.5–6 nM, 4 nM	Nutrient type, scavenging
Zn	Zn^{2+}, $ZnOH^+$	0.05–9 nM, 6 nM	Nutrient type
Ga	$Ga(OH)_4^-$	5–30 pM	?
As	$HAsO_4^{2-}$	15–25 nM, 23 nM	Nutrient type
Se	SeO_4^{2-}, SeO_3^{2-}	0.5–2.3 nM, 1.7 nM	Nutrient type
Br	Br^-	0.84 nM	Conservative
Rb	Rb+	1.4 μM	Conservative
Sr	Sr^{2+}	90 μM	Conservative
Y	YCO_3^+	0.15 nM	Nutrient type
Zr	$Zr(OH)_4$	0.3 nM	?
Nb	$NbCO_3^+$	50 pM	Nutrient type (?)
Mo	MoO_4^{2-}	0.11 μM	Conservative
Tc	TcO_4^-	No stable isotope	?
Ru	?	<0.05 pM	?
Rh	?	?	?
Pd	$PdCl_4$	0.2 pM	?
Ag	$AgCl_2^-$	0.5–35 pM, 25 pM	Nutrient type
Cd	$CdCl_2^-$	0.001–1.1 nM, 0.7 nM	Nutrient type
In	$In(OH)_3$	1 pM	?
Sn	$Sn(OH)_4$	1–12 pM, 4 pM	Surface input

continued

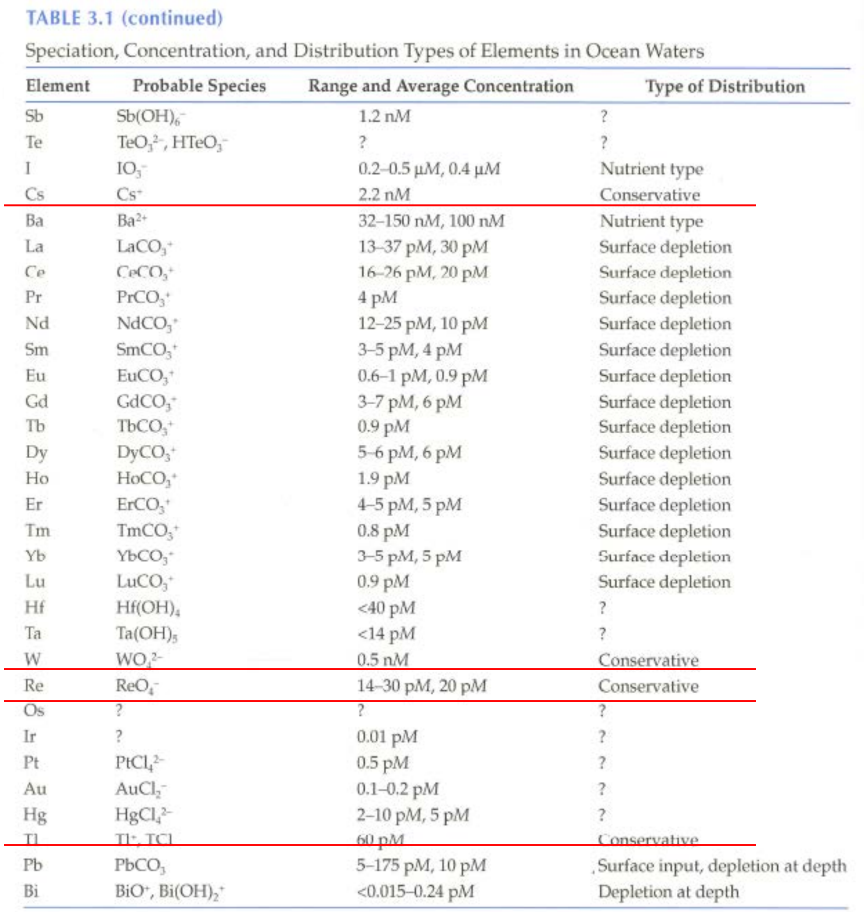
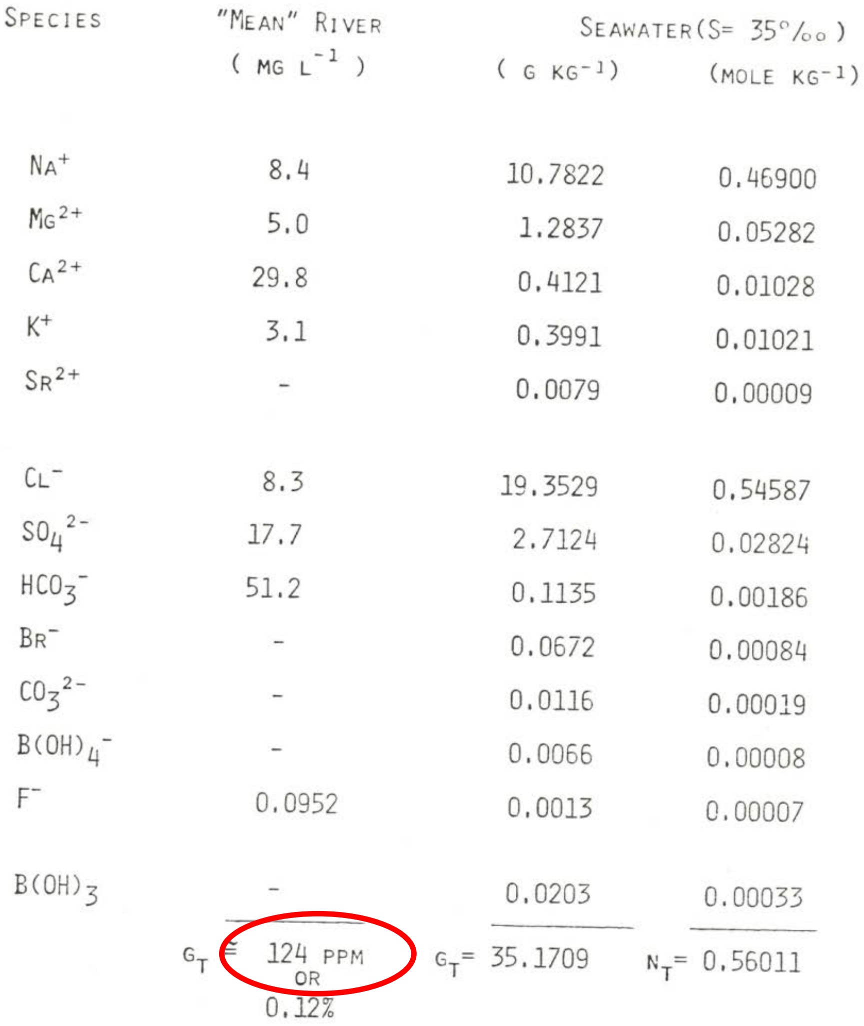


TABLE 3.1 (continued)

Speciation, Concentration, and Distribution Types of Elements in Ocean Waters

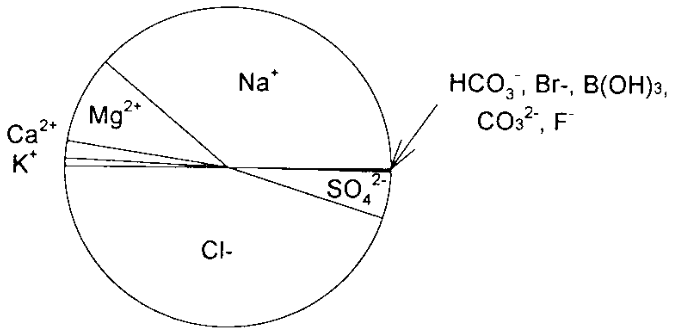
Element	Probable Species	Range and Average Concentration	Type of Distribution
Sb	$Sb(OH)_6^-$	1.2 nM	?
Te	TeO_3^{2-}, $HTeO_3^-$	?	?
I	IO_3^-	0.2–0.5 μM, 0.4 μM	Nutrient type
Cs	Cs^+	2.2 nM	Conservative
Ba	Ba^{2+}	32–150 nM, 100 nM	Nutrient type
La	$LaCO_3^+$	13–37 pM, 30 pM	Surface depletion
Ce	$CeCO_3^+$	16–26 pM, 20 pM	Surface depletion
Pr	$PrCO_3^+$	4 pM	Surface depletion
Nd	$NdCO_3^+$	12–25 pM, 10 pM	Surface depletion
Sm	$SmCO_3^+$	3–5 pM, 4 pM	Surface depletion
Eu	$EuCO_3^+$	0.6–1 pM, 0.9 pM	Surface depletion
Gd	$GdCO_3^+$	3–7 pM, 6 pM	Surface depletion
Tb	$TbCO_3^+$	0.9 pM	Surface depletion
Dy	$DyCO_3^+$	5–6 pM, 6 pM	Surface depletion
Ho	$HoCO_3^+$	1.9 pM	Surface depletion
Er	$ErCO_3^+$	4–5 pM, 5 pM	Surface depletion
Tm	$TmCO_3^+$	0.8 pM	Surface depletion
Yb	$YbCO_3^+$	3–5 pM, 5 pM	Surface depletion
Lu	$LuCO_3^+$	0.9 pM	Surface depletion
Hf	$Hf(OH)_4$	<40 pM	?
Ta	$Ta(OH)_5$	<14 pM	?
W	WO_4^{2-}	0.5 nM	Conservative
Re	ReO_4^-	14–30 pM, 20 pM	Conservative
Os	?	?	?
Ir	?	0.01 pM	?
Pt	$PtCl_4^{2-}$	0.5 pM	?
Au	$AuCl_2^-$	0.1–0.2 pM	?
Hg	$HgCl_4^{2-}$	2–10 pM, 5 pM	?
Tl	Tl^+, TCl	60 pM	Conservative
Pb	$PbCO_3$	5–175 pM, 10 pM	Surface input, depletion at depth
Bi	BiO^+, $Bi(OH)_2^+$	<0.015–0.24 pM	Depletion at depth

Seawater composition

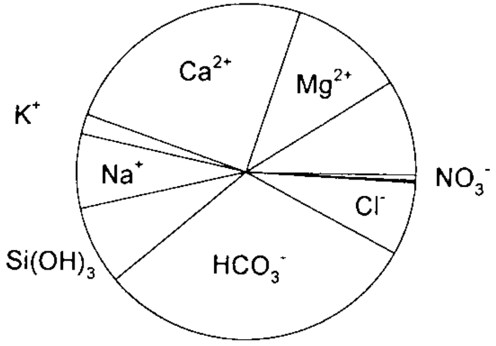


Species	"Mean" River (mg L^{-1})	Seawater ($S= 35‰$) (g kg^{-1})	 (mole kg^{-1})
Na^+	8.4	10.7822	0.46900
Mg^{2+}	5.0	1.2837	0.05282
Ca^{2+}	29.8	0.4121	0.01028
K^+	3.1	0.3991	0.01021
Sr^{2+}	-	0.0079	0.00009
Cl^-	8.3	19.3529	0.54587
SO_4^{2-}	17.7	2.7124	0.02824
HCO_3^-	51.2	0.1135	0.00186
Br^-	-	0.0672	0.00084
CO_3^{2-}	-	0.0116	0.00019
$B(OH)_4^-$	-	0.0066	0.00008
F^-	0.0952	0.0013	0.00007
$B(OH)_3$	-	0.0203	0.00033
	$G_T \equiv$ 124 ppm or 0.12%	$G_T=$ 35.1709	$N_T=$ 0.56011

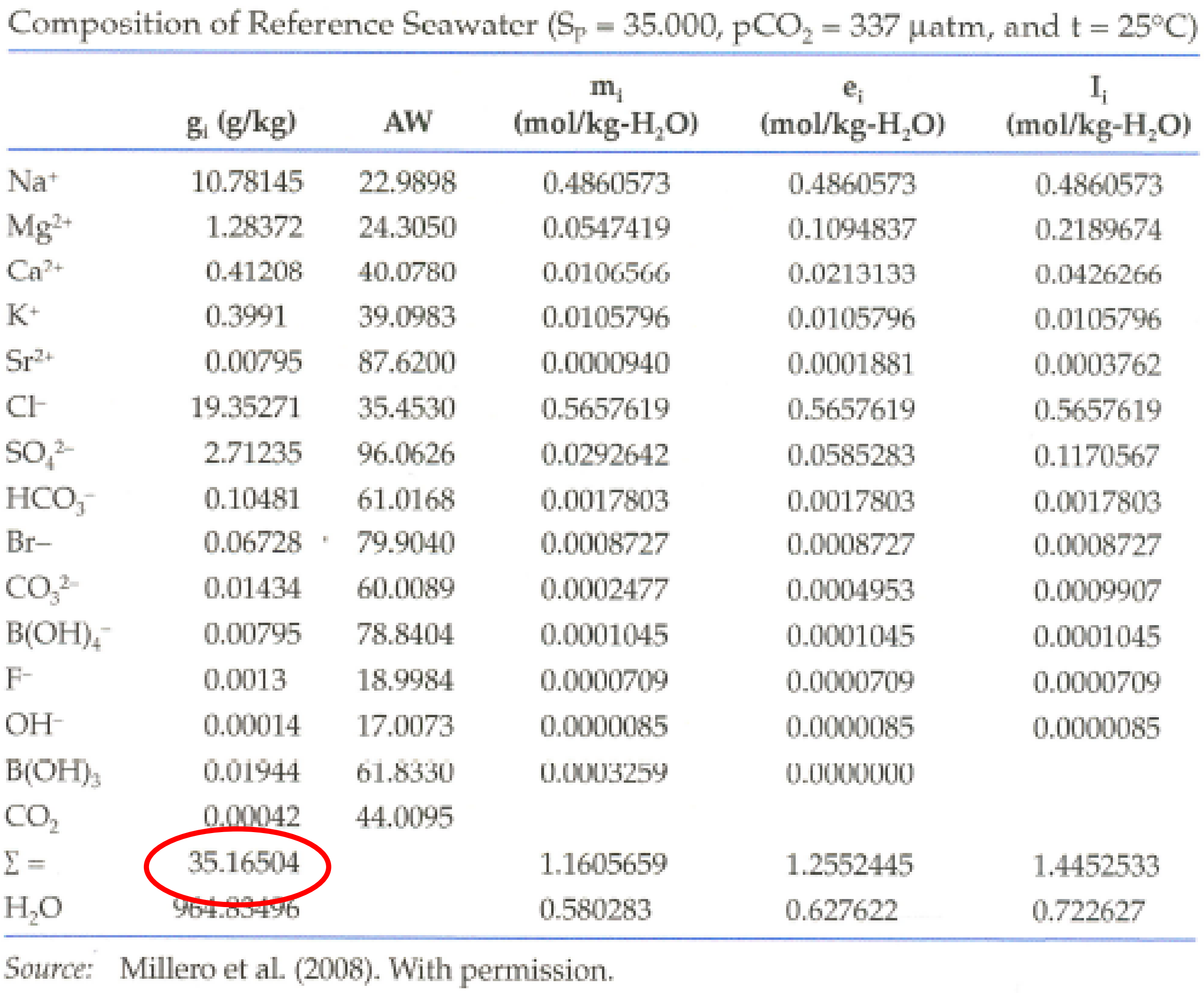
Seawater



River Water



Seawater composition



Composition of Reference Seawater ($S_P = 35.000$, $pCO_2 = 337$ μatm, and t = 25°C)

	g_i (g/kg)	AW	m_i (mol/kg-H_2O)	e_i (mol/kg-H_2O)	I_i (mol/kg-H_2O)
Na^+	10.78145	22.9898	0.4860573	0.4860573	0.4860573
Mg^{2+}	1.28372	24.3050	0.0547419	0.1094837	0.2189674
Ca^{2+}	0.41208	40.0780	0.0106566	0.0213133	0.0426266
K^+	0.3991	39.0983	0.0105796	0.0105796	0.0105796
Sr^{2+}	0.00795	87.6200	0.0000940	0.0001881	0.0003762
Cl^-	19.35271	35.4530	0.5657619	0.5657619	0.5657619
SO_4^{2-}	2.71235	96.0626	0.0292642	0.0585283	0.1170567
HCO_3^-	0.10481	61.0168	0.0017803	0.0017803	0.0017803
Br–	0.06728	79.9040	0.0008727	0.0008727	0.0008727
CO_3^{2-}	0.01434	60.0089	0.0002477	0.0004953	0.0009907
$B(OH)_4^-$	0.00795	78.8404	0.0001045	0.0001045	0.0001045
F^-	0.0013	18.9984	0.0000709	0.0000709	0.0000709
OH^-	0.00014	17.0073	0.0000085	0.0000085	0.0000085
$B(OH)_3$	0.01944	61.8330	0.0003259	0.0000000	
CO_2	0.00042	44.0095			
$\Sigma =$	35.16504		1.1605659	1.2552445	1.4452533
H_2O	964.83496		0.580283	0.627622	0.722627

Source: Millero et al. (2008). With permission.

Definition of salinity and chlorinity

1901 (Knudsen): **Salinity is defined as the weight of inorganic salts in one kilogram of seawater, when all bromides (and iodides) are replaced by an equivalent quantity of chlorides, and all carbonates are replaced by an equivalent quantity of oxides.**

The values of S‰ were determined by evaporating the seawater over 5 days at temperatures up to 480°C.

1902 (International Commission chaired by Knudsen under the auspices of the International Council for the Exploration of the Sea (ICES)):

$$\text{Chlorinity} = \text{Cl‰} = (\text{Wt}_{\text{Ag}} \times \text{M.W. Cl})/\text{M.W. Ag}$$

where Wt_{Ag} is the weight of silver needed to precipitate all the halides in 1 kg of seawater. M.W. Cl and M.W. Ag are the atomic weights of chlorine and silver, respectively.

Hence, the chlorinity is the mass equivalent in chloride of the mass of halogens in 1 kg of seawater.

$$\text{S‰} = 1.8050\ \text{Cl‰} + 0.030$$

(from the analysis of 9 samples: Red Sea, North Atlantic, North Sea, 6 from the Baltic Sea)

Definition of salinity and chlorinity

Between 1902 and 1937, the atomic weights of chlorine and silver were often revised following the development of more sophisticated instruments or the institution of new conventions (e.g., assigning a mass of 12.0000 to carbon-12).

In order not to invalidate previously published hydrographic tables, in 1937, chlorinity was redefined as:
mass of silver in grams required to precipitate the halogens in 0.3285234 kg of seawater

or $$Cl(‰) = 0.3285234\, Ag(gram)$$

where *Ag(‰)* is the weight of silver in grams needed to precipitate all the halides in 1 kg of seawater

Although, officially, chlorinity superseded salinity to describe the salt content of seawater, the relationship obtained by Knudsen was still being (erroneously) used.

$$S‰ = 1.8050\, Cl(‰) + 0.030$$

The relationship between chlorinity and salinity was re-determined and, since 1969, it is given by:

$$S‰ = 1.80655\, Cl(‰) \text{ (Unesco-1967)}$$

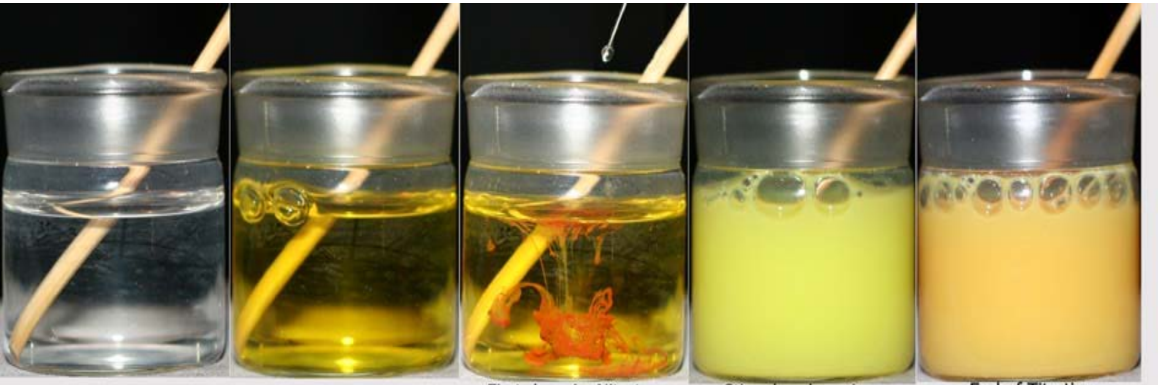
Chlorinity determination

$Ag^+ + Cl^- \rightarrow AgCl_{(s)}$ (colorless, white) $pK_{sp} = 9.96$

$Ag^+ + Br^- \rightarrow AgBr_{(s)}$ (light yellow) $pK_{sp} = 12.4$

$Ag^+ + I^- \rightarrow AgI_{(s)}$ (orange) $pK_{sp} = 16$

$2Ag^+ + CrO_4^{2-} \rightarrow Ag_2CrO_{4(s)}$ (red brown) $pK_{sp} = 12.2$



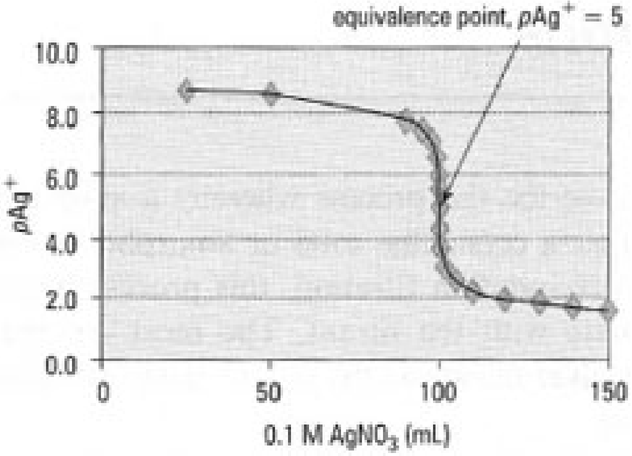
10cc diluted solution + 10cc water

+ 6 drops indicator

First drop Ag Nitrate. The red color will give way when stirred

Stirred and coming close to the end of Titration

End of Titration. (perhaps a bit too far)



Standard seawater

(a.k.a. Copenhagen Standard Seawater)

For reasons of compatibility between laboratories in the world, the International Commission established the Standard Sea Water Service. For more than six decades, the International Association for the Physical Sciences of Oceanography (IAPSO) has prepared and distributed seawater collected in the North Atlantic and diluted with distilled water to a chlorinity of approximately 19.374‰.

Definition of salinity and chlorinity

In 1967, Cox et al. measured the conductivity ratio R_{15} of open ocean seawater at 15°C and 1 standard atmosphere pressure relative to standards of known *Cl(‰)* and converted the resulting relationship to salinity using the Unesco-1967 relationship.

$$S(‰) = 1.80655\, Cl(‰)$$

$$S(‰) = 1.80655 \times 0.3285234\, Ag(‰)$$

$$S(‰) = -0.08996 + 28.29720\, R_{15} + 12.80832\, R_{15}^2 - 10.67869\, R_{15}^3 + 5.98624\, R_{15}^4 - 1.32311\, R_{15}^5$$

where R_{15} is the ratio of the conductivity of a water sample to that of water having a chlorinity of exactly 19.3740‰

In 1975, this became **the International Practical Salinity Scale (S_P)**. Since the IPSS was strictly based on a relationship to the conductivity, a KCl solution (32.4352 g KCl/kg at 15°C) with the same conductivity as Standard Seawater was assigned a Practical Salinity (S_P) of 35 and the ratio of the conductivity of a seawater sample to the KCl solution is referred to a K_{15}.

In 1985, the units (‰, ppt, psu) were dropped since the salinity and chlorinity do not represent ratios of anything tangible but are operational definitions.

Definition of salinity

Given that the temperature scale and atomic weights of the elements were revised in 2005 (IUPAC, 2005), SCOR and IAPSO established Working Group 127 on the "Thermodynamics and Equation of State of Seawater" to arrive at a series of algorithms that incorporate our best knowledge of seawater thermodynamics.
They introduced the concept of Absolute Salinity (S_A) over Practical Salinity (S_P) because the thermodynamic properties of seawater are directly influenced by the mass of dissolved constituents (i.e., Absolute Salinity) whereas Practical Salinity depends on conductivity. Hence, Absolute Salinity is defined as the mass fraction of dissolved material in seawater and determined from the Reference Salinity (S_R = 35.16504 g kg^{-1}) computed from the Practical Salinity (S_P, PSS-78) derived from conductivity measurements. Thus,

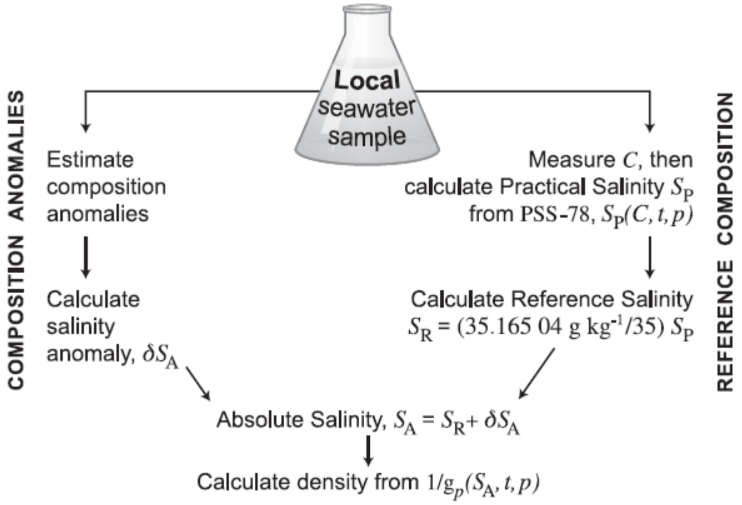
$$S_R = (35.16504 \text{ g kg}^{-1}/35) * S_P$$

and the Absolute Salinity is given by

$$S_A = S_R + \delta S_A \text{ (g kg}^{-1}\text{)}$$

where δS_A is calculated from the density anomaly of the sample.

Definition of salinity



Local seawater sample

COMPOSITION ANOMALIES

Estimate composition anomalies

Calculate salinity anomaly, δS_A

REFERENCE COMPOSITION

Measure C, then calculate Practical Salinity S_P from PSS-78, $S_P(C, t, p)$

Calculate Reference Salinity $S_R = (35.165\,04 \text{ g kg}^{-1}/35)\, S_P$

Absolute Salinity, $S_A = S_R + \delta S_A$

Calculate density from $1/g_p(S_A, t, p)$

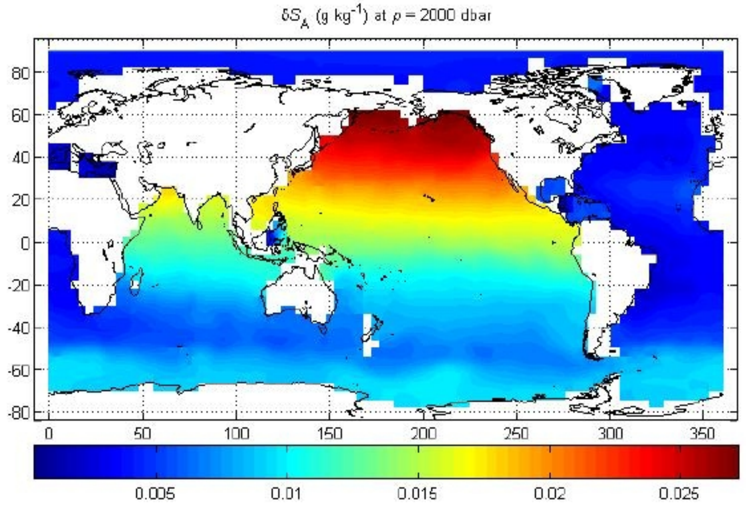


Figure 2 (a) Absolute Salinity Anomaly δS_A at $p = 2000$ dbar.

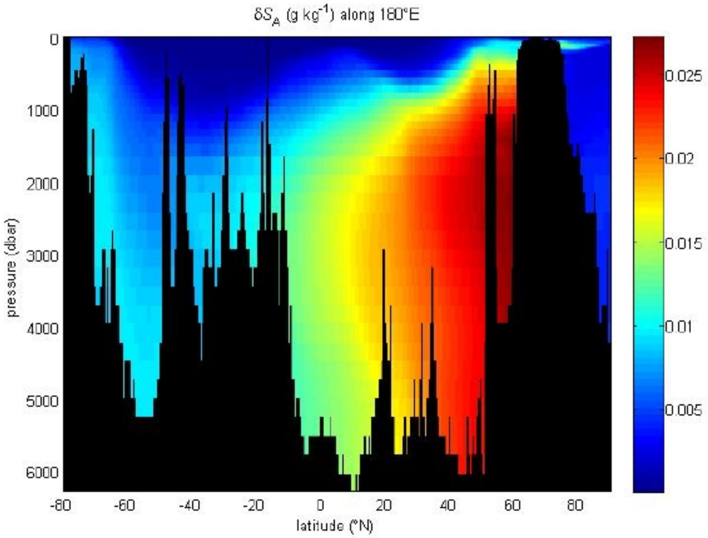
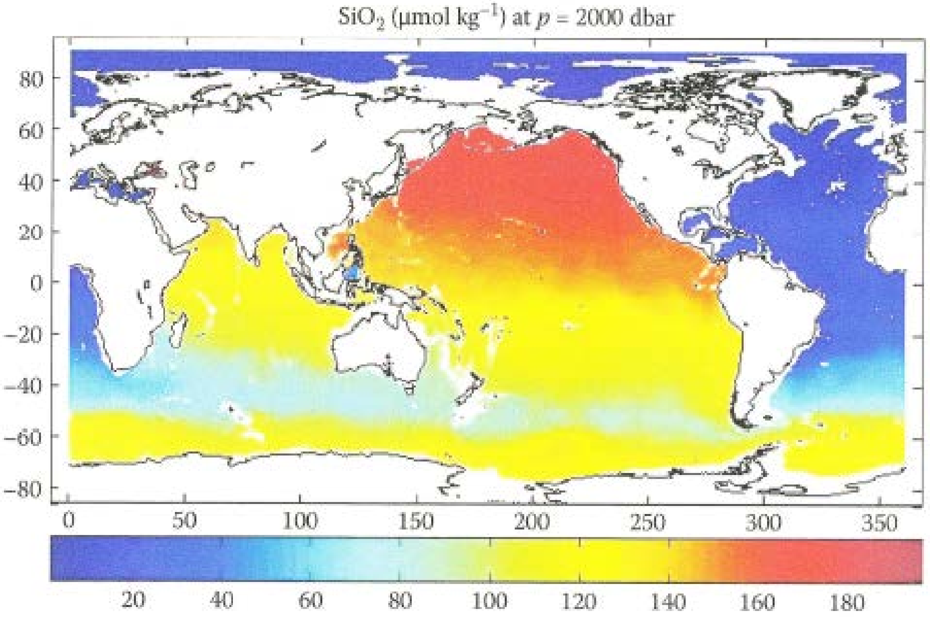


Figure 2 (b). A vertical section of Absolute Salinity Anomaly δS_A along 180°E in the Pacific Ocean.

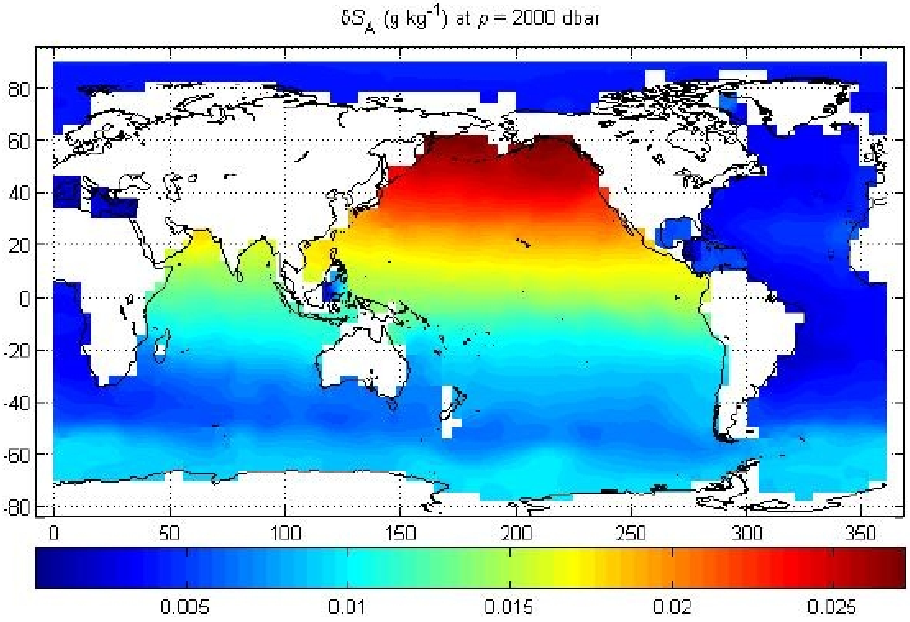
From: McDougall et al. (2009) Calculation of the Thermodynamic Properties of Seawater, IOCCP Report No. 14, ICOP Publication Series no. 134.

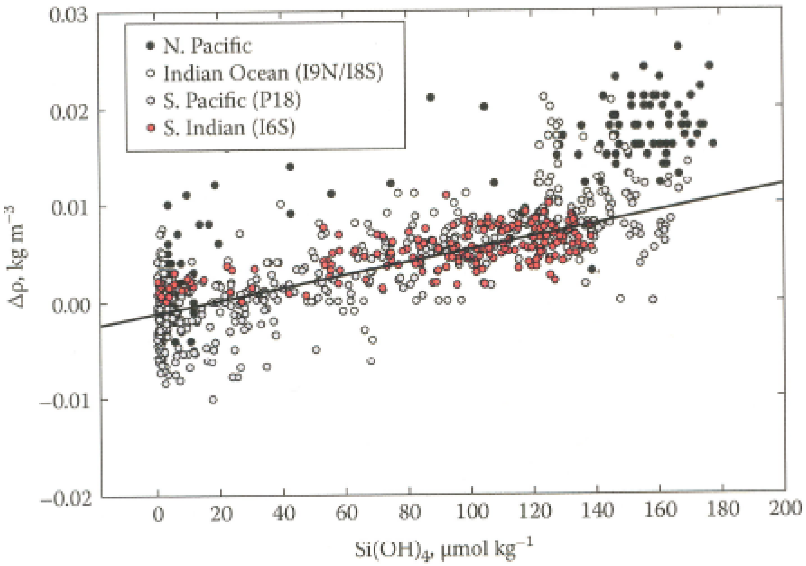
Definition of salinity



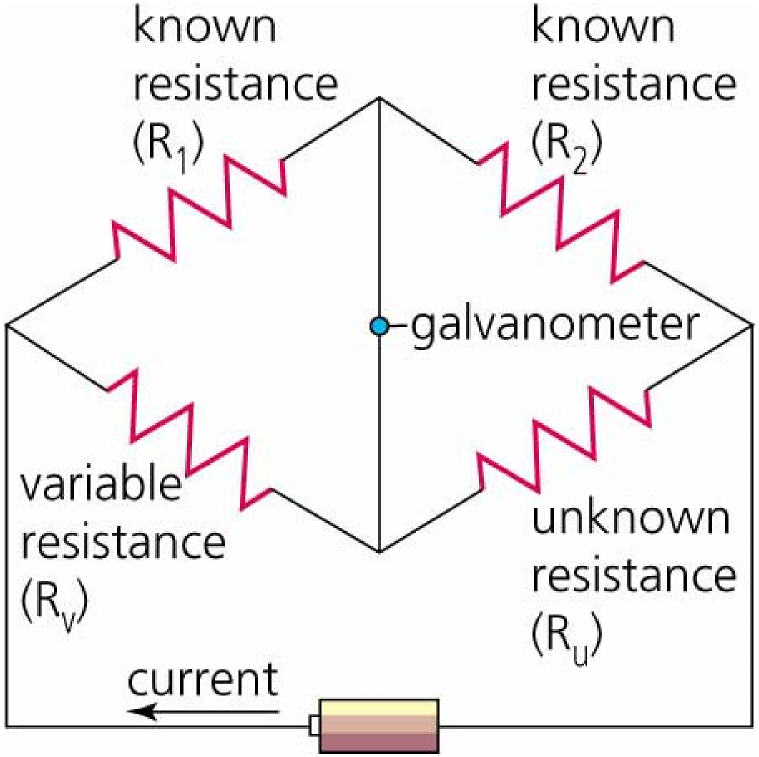
$$\delta S_A = \Delta\rho/0.7519$$

where Δρ is the difference between the measured densities and the values determined from the equation of state of seawater.





Physical procedures for the determination of seawater salinity: electrical conductivity

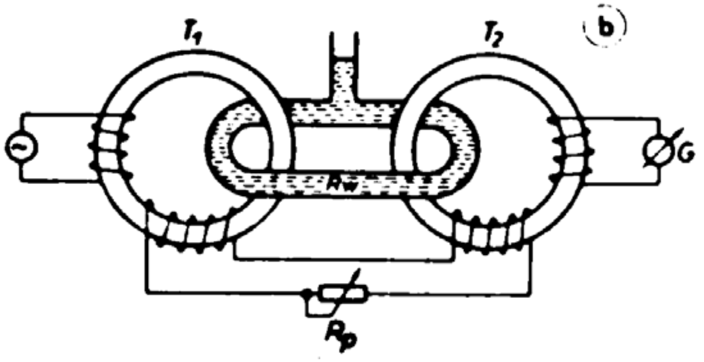


Academy Artworks

Wheatstone bridge

Conductivity is very sensitive to temperature

Physical procedures for the determination of seawater salinity: electrical conductivity



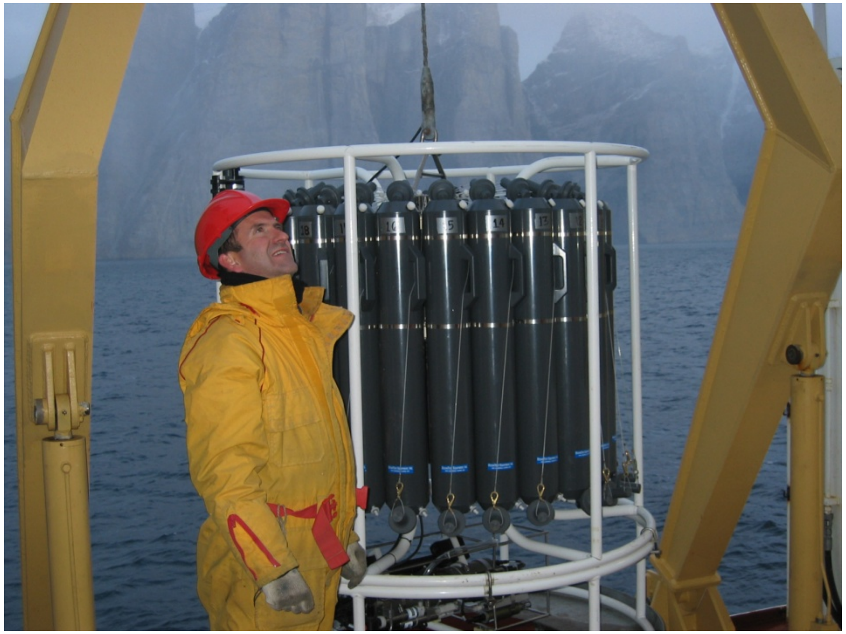
Inductive coil: The seawater sample serves as a conductive loop between a primary and secondary coil to a toroidal transformer.

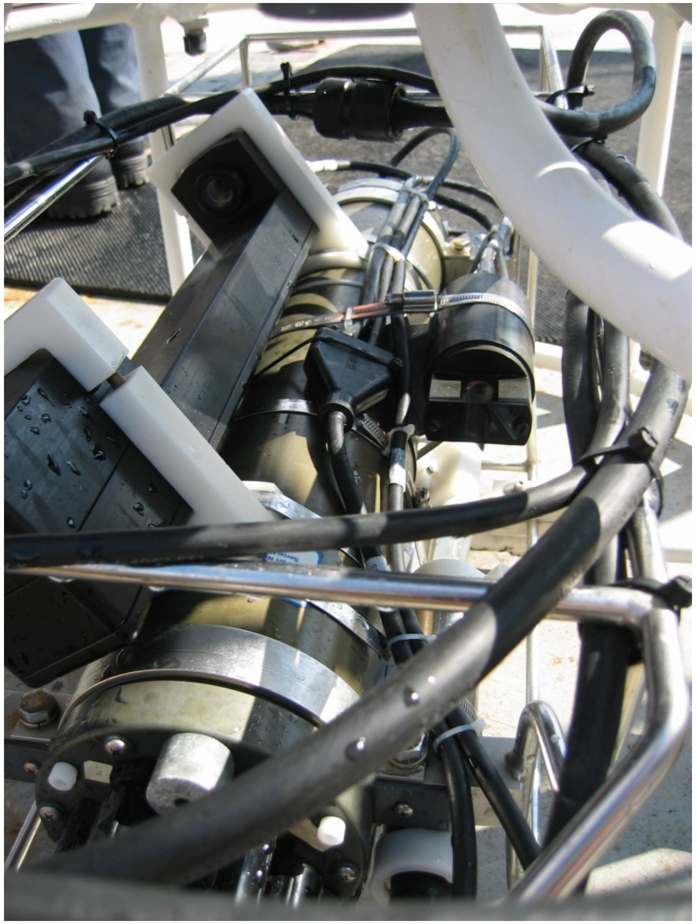
In the early 1980's, the International Practical Salinity Scale (PSS-78) was redefined as:

$$S_p = 0.0080 - 0.1692\,K_{15}^{0.5} + 25.3851\,K_{15} + 14.0941\,K_{15}^{1.5} - 7.0261\,K_{15}^{2} + 2.7081\,K_{15}^{2.5}$$

where K_{15} is the ratio of the conductivity of a water sample to that of water having a practical salinity of exactly 35.000 or a KCl solution (32.4352 g KCl/kg) .

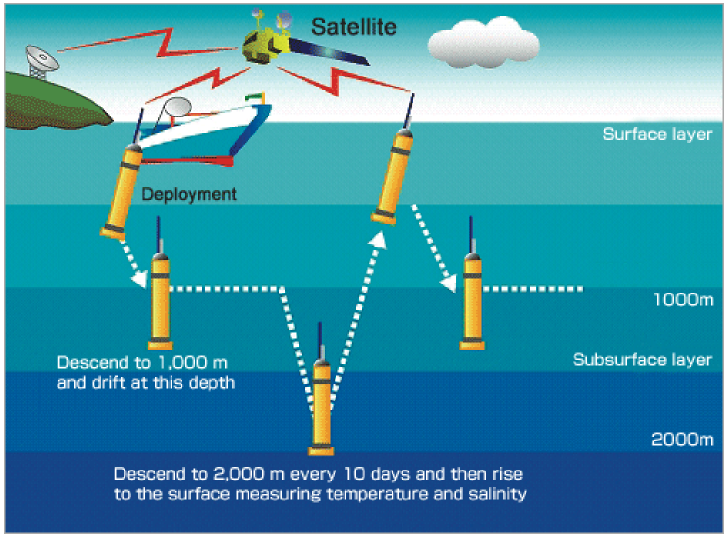
Physical procedures for the determination of seawater salinity: electrical conductivity

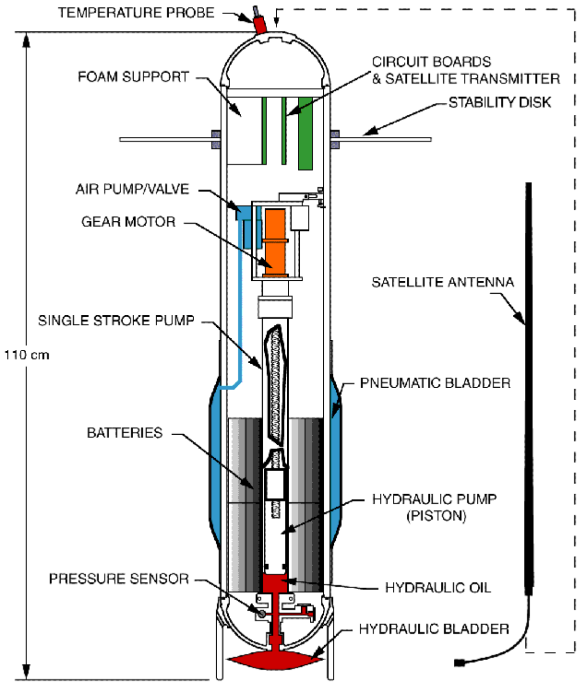


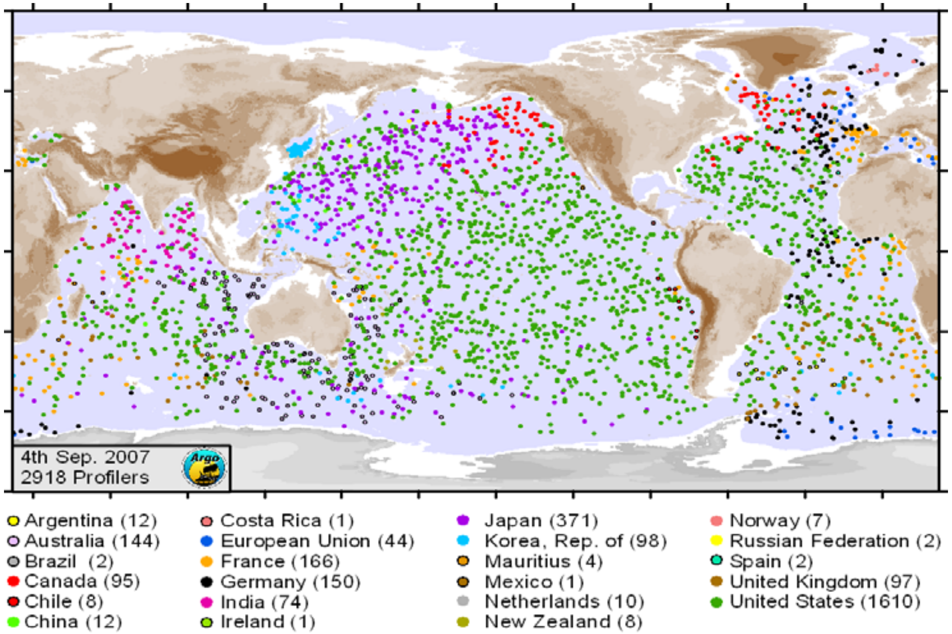


Since conductivity is pressure and temperature dependent, these are compensated for electronically.

Physical procedures for the determination of seawater salinity: electrical conductivity



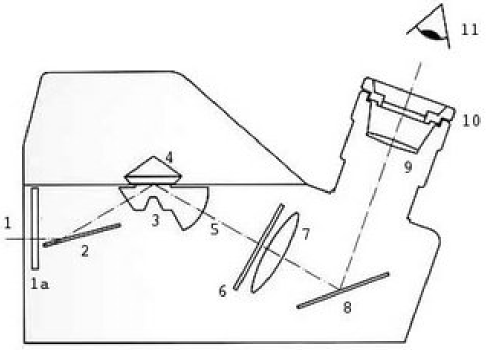


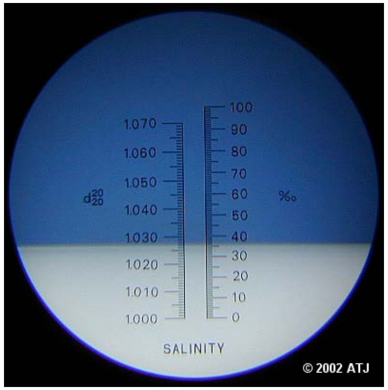


Physical procedures for the determination of seawater salinity: refraction index

Refraction index increases by 0.00002 per salinity unit.

Temperature-controlled interferometer +/- 0.01S

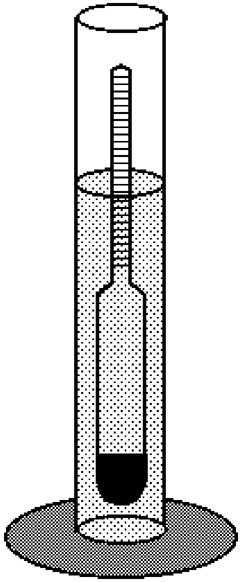


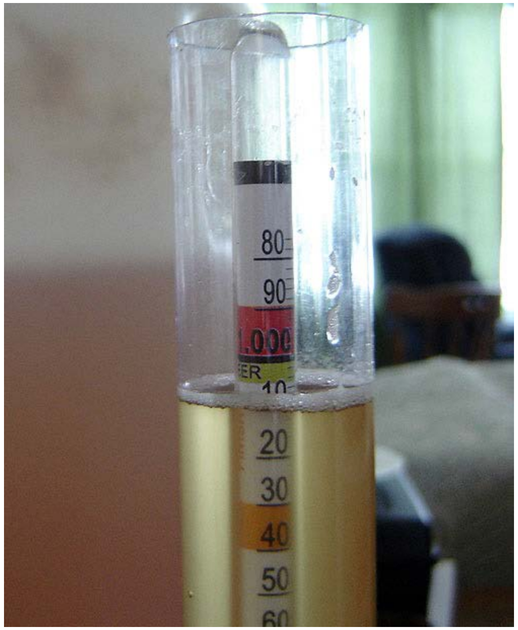


Ambient temperature refractometer +/- 0.5S

Physical procedures for the determination of seawater salinity: density

Figure 48. – Pycnomètre KNUDSEN (N° 99 1422). *(photo Y. Berard)*



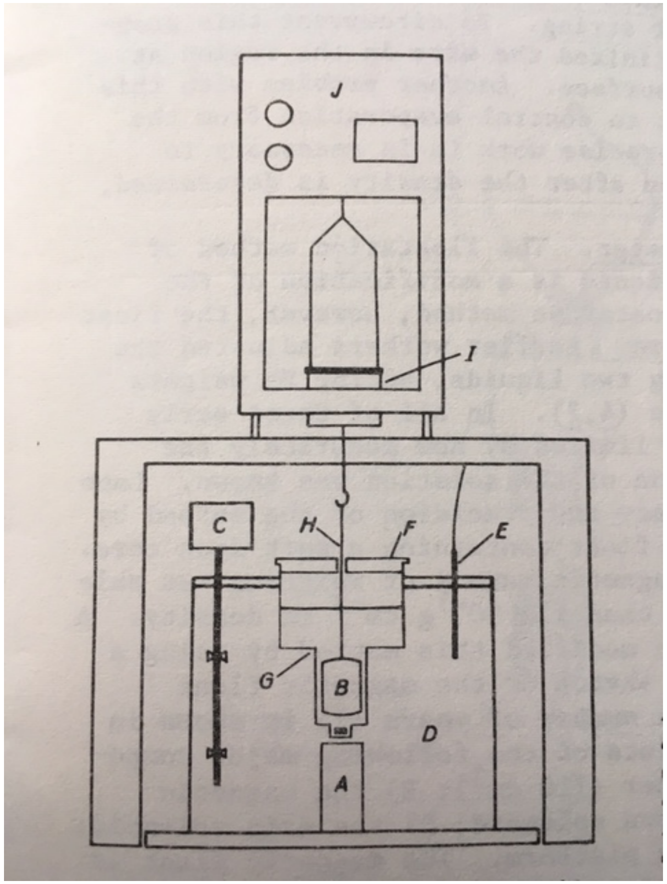


Knudsen’s pycnometer

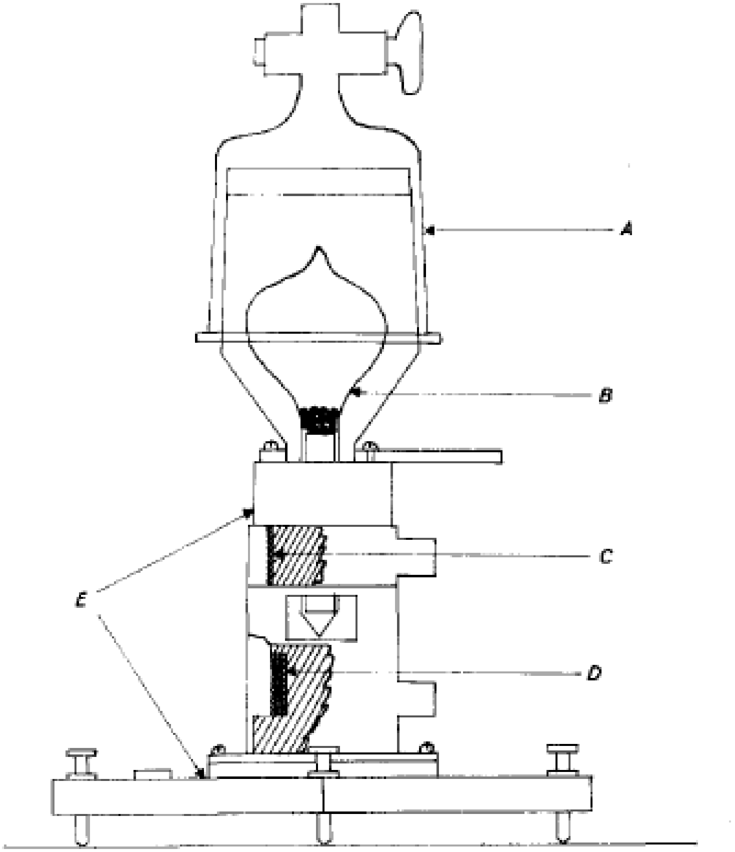
Stem hydrometers

Superseded by immersion hydrometers (a collapsible, negatively buoyant float) which could be pressurized until neutral buoyancy was attained, applied P α density. Replaced by a hydrostatic float and magnetic float densimeters.

Physical procedures for the determination of seawater salinity: density



Sketch of hydrostatic balance densimeter
(A) Magnetic stirrer; (B) glass float; (C) stirring motor; (D) Constant temperature bath; (E) Nickel thermometer; (F) Lucite plug; (G) Sample container; (H) Nylon wire; (I) Suspension hook; (J) Analytical balance.



Sketch of magnetic float densimeter
(A) Solution container; (B) magnetic float; (C) pull-down solenoid; (D) main solenoid; support and leveling platform.

Physical procedures for the determination of seawater salinity: density

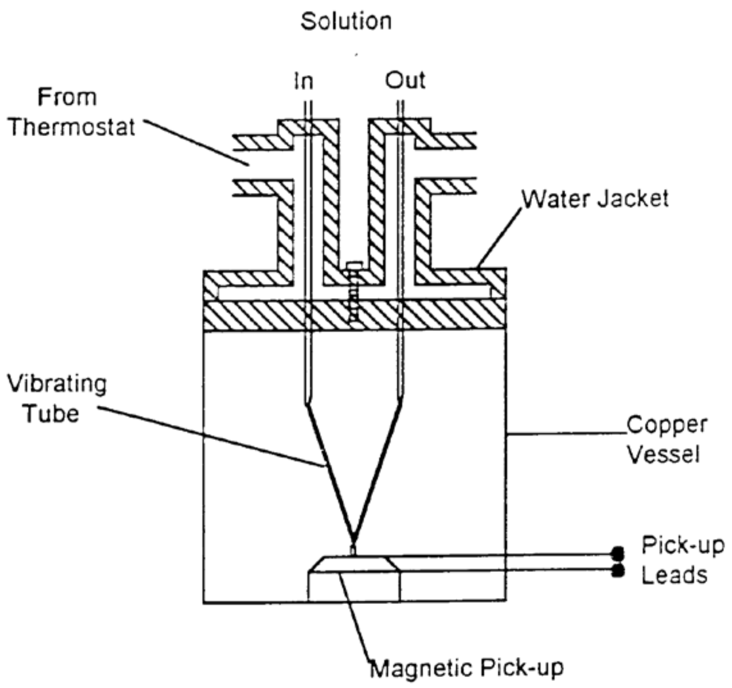


FIGURE 2.6. Sketch of a vibrating densimeter.

Capable of measuring density to ± 0.000003, if temperature can be maintained to ± 0.01°C.

$$\text{density } \alpha\ \tau^2$$

$$(d_{sample} - d_{H2O}) = k\ (\tau^2_{sample} - \tau^2_{H2O})$$

Unesco-1981

$\Gamma_{rel} = d/(d_o)^{4°C}$

$\Gamma = \Gamma_o + AS + BS^{1.5} + CS^2$

$A = 8.24493\text{x}10^{-4} – 4.0899\text{x}10^{-7}t + 7.6438\text{x}10^{-8}t^2$
$- 8.2467\text{x}10^{-10}t^3 + 5.3875\text{x}10^{-12}t^4$

$B = -5.72466\text{x}10^{-6} + 1.0227\text{x}10^{-7}t – 1.6546\text{x}10^{-9}t^2$

$C = 4.83\text{x}10^{-7}$

$\Gamma_o = 0.999842594 + 6.793932\text{x}10^{-5}t$
$-9.09529\text{x}10^{-6}t^2 + 1.001685\text{x}10^{-7}t^3$

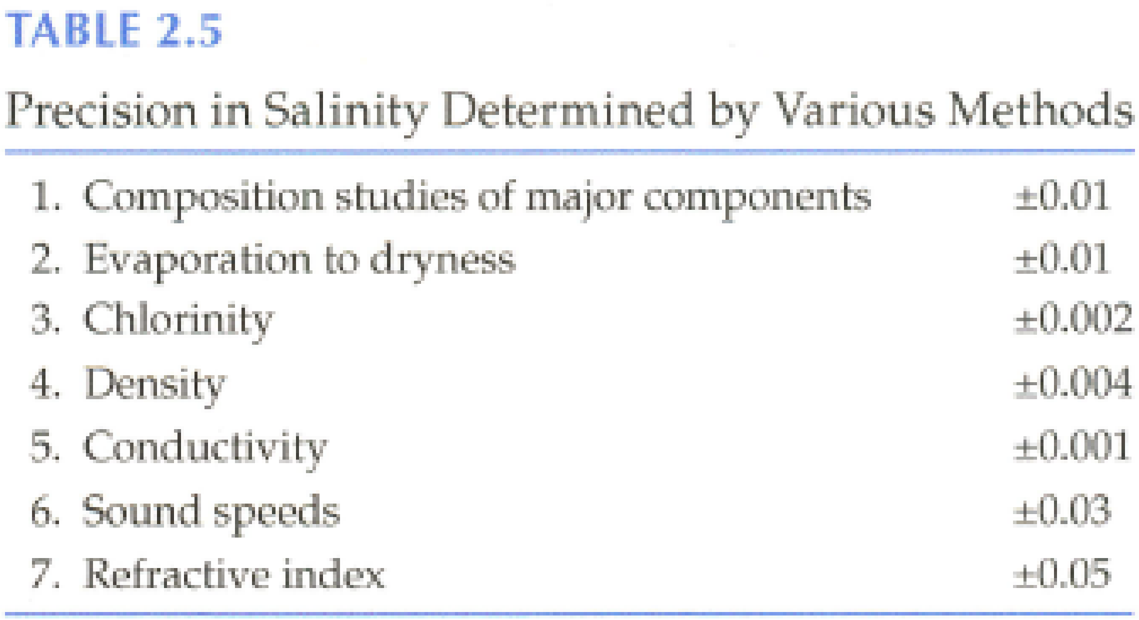
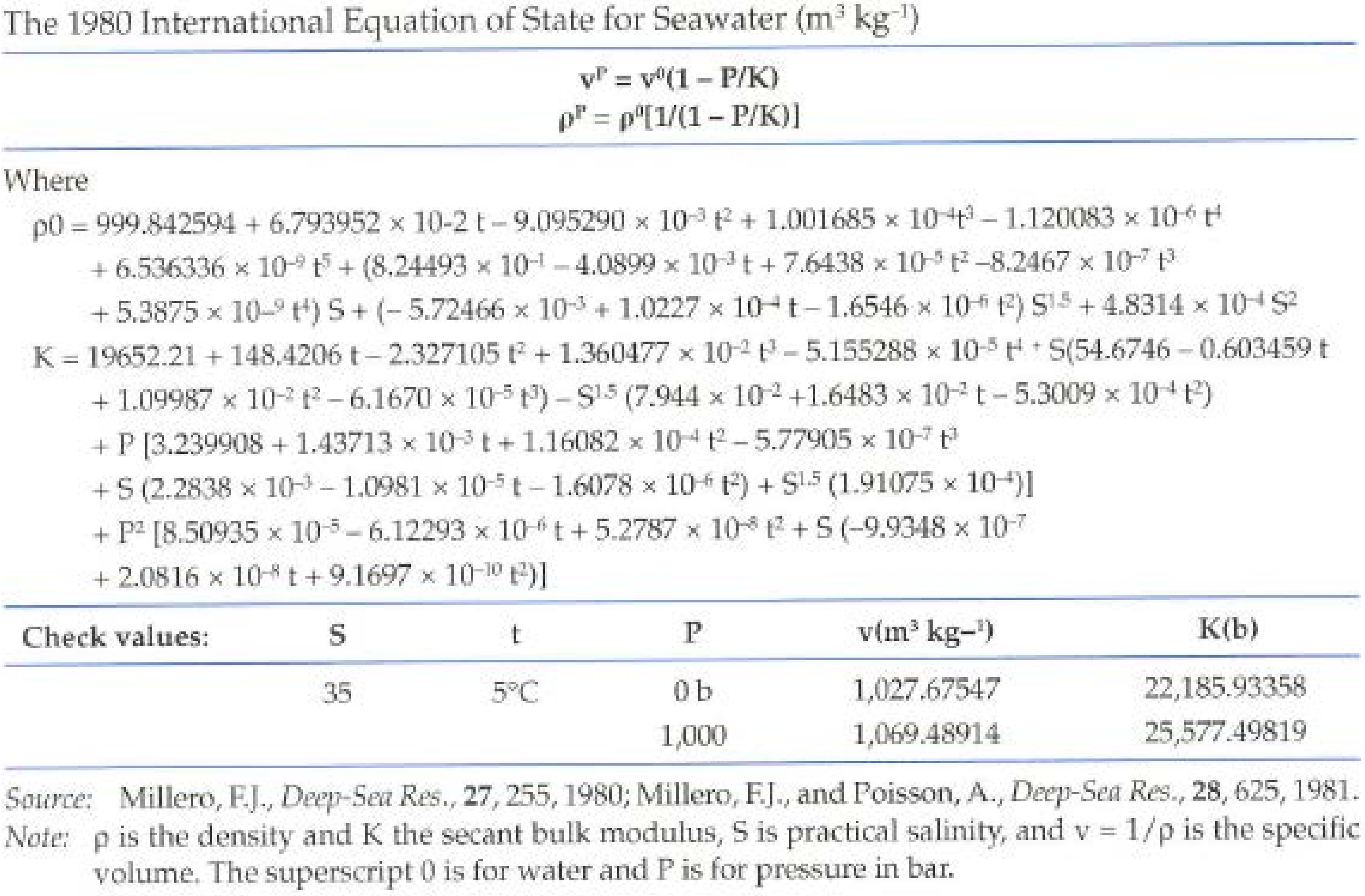


TABLE 2.5

Precision in Salinity Determined by Various Methods

1. Composition studies of major components	±0.01
2. Evaporation to dryness	±0.01
3. Chlorinity	±0.002
4. Density	±0.004
5. Conductivity	±0.001
6. Sound speeds	±0.03
7. Refractive index	±0.05

Equation of State for Seawater



The 1980 International Equation of State for Seawater ($m^3\ kg^{-1}$)

$$v^P = v^0(1 - P/K)$$
$$\rho^P = \rho^0[1/(1 - P/K)]$$

Where

$$\rho0 = 999.842594 + 6.793952 \times 10-2\ t - 9.095290 \times 10^{-3}\ t^2 + 1.001685 \times 10^{-4} t^3 - 1.120083 \times 10^{-6}\ t^4$$
$$+ 6.536336 \times 10^{-9}\ t^5 + (8.24493 \times 10^{-1} - 4.0899 \times 10^{-3}\ t + 7.6438 \times 10^{-5}\ t^2 - 8.2467 \times 10^{-7}\ t^3$$
$$+ 5.3875 \times 10^{-9}\ t^4)\ S + (-5.72466 \times 10^{-3} + 1.0227 \times 10^{-4}\ t - 1.6546 \times 10^{-6}\ t^2)\ S^{1.5} + 4.8314 \times 10^{-4}\ S^2$$

$$K = 19652.21 + 148.4206\ t - 2.327105\ t^2 + 1.360477 \times 10^{-2}\ t^3 - 5.155288 \times 10^{-5}\ t^4 + S(54.6746 - 0.603459\ t$$
$$+ 1.09987 \times 10^{-2}\ t^2 - 6.1670 \times 10^{-5}\ t^3) - S^{1.5}\ (7.944 \times 10^{-2} + 1.6483 \times 10^{-2}\ t - 5.3009 \times 10^{-4}\ t^2)$$
$$+ P\ [3.239908 + 1.43713 \times 10^{-3}\ t + 1.16082 \times 10^{-4}\ t^2 - 5.77905 \times 10^{-7}\ t^3$$
$$+ S\ (2.2838 \times 10^{-3} - 1.0981 \times 10^{-5}\ t - 1.6078 \times 10^{-6}\ t^2) + S^{1.5}\ (1.91075 \times 10^{-4})]$$
$$+ P^2\ [8.50935 \times 10^{-5} - 6.12293 \times 10^{-6}\ t + 5.2787 \times 10^{-8}\ t^2 + S\ (-9.9348 \times 10^{-7}$$
$$+ 2.0816 \times 10^{-8}\ t + 9.1697 \times 10^{-10}\ t^2)]$$

Check values:	S	t	P	v($m^3\ kg^{-1}$)	K(b)
	35	5°C	0 b	1,027.67547	22,185.93358
			1,000	1,069.48914	25,577.49819

Source: Millero, F.J., *Deep-Sea Res.*, **27**, 255, 1980; Millero, F.J., and Poisson, A., *Deep-Sea Res.*, **28**, 625, 1981.

Note: ρ is the density and K the secant bulk modulus, S is practical salinity, and $v = 1/\rho$ is the specific volume. The superscript 0 is for water and P is for pressure in bar.

Physical properties of water and seawater: temperature of freezing and of maximum density

$\Delta T_f \approx -0.097\ \mathrm{Cl},\ T_f = 0°\mathrm{C}$ at $\mathrm{Cl} = 0$

$\Delta T_M \approx -0.39\ \mathrm{Cl},\ T_M = 4°\mathrm{C}$ at $\mathrm{Cl} = 0$

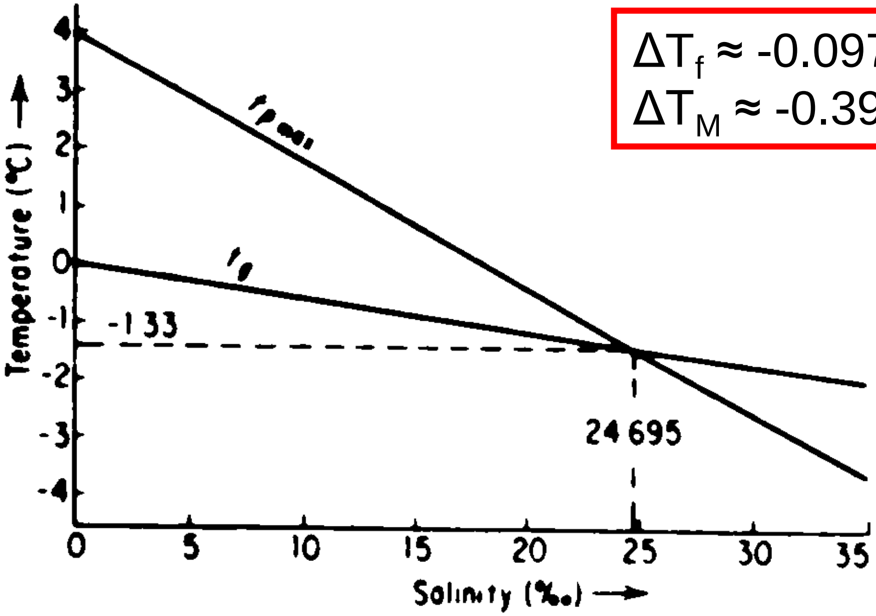


Figure 3.6 Temperature of the density maximum, $t_{\rho\,\max}$, and temperature of the freezing point, t_g, for sea water of different salinities.

From: Neumann, G. and Pierson, W. J. (1966)
Principles of Physical Oceanography, Prentice-Hall Inc.

Preparation of artificial seawater

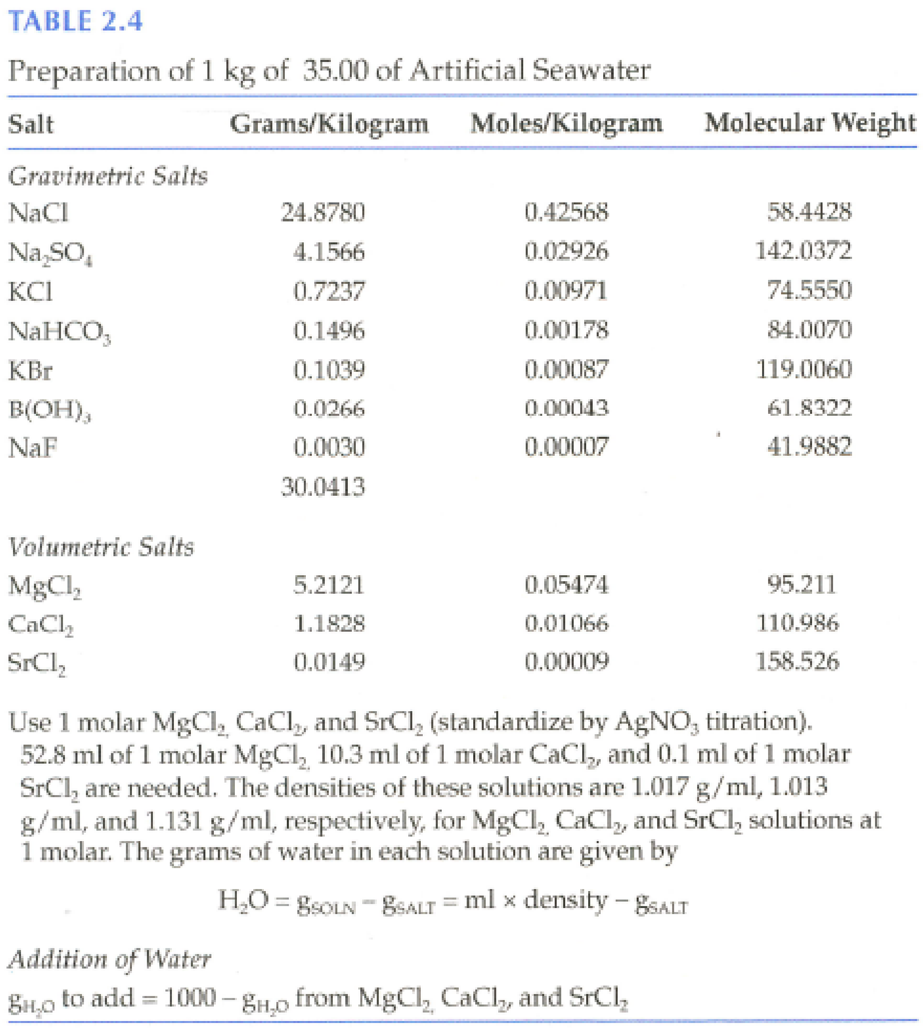


TABLE 2.4

Preparation of 1 kg of 35.00 of Artificial Seawater

Salt	Grams/Kilogram	Moles/Kilogram	Molecular Weight
Gravimetric Salts			
NaCl	24.8780	0.42568	58.4428
Na_2SO_4	4.1566	0.02926	142.0372
KCl	0.7237	0.00971	74.5550
$NaHCO_3$	0.1496	0.00178	84.0070
KBr	0.1039	0.00087	119.0060
$B(OH)_3$	0.0266	0.00043	61.8322
NaF	0.0030	0.00007	41.9882
	30.0413		
Volumetric Salts			
$MgCl_2$	5.2121	0.05474	95.211
$CaCl_2$	1.1828	0.01066	110.986
$SrCl_2$	0.0149	0.00009	158.526

Use 1 molar $MgCl_2$, $CaCl_2$, and $SrCl_2$ (standardize by $AgNO_3$ titration). 52.8 ml of 1 molar $MgCl_2$, 10.3 ml of 1 molar $CaCl_2$, and 0.1 ml of 1 molar $SrCl_2$ are needed. The densities of these solutions are 1.017 g/ml, 1.013 g/ml, and 1.131 g/ml, respectively, for $MgCl_2$, $CaCl_2$, and $SrCl_2$ solutions at 1 molar. The grams of water in each solution are given by

$$H_2O = g_{SOLN} - g_{SALT} = ml \times density - g_{SALT}$$

Addition of Water

g_{H_2O} to add = 1000 − g_{H_2O} from $MgCl_2$, $CaCl_2$, and $SrCl_2$