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The International System of Units (SI) in Oceanography

Report of IAPSO Working Group on Symbols, Units and Nomenclature in Physical Oceanography (SUN)

This report was prepared under the auspices of the International Association for the Physical Sciences of the Ocean (IAPSO). The first part is a revised version of IAPSO Publication Scientifique No. 31 (SUN Report).

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PREFACE

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XVI GENERAL ASSEMBLY OF THE
INTERNATIONAL ASSOCIATION FOR THE PHYSICAL
SCIENCES OF THE OCEAN (IAPSO)
GRENOBLE, FRANCE, AUGUST 1975

RESOLUTION No 6 - 1975

IAPSO recommends the use of SI units and symbols in physical oceanography. To encourage the preferential use of the SI, a table should be prepared of units and symbols at present in common use, and the new recommended units and symbols of the SI.

XVII GENERAL ASSEMBLY OF IAPSO
CANBERRA, AUSTRALIA, DECEMBER 1979

RESOLUTION No 9 - 1979

IAPSO, having carefully considered the report of the IAPSO Working Group on Symbols, Units and Nomenclature in Physical Oceanography, adopts the first part, with minor modification, of the draft report on the use in the physical sciences of the ocean of the International System of Units (SI). IAPSO urges the scientific community to use henceforth this system so as to ensure greater uniformity in the reporting of oceanographic data.

IAPSO expresses its gratitude to the Working Group and in particular to Mr. M. Menaché for the large effort which went into this report. IAPSO urges a speedy completion of Part Two of the SUN report which will serve as a guideline to the use of uniform symbols and corresponding units within the SI system.

XVIII GENERAL ASSEMBLY OF IAPSO
HAMBURG, GERMANY, AUGUST 1983

RESOLUTION No 6 - 1983

"Recognizing : the need of SI units in Physical Oceanography ; and
noting : IAPSO Resolution No 9 adopted in Canberra ;

IAPSO : welcomes Part Two of the SUN report ; and

recommends : the adoption of the complete SUN report in final form and urges the scientific community to study the report and consider its use by scientists, publishers and editors of oceanographic journals, hopefully by 1st January 1986."

Abstract

The report of the IAPSO Working Group introduces the International System of Units (SI) in physical oceanography.

The first part is devoted to physical quantities, units and symbols, SI units and basic rules, and specific recommendations for the field of physical sciences of the ocean.

The second part consists of the tables of the quantities that are used in physical oceanography (fundamental quantities of sea water, physical properties of pure and sea water, dynamical oceanography, optical oceanography, marine geophysics, marine geochemistry and chemical oceanography). Each table contains its preferred symbol, a short definition if necessary, and its unit in the SI, together with its symbol. Conversion factors between certain units and the corresponding (SI) units are given for dynamical oceanography and marine geophysics.

Résumé

Le rapport du Groupe de travail de l'AISPO présente le Système international d'unités (SI) relatif à l'océanographie physique.

La première partie est consacrée aux grandeurs, unités et symboles physiques, aux unités et règles de base du SI et à des recommandations concernant spécifiquement le domaine des sciences physiques de l'océan.

La seconde partie est constituée par les tableaux des grandeurs utilisées en océanographie physique (propriétés fondamentales de l'eau de mer, propriétés physiques de l'eau pure et de l'eau de mer, océanographie dynamique, océanographie optique, géophysique marine, géochimie marine et océanographie chimique). Chaque tableau donne le symbole préférentiel de la grandeur, une définition succincte s'il y a lieu et l'unité du SI avec le symbole correspondant. Les facteurs de conversion entre certaines unités et les unités (SI) correspondantes sont indiqués pour l'océanographie dynamique et la géophysique marine.

Resumen

En el informe del Grupo de Trabajo sobre la IAPSO se introduce el Sistema Internacional de Unidades (SI) a la oceanografía física.

La primera parte está consagrada a las magnitudes físicas, las unidades y los símbolos, las unidades y reglas básicas del SI, así como recomendaciones específicas en materia de las ciencias físicas del océano.

La segunda parte contiene las tablas de las magnitudes utilizadas en oceanografía física (magnitudes fundamentales de agua de mar, propiedades físicas del agua pura y salada, oceanografía dinámica, oceanografía óptica, geofísica marina, geoquímica marina y oceanografía química). En cada tabla figura el símbolo preferido, una breve definición si es necesario, y su unidad en el SI, junto con su símbolo. Para la oceanografía dinámica y la geofísica marina se dan factores de conversión entre ciertas unidades y las correspondientes unidades del SI.

Резюме

В докладе рабочей группы МАФНО описывается Международная система единиц (СИ) в области физической океанографии.

Первая часть доклада посвящена физическим параметрам, единицам и символам, единицам и основным правилам в системе СИ и конкретным рекомендациям в области физических наук об океане.

Вторая часть содержит таблицы параметров, которые используются в физической океанографии (основные параметры морской воды, физические показатели чистой и морской воды, динамическая океанография, оптическая океанография, морская геофизика, морская геохимия и химическая океанография). Каждая таблица содержит свой предпочтительный символ, краткое необходимое определение и свою единицу в системе СИ вместе со своим символом. Для динамической океанографии и морской геофизики представлены коэффициенты перевода между определенными единицами и соответствующими единицами СИ.

مستخلص

ان تقرير فريق العمل التابع للرابطة الدولية للعلوم الفيزيائية المتعلقة بالمحيطات (يابسو) يدخل نظام الوحدات الدولى (وحد) فى الأقيانوغرافيا الفيزيائية .

وقد خصص الجزء الأول للكميات والوحدات والرموز الفيزيائية، ووحدات "وحد" وقواعده الأساسية ، ولعدد من التوصيات المحددة فى ميدان علوم المحيطات الفيزيائية .

أما الجزء الثانى فيتألف من الجداول الكمية المستخدمة فى الأقيانوغرافيا الفيزيائية (الكميات الأساسية من مياه البحر ، والخصائص الفيزيائية للماء النقى ولماء البحر ، والأقيانوغرافيا الدينامية ، والأقيانوغرافيا البصرية، والجيوفيزيقا البحرية ، والجيوكيمياء البحرية ، والأقيانوغرافيا الكيميائية). ويشتمل كل جدول على رمزه المفضل ، وعلى تعريف موجز عند الضرورة ، وعلى الوحدة الخاصة بالجدول فى نظام الوحدات الدولى (وحد)، بالاضافة الى الرمز المعنى . كما ترد أيضا عوامل التحويل بين بعض الوحدات وبين وحدات "وحد" المناظرة ، وذلك فيما يتعلق بالأقيانوغرافيا الدينامية والجيوفيزيقا البحرية .

摘　要

国际海洋自然科学协会工作组的报告对物理海洋学方面的国际单位制（ SI ）作了介绍。

第一部分主要论述物理海洋学方面的物理量、单位和符号、国际单位制和基本标准，以及一些具体建议。

第二部分包括物理海洋学中使用的各种数量表（海水的基本量，纯水与海水的物理性能，动力海洋学，光学海洋学，海洋地球物理学，海洋地球化学及化学海洋学）。每表载有其选用的符号、必要的简短说明、其国际单位制单位及其符号。还列出了动力海洋学和海洋地球物理学方面使用的某些单位与相应的（国际单位制）单位之间的换算因数。

CONTENTS

FOREWORD

This document introduces to oceanographers the International System of Units (SI) in Physical Oceanography, the modern version of the Metric System, whose motto is "A tous les temps, à tous les peuples"*. The SI constitutes a universal language, designed to be understood by all scientists. Its purpose is to facilitate their mutual comprehension and exchange of views and results of their work. The present report was produced in response to Resolution 6, adopted by the IAPSO General Assembly in Grenoble, France, in 1975, which recommends the use of SI units and symbols in physical oceanography. All oceanographers, as well as editors and publishers of oceanographic literature are urged to use this universal language.

The preparation and review of this document is the result of effort by many people over many years. First and foremost, the members of the IAPSO Working Group on Symbols, Units and Nomenclature in Physical Oceanography (SUN) must be commended, namely, Mr. M. Menaché (Chairman), Mr. J. Crease, Mr. G. Girard, Professor R. B. Montgomery and Dr. G. N. Ivanoff-Frantzkevitch. Others who prepared and reviewed tables of Part II of this report are Professors B. Saint-Guily and J. Gonella; Professor André Morel and the IAPSO Working Group on Optical Oceanography; Professors M. Yasui and G. Grau; Professors P. J. Wangersky and J. D. Burton.

The role of the IAPSO officers is also acknowledged, namely IAPSO Presidents: Professors Henri Lacombe, Robert Stewart, Devendra Lal and Wolfgang Krauss; IAPSO Secretary General, Dr. Eugene C. Lafond; Deputy Secretary General, Professor Joris Gieskes; as well as the efforts of Dr. Selim Morcos, Unesco Division of Marine Sciences, under whose responsibility this report was prepared for publication.

The IUGG Publications Office is also acknowledged for distributing in 1979, in cooperation with Unesco, the first version of Part I of the SUN Report as "IAPSO Publication scientifique No. 31".

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* "To all times, to all people".

Special acknowledgement should be made of the Chairman of the Working Group, Mr. Maurice Menaché, who for 8 years worked wholeheartedly to develop and perfect this document. His efforts have been a dominant factor in the success of this undertaking. To pay hommage to him for his contribution to the oceanographic community, the IAPSO Executive Committee created the distinguished "IAPSO Hard Work Award" and made its first recipient Mr. Maurice Menaché.

On Mr. Menaché's retirement from the Working Group, Mr. Georges Girard was appointed at the IAPSO General Assembly in Hamburg, Germany, in August 1983, to continue the work as IAPSO Advisor for SUN. The present report was completed under Mr. Girard's direction to the grateful satisfaction of both IAPSO and Unesco.

INTRODUCTION

IAPSO-SUN Working Group

This document is the result of the work initiated by the Working Group on Symbols, Units and Nomenclature in Physical Oceanography (SUN-WG) whose setting-up was agreed (1) during the XVIth General Assembly of the International Association for the Physical Sciences of the Ocean (IAPSO) held in Grenoble, France, in August 1975.

The task that had been given to this Working Group was clearly settled in the Resolution n° 6 adopted by the same General Assembly :

"IAPSO recommends the use of SI units and symbols in physical oceanography. To encourage the preferential use of the SI, a table should be prepared of units and symbols at present in common use, and the new recommended units and symbols of the SI."

The work started immediately and went on by correspondence between the different members of the SUN-WG concerning the two papers prepared by the dynamic president, Maurice Menaché. These papers have been distributed for comments to a great number of physical oceanographers.

A first draft report was prepared in April 1979 and submitted for criticisms to a great number of members of the international physical oceanography community, thanks to a wide distribution, undertaken jointly by Professor E.C. LAFOND, Secretary-General IAPSO and the Working Group. In the covering letter, dated 21 April 1979, the SUN-WG expressed the wish to receive as many comments as possible by August 15, 1979.

The Working Group met therefore in Paris, at the Institut Océanographique, on 27-29 August 1979. It analysed all the very numerous comments received and consequently amended the draft report. This text, after amendments (amended version - August 1979), was finally submitted for examination to the IAPSO XVIIth General Assembly held in Canberra, Australia, in December 1979.

It consisted of two parts:

Part One, devoted to Physical Quantities, Units and Symbols, as well as the international standard rules governing their use. An important section

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(1) see setting-up of the SUN-WG page x.

of this report (Chapter III) deals with the International System of Units (SI), and another one (Chapter VI), with specific recommendations in the field of Physical Sciences of the Ocean ;

Part Two, on specific tables for different fields of Physical Oceanography, proposed by invited experts : 1) tables of correspondence between quantities, units and symbols ; 2) tables of conversion factors enabling the SI units to be obtained in place of old units.

The compilation of the different tables was entrusted to experts (2) who have kindly accepted responsibility for the field in which they are highly competent.

The IAPSO General Assembly, after having "carefully considered" this draft report, took the following decisions :

1. Adoption of Part One, with a "minor modification". This minor modification concerns a possible change of the Knudsen's parameter σ (abbreviated representation of the relative density) on which the Working Group was unable to reach an agreement.

2. IAPSO preferred to delay its decision on Part Two of the draft report and suggested that each of the six topics included be referred to its respective Group.

3. IAPSO dissolved the Working Group and asked M. Menaché as Advisor to complete the adjustment of the final report (Parts One and Two) according to his recommendations.

After that meeting, Part One was amended according to the decisions taken and published in 1980 by the IUGG Publications Office as "IAPSO Publication Scientifique n° 31".

Since the General Assembly, two highly important events have occurred : the definitive adoption by UNESCO/ICES/SCOR/IAPSO Joint Panel on Oceanographic Tables and Standards (JPOTS) of the definition of Practical Salinity, 1978, and a new Equation of State of Sea Water, 1980. Both these

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(2) see list of experts page xi.

events, which have been approved by all the world oceanographic organizations, have led to several constructive decisions being made concerning Salinity and Density, as well as other related concepts (sigma in particular).

The advent of Practical Salinity and the new Equation of State of Sea Water has required the rewriting of the whole of Chapter VI "Specific recommendations for the field of physical sciences of the ocean" in accordance with the decisions taken by JPOTS in August 1983.

The reappraisal of the Knudsen's parameter $\underline{\sigma}$ has led to a general study of the different ways of representing the quantities, density and specific volume (French : "volume massique"), which have been the subject of hot discussion.

As for the specific tables requested by IAPSO, it was decided that each one should be revised by another expert (3). These revisions have been made, and Part Two as well as the revised Chapter VI were submitted to the XVIIIth IAPSO General Assembly held in Hamburg, in August 1983.

During this General Assembly, IAPSÓ adopted the Report on Symbols, Units and Nomenclature in Physical Oceanography with its Resolution n° 6 - 1983 :

"Recognizing : the need of SI units in Physical Oceanography ; and noting : IAPSO Resolution n° 9 adopted in Canberra ;

IAPSO : welcomes Part Two of the SUN Report ; and

recommends : the adoption of the complete SUN Report in final form and urges the scientific community to study the report and consider its use by scientists, publishers and editors of oceanographic journals, hopefully by 1st January 1986."

Maurice Menaché having asked to be relieved of his responsibilities, IAPSO asked Georges Girard, former member of the Working Group, to finish the adjustment of this document and follow through its publication. This was finally achieved through the close cooperation of Georges Girard and Selim Morcos (Unesco), who were supported in their efforts by J. Crease, J. Gieskes and E. Lafond.

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(3) See list of revisors page xi.

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I - PREAMBLE

PHYSICAL QUANTITIES

UNITS, NUMERICAL VALUES

1.- Relations between physical quantities

Any physical quantity (in French "grandeur physique") can be defined in terms of other physical quantities, and this definition can be represented by an appropriate algebraic equation, which may be called "equation of definition".

Thus, velocity $\underline{v}$ can be defined with the help of two quantities : length $\underline{l}$ and time $\underline{t}$, by the equation :

(1) $\underline{v} = \underline{l}.\underline{t}^{-1}.$

The above relation is not unique and velocity $\underline{v}$ can also be defined in terms of force $\underline{F}$, mass $\underline{m}$ and time $\underline{t}$ by the equation :

$$\underline{v} = \underline{F}.\underline{m}^{-1}.\underline{t}.$$

These two equations are not, of course, independent and it is possible to write :

$$\underline{F} = \underline{m}.\underline{l}.\underline{t}^{-2}.$$

in which force is defined in terms of mass and acceleration

In general, equations of definition contain no numerical coefficient. Some, however, do contain one, and this is the case with the equation for kinetic energy $\underline{E}_k$, in terms of mass $\underline{m}$ and velocity $\underline{v}$, which is written :

(2) $\underline{E}_k = \frac{1}{2}\,\underline{m}.\underline{v}^2.$

It is convenient to choose, once and for all, as base elements for definitions, a small number of quantities which are considered mutually independent and which will be called base quantities. All the other quantities will be called derived quantities and can be defined progressively with the help of equations containing base quantities only.

Supposing that the three following quantities, $\underline{Q_1}$, $\underline{Q_2}$, $\underline{Q_3}$, are chosen to form a system of base quantities. These quantities are considered independent of each other.

Any other quantity $\underline{Q}$ is a derived one, and can be defined by the following type of equation :

(3) $$\underline{Q} = \underline{k} \cdot \underline{Q_1}^{\underline{\alpha}} \cdot \underline{Q_2}^{\underline{\beta}} \cdot \underline{Q_3}^{\underline{\gamma}},$$

$\underline{k}$ being in most cases equal to the unity.

In this equation, the factor $\underline{Q_1}^{\underline{\alpha}}$, for instance, does not mean that the base quantity $\underline{Q_1}$ must be raised to the power of $\underline{\alpha}$, but that equal or different $\underline{\alpha}$ measured values of the same quantity $\underline{Q_1}$ have to be multiplied together. For example, the equation :

$$\underline{v} = \underline{l}^3,$$

defining volume $\underline{v}$ in terms of length $\underline{l}$, means that volume is obtained by multiplying together three lengths (of equal or different sizes). This equation between symbols can very well represent, for example, the volume of a parallelepiped.

With equation (3), it is possible to describe the two essential aspects of a physical quantity :

1°) its dimension ; 2°) its measure or value.

2.- Dimension of a physical quantity

The dimension is the descriptive aspect of a physical quantity. It shows the series of algebraic operations to be carried out on the base quantities in order to obtain a qualitative representation of the quantity under consideration. It provides no quantitative information.

Let us go back to equation (3). We shall infer from it, removing the numerical coefficient $\underline{k}$:

(4) $$Q = Q_1^{\underline{\alpha}} \cdot Q_2^{\underline{\beta}} \cdot Q_3^{\underline{\gamma}},$$

in which Q_1, Q_2, Q_3 represent the "dimensions" of the base quantities $\underline{Q}_1$, $\underline{Q}_2$, $\underline{Q}_3$. This relation, which gives Q, the dimension of the quantity $\underline{Q}$, is called a dimensional equation, in which the exponents, qualified dimensional, are, as a general rule but not always, whole numbers and can be positive, negative or nil. Only these exponents may change when passing from one physical quantity to another. It may be said that the dimension of Q is the product of the three dimensional factors of the right hand side, i.e. :

(5) $$\text{dimension } \underline{Q} = Q_1^{\alpha} \cdot Q_2^{\beta} \cdot Q_3^{\gamma}.$$

A dimensional factor having a nil exponent can be left out of the second member ($Q^0 = 1$). When all the exponents are nil $\left((\text{dimension } \underline{Q}) = 1\right)$, $\underline{Q}$ is independent from the base quantities. It is said to be dimensionless.

The dimension of a quantity of the same nature as a base quantity is of course the same as the one of this base quantity. It expresses itself, for example, by :

$$Q = Q_1^0 \cdot Q_2^1 \cdot Q_3^0.$$

Only quantities of the same dimension can be compared, added, substracted and form the terms of an equation. The ratio of two quantities of the same dimension is a quantity, said "dimensionless", i.e. a quantity of dimension 1. Quantities of different dimensions can be multiplied or divided between one another.

Below, examples are given of the dimensions of some physical quantities expressed in relation to the dimensions L, M, T, I, Θ, N, I_v of the base quantities length, mass, time, electric current, temperature, amount of substance, luminous intensity of the International System of Units (SI) :

pressure	: $L^{-1}.M^1.T^{-2}.I^0.\Theta^0.N^0.I_v^0 = L^{-1}.M.T^{-2}$
electric potential	: $L^2.M.T^{-3}.I^{-1}$
density	: $L^{-3}.M$
mass	: M
acceleration	: $L.T^{-2}$
molar entropy	: $L^2.M.T^{-2}.\Theta^{-1}.N^{-1}$
refractive index	: 1 (dimensionless).

Dimensional equations are useful in many fields, in particular for verifying the homogeneity of certain formulae between physical quantities of different dimensions. The following are two examples of this type of verification :

1°) The pressure $\underline{p}$ exerted by a column of liquid of height $\underline{h}$, having a constant density $\underline{\rho}$, $\underline{g}$ being the acceleration due to gravity, is given by the formula :

$$\underline{p} = \underline{\rho}.\underline{g}.\underline{h}.$$

The dimensions of the quantities appearing in this formula are :

$$\dim \underline{p} = L^{-1}.M.T^{-2} \; ; \quad \dim \underline{\rho} = L^{-3}.M \; ; \quad \dim \underline{g} = L.T^{-2} \; ; \quad \dim \underline{h} = L,$$

which gives :

$$L^{-1}.M.T^{-2} = (L^{-3}.M) \times (L.T^{-2}) \times L = L^{-1}.M.T^{-2}.$$

2°) The period $\underline{t}$ of the oscillation of a pendulum of length $\underline{l}$ is :

$$\underline{t} = 2\pi \; (\underline{l}/\underline{g})^{\frac{1}{2}},$$

$\underline{g}$ being the acceleration due to gravity.

Verification of the homogeneity gives :

$$\dim \underline{t} = (L.L^{-1}.T^{2})^{\frac{1}{2}} = T.$$

Finally, let us note that in certain equations between physical quantities, there is one (or more) constant which is not a pure number, but which possesses a dimension. This dimension may be calculated from the corresponding dimensional equation.

For example, in the equation of perfect gases :

$$\underline{pV} = \underline{NRT},$$

$\underline{R}$ is not a pure number. Its dimension is obtained thus :

$$\dim \underline{R} = (L^{-1}.M.T^{-2}) \times (L^{3}) \times N^{-1} \; \Theta^{-1} = L^{2}.M.T^{-2}N^{-1}\Theta^{-1}.$$

Important remarks.- In relations between quantities, a distinction must be made between equations of definition and dimensional equations. The dimensional equations contain no numerical factor, and the quantity, the dimension of which is to be determined, is always reduced to the base quantities only. On the other hand, equations of definition can contain numerical factors and a quantity can be defined with the help of quantities other than base ones. As seen above, pressure $\underline{p}$ is represented by the dimensional equation :

$$\dim \underline{p} = L^{-1}.M.T^{-2}$$

in which only the dimension of the base quantities appear, whereas it can in some circumstances be expressed by the following equation in which the derived quantities $\underline{\rho}$ and $\underline{g}$ appear :

$$\underline{p} = \underline{\rho}.\underline{g}.\underline{h}.$$

The related equation :

$$\dim \underline{p} = \dim \underline{\rho}.\dim \underline{g}.\ \dim \underline{h}$$

and similar relations can often be used directly to check the homogeneity of the formulas or equations.

3.- Measure of a physical quantity, Unit.- Measure of a derived quantity.- Coherent system of units

A physical quantity can be measured by comparing it to another quantity of the same dimension, chosen as reference quantity and called unit.

$\underline{Q}$ being the quantity, u its unit, this gives :

(6) $$\underline{Q}/u = \underline{q}$$

or

(7) $$\underline{Q} = \underline{q}.u.$$

The product $\underline{q}$.u represents the measure or value of the quantity $\underline{Q}$, $\underline{q}$ being the numerical value of this quantity expressed with the help of the chosen unit u ; $\underline{q}$ is a pure number. It may be symbolized by $\underline{Q}$/u. It is essential to make here a distinction between the value of a quantity and its numerical value, which each have a different meaning.

The same quantity measured with the help of a different unit u' has a different numerical value $\underline{q}'$ obtained by the equation :

$$\underline{Q} = \underline{q}'.u'.$$

This gives then :

$$\underline{Q} = \underline{q}.u = \underline{q}'.u' \qquad (8)$$

which calls for the following remarks :

1°) The measure, or value, of a quantity does not depend on the choice of units ;

2°) The numerical value attributed to a quantity has no significance, unless accompanied by an indication of the unit chosen to measure this quantity.

3°) When the same quantity is measured in succession with the help of different units, the numerical values obtained are inversely proportional to these units.

Returning to equation (8) : if the ratio u'/u of both units is known, the new numerical value $\underline{q}'$ may be calculated from the former value $\underline{q}$ supposed known :

$$\underline{q}' = \underline{q} \times u/u'.$$

If, for example, u' = 10 u, we have : $\underline{q}' = 0.1\ \underline{q}$.

Measure of a derived quantity.- Given that $\underline{Q}$ is the derived quantity defined in terms of the base quantities by the equation (3) :

$$\underline{Q} = \underline{k} \cdot \underline{Q_1}^{\alpha} \cdot \underline{Q_2}^{\beta} \cdot \underline{Q_3}^{\gamma}$$

u_1, u_2, u_3 being the base units, $\underline{q_1}$, $\underline{q_2}$, $\underline{q_3}$ the numerical values of $\underline{Q_1}$, $\underline{Q_2}$, $\underline{Q_3}$, u and $\underline{q}$ respectively the unit and the numerical value of $\underline{Q}$. This will give :

$$\underline{Q} = \underline{q}\cdot u = \underline{k} \times (\underline{q}_1 \cdot u_1)^{\underline{\alpha}} \times (\underline{q}_2 \cdot u_2)^{\underline{\beta}} \times (\underline{q}_3 \cdot u_3)^{\underline{\gamma}} =$$

$$= \underline{k} \times (\underline{q}_1^{\underline{\alpha}} \cdot \underline{q}_2^{\underline{\beta}} \cdot \underline{q}_3^{\underline{\gamma}}) \times (u_1^{\underline{\alpha}} \cdot u_2^{\underline{\beta}} \cdot u_3^{\underline{\gamma}}).$$

In the general case, when u is chosen arbitrarily, we would write :

(9) $$u = \underline{k}' \times u_1^{\underline{\alpha}} \cdot u_2^{\underline{\beta}} \cdot u_3^{\underline{\gamma}}$$

(10) $$\underline{q} = (\underline{k}/\underline{k}') \times \underline{q}_1^{\underline{\alpha}} \cdot \underline{q}_2^{\underline{\beta}} \cdot \underline{q}_3^{\underline{\gamma}}.$$

The equation between units (9) and that between numerical values (10) are both affected by new numerical factors, respectively $\underline{k}'$ and $1/\underline{k}'$.

A system of units in which the derived units are chosen arbitrarily is inconvenient, for it introduces new numerical factors into the equations between units and the equations between numerical values, and is therefore not recommendable.

Coherent system of units.- A system of units is said to be coherent when, for all units of the system, we have $\underline{k}' = 1$ in all the equations between units and in all those between numerical values. The equations (9) and (10) become :

(9') $$u = u_1^{\underline{\alpha}} \cdot u_2^{\underline{\beta}} \cdot u_3^{\underline{\gamma}}$$

(10') $$\underline{q} = \underline{k} \times \underline{q}_1^{\underline{\alpha}} \cdot \underline{q}_2^{\underline{\beta}} \cdot \underline{q}_3^{\underline{\gamma}}$$

which makes it possible to write (10') more explicitly :

(11) $$\underline{Q}/u = \underline{k} \times (\underline{Q}_1/u_1)^{\underline{\alpha}} \times (\underline{Q}_2/u_2)^{\underline{\beta}} \times (\underline{Q}_3/u_3)^{\underline{\gamma}}.$$

Thus, in a coherent system :

1°) equations between units (9') do not contain any numerical factors, nor even a power of 10 ;

2°) equations between quantities (3) and those between numerical values (10') have exactly the same form.

It will also be seen that in such a system, the equation between units

(9') has exactly the same form as the dimensional equation (4). We pass from (4) to (9') by substituting the units for the corresponding dimensions of quantities.

A unit calculated from (9') is said to be coherent.

In the Système International d'Unités, the SI units comprising the base, derived and supplementary units are coherent. The whole set of these units form the coherent SI system. The multiples of these units formed by SI units multiplied by a power of 10 are therefore not coherent.

4.- Need for standardization

Each day standardization becomes more urgent in all scientific fields. The main aim is to arrive at a uniform scientific language and writing, so as to avoid confusion as far as possible, and to ensure the best possible understanding among men of science.

In the domain of quantities and units, it is important that this mutual understanding should exist, not only between members of the same scientific discipline, but also, and above all, on an interdisciplinary basis.

The same physical quantity should be given the same name in all scientific disciplines. The quantity should be clearly defined and its name chosen so as to avoid all possibility of confusion between any neighbouring quantities such as : "compressibility" ($\kappa = -(1/V)(dV/dp)$), "pressure coefficient" ($\beta = dp/dT$) and "relative pressure coefficient" ($\alpha_p = (1/p)(dp/dT)$), V being the volume and p the pressure.

Furthermore, any name likely to lead to mistakes or confusion when translating from one language to another, should be avoided.

We should avoid giving to a unit belonging to a particular discipline a proper name which may remain unknown to members of other disciplines, unless this new proper name is adopted by the Conférence Générale des Poids et Mesures (CGPM), and consequently appears in the "table of units having a special name", distributed by the Bureau International des Poids et Mesures (BIPM) [1].

The worldwide adoption of the Système International d'Unités, with its SI symbols and prefixes, and its very strict rules for writing, is in fact proposed with the aim of contributing in a decisive manner to this effort of standardization.

Indeed the ultimate objective is that a scientific paper in a particular discipline can be read by a scientist from another discipline, or translated into another language, so that the quantities, units and symbols therein remain perfectly comprehensible, and also that no conversion calculation is required.

II - PHYSICAL QUANTITIES

Every physical quantity must be identified by a name and a definition and receive the attribution of one or more symbols. The definition is the most important element, which will differentiate this quantity from all others. The name and symbols are usually proposed on an interdisciplinary level by the International Organization for Standardization (ISO), and by various scientific organizations.

The definition of a quantity with regard to the seven base quantities permits the attribution to this quantity of one unique SI unit and a dimension.

For the main physical quantities in the different scientific disciplines, the name, definition, symbols and SI unit with its symbol are tabulated in the 13 parts (n° 1 to 13) of the ISO 31 [2], a comprehensive publication of the ISO. Various booklets [3, 4, 5] published by different scientific organizations also give lists of the principal quantities in different disciplines together with the name, a very brief definition (only when necessary) and the symbols recommended by each of these organizations.

1.- Base quantities

For the requirements of the Système International d'Unités, seven base quantities, supposed mutually independent, have been selected with their seven corresponding base units. The following table indicates these base quantities and their symbols.

Quantity	Symbol	Quantity	Symbol
length	l	thermodynamic temperature	T
mass	m	amount of substance	n
time	t	luminous intensity	I_v
electric current intensity	I		

2.- Derived quantities

Each quantity different from base quantities is a derived quantity. It must, first of all, receive a name and appropriate symbol.

2.1.- Name of a derived quantity. The name is chosen with a view to avoiding any confusion with neighbouring quantities, or in translating from one language to another. Some examples of these sources of confusion will be found in I.4.

The same quantity should have the same name in all scientific disciplines. Finally it would be preferable for all scientists to use only "recommended names".

2.1.1.- Supplementary quantities. Two derived quantities, called "supplementary", were, until 1980, considered at will either base or derived quantities. They are :

Quantity	Symbols
plane angle	α, β, γ, θ, ϕ
solid angle	Ω, ω.

In 1980, the Comité International des Poids et Mesures (CIPM) considering that the plane angle is generally expressed as the ratio between two lengths and the solid angle as the ratio between an area and a square length, stated that in the Système International these quantities (plane angle and solid angle) should be considered as derived dimensionless quantities.

2.1.2.- Use of the adjectives "specific" and "molar". The adjective "specific" placed before the name of an extensive quantity is restricted to the meaning "divided by mass". The corresponding French term is "massique". When the extensive quantity is symbolized by a capital letter, the corresponding specific one may be symbolized by the corresponding lower case letter.

E.g. : volume, V
specific volume, $v = V/m$
(in French - volume massique).

The adjective "molar" in front of the name of an extensive quantity is restricted to the meaning "divided by amount of substance". The corresponding French term is "molaire". The subscript m attached to the symbol, for this extensive quantity denotes the corresponding molar quantity.

E.g. : volume, V
Molar volume, $V_m = V/n$ (in French "volume molaire")

The subscript m may be omitted when there is no risk of ambiguity.

The two above rules are not always applied strictly. E.g. :

1°) for specific, we must not forget that even now the term "specific gravity", for many people, means "relative density", i.e. the ratio of the mass of a volume of a given substance to the mass of the same volume of a reference substance ;

2°) for molar, the quantity "molar conductivity of an electrolyte", e.g., κ/c, means "conductivity divided by the amount-of-substance concentration (amount-of-substance concentration = amount of the solute divided by the volume of solution).

2.2.- Symbols of a derived quantity. The ideal would be that every derived quantity received its own symbol. This unfortunately is impossible. The number of quantities is so great and constantly increasing that all capital and lower case and even bold-faced letters of all the alphabets we use, both Latin and Greek, still remain insufficient. The same symbol must therefore necessarily represent several different quantities : T for thermodynamic temperature and period, t for Celsius temperature and time, V for volume and electric potential ; v for specific volume and velocity ; m for mass and electromagnetic moment ; n for amount of substance and refractive index ; ω for solid angle and angular velocity etc. This explains why, frequently, several symbols are proposed for one quantity, of which one or two are principal symbols and the remaining alternative or reserve ones.

Authors of scientific texts must therefore be given wide freedom in choosing physical quantity symbols. Consequently, to avoid all confusion, strong recommendations are made for the application of the following rule :

All the symbols for physical quantities appearing in a scientific text should be identified, either as they appear in the text, or grouped in a table at the beginning or the end of the text.

This rule should be applied even when all the symbols used are those recommended exclusively by competent International Organizations. [6]

However we should be careful to avoid a symbol changing its meaning within the same text.

3.- Printing and writing of symbols for physical quantities

It happens frequently that one letter is, at the same time, the symbol both for a quantity and a unit of different dimensions. This is the case for example with the letter "m", which is the symbol both for mass and metre. To avoid any confusion, symbols for units should always be printed, typed and written in roman (upright) type, whilst those for quantities should always be printed in italic (sloping) type. In typescript or manuscript, symbols for quantities should be underlined.

The symbols of vector quantities should be printed in bold-faced italic type or, if no risk of ambiguity exists, italic type with an arrow overhead may then be used.

A symbol is never followed by a full stop, unless it is at the end of a sentence.

4.- Subscripts and superscripts

When necessary, the symbol for a physical quantity may be modified by attaching to it subscripts and/or superscripts and other modifying signs having a specified meaning.

E.g. :

$\underline{\rho}_{max}$ = maximal value, in terms of temperature, of density of water

$\underline{p}$ and $\underline{p}'$, two different pressures

$\underline{t}_1$ and $\underline{t}_2$, two different temperatures

Second order indices (subscripts and/or superscripts) should be avoided as far as possible :

Do not write $\underline{m}_{O_2}$ = 5.12 g, but : $\underline{m}(O_2)$ = 5.12 g

" " " $\underline{\rho}_{20°C}$ but : $\underline{\rho}$(20°C)

" " " e^{x^2} but : exp x^2

Some recommended superscripts

*	pure substance
°	standard in general
id.	ideal
∞	infinite dilution
+, -	positive, negative ion, electrode

Some recommended subscripts

$\underline{p}$, $\underline{v}$, $\underline{t}$, ...	indicating constant pressure, volume, temperature, ... respectively
g, l, s, c,	referring to gas, liquid, solid and crystalline state, respectively.

When two or more subscripts, or two or more superscripts having separate meanings, are attached to the same symbol, they should be separated by commas. In French texts, when some decimal numbers, in which the decimal sign is the comma, appear among the indices, the separation could be made by a point (.) or a semicolon (;).

Subscripts or superscripts, which are themselves symbols for physical quantities, and also running suffixes or exponents, should be printed in italic type and all others in roman type.

E.g. : $\underline{C}_{\underline{p}}$ for heat capacity at constant pressure
$\underline{C}_B$ " " " of substance B.

5.- Symbols for particular cases of physical quantities

$\underline{\rho}$ being in general the symbol of density, if we want to represent the density of sea water in certain particular conditions, e.g., at 15 °C and under the pressure of one standard atmosphere, we may indicate these particular conditions in parentheses attached to the symbol $\underline{\rho}$, in preference to subscript, i.e.

$\underline{\rho}$ (15 °C, 101 325 Pa), in preference to : $\underline{\rho}_{15\ °C,\ 101\ 325\ Pa}$.

In the English language, the two data appear in parentheses or subscripts, separated by a comma. In French, where the comma is the decimal sign, the separation may be indicated by a semicolon (;) or a point (.).

Both these ways of writing can moreover be combined. E.g. :

$\underline{\rho}_{max}$ (SMOW)

may be written in this manner to represent the maximal value of the density of the pure reference water "SMOW" (Standard Mean Ocean Water [7]). We will deal later with the notation rules recommended for symbolizing the density of sea water and related quantities in terms of its salinity, temperature and pressure.

The two rules recommended above to represent a physical quantity in particular conditions may be applied in a general way in wider fields of science. They are particularly convenient for representing concentrations of chemical solutions. Thus, to say that the "amount-of-substance concentration", symbol $\underline{c}$, of NaCl in an aqueous solution at 20 °C, is equal to 15.2 $mol.m^{-3}$, it is preferable to write :

$\underline{c}$ (NaCl, 20 °C) = 15.2 $mol.m^{-3}$

or at least :

$\underline{c}_{NaCl,\ 20\ °C}$ = 15.2 $mol.m^{-3}$

but never :

$\underline{c}$ = 15.2 mol $NaCl/m^3$ sol.20°C

This latter way of writing is to be strongly discouraged, the concentration unit, $mol.m^{-3}$, having always to be written as a whole.

6.- Mathematical operations on physical quantities

Provided that they have the same dimension, two physical quantities $\underline{a}$ and $\underline{b}$ may be added or substracted. The operations may be represented in either of the following ways :

$$\underline{a} + \underline{b} \qquad \text{and} \qquad \underline{a} - \underline{b}$$

The same operations may be made, of course, with several quantities of the same dimensions :

$$\underline{a} + \underline{b} - \underline{c} - \underline{d} + \underline{f}$$

Two physical quantities, $\underline{a}$ and $\underline{b}$, can be multiplied or divided by each other, whatever their dimensions.

The multiplications of $\underline{a}$ by $\underline{b}$ can be indicated in any of the following ways :

$$\underline{ab} \qquad \underline{a}\ \underline{b} \qquad \underline{a}.\underline{b} \qquad \underline{a} \times \underline{b} \qquad \underline{a} \cdot \underline{b}$$

The division of the quantity $\underline{a}$ by the quantity $\underline{b}$ can be represented in any of the following ways :

$$\frac{\underline{a}}{\underline{b}} \quad \underline{a}/\underline{b} \quad \underline{ab}^{-1} \quad \underline{a}\ \underline{b}^{-1} \quad \underline{a} \cdot \underline{b}^{-1} \quad \underline{a}.\underline{b}^{-1} \quad \underline{a} \times \underline{b}^{-1}$$

Many physical quantities can be linked together by a series of equations comprising additions, substractions, multiplications and divisions. The whole of these operations must be indicated in a perfectly clear manner, using as many parentheses, brackets, etc... as necessary.

E.g. :

$$\left(\frac{\underline{a} + \underline{b}}{\underline{c} + \underline{d}} - \underline{e}\right) \sin \underline{x}$$

If the solidus (/) is used to separate a numerator from a denominator and if there is any doubt as to where the numerator starts or the denominator ends, parentheses, brackets, etc... should be used :

$$\left[(\underline{a} + \underline{b}) \ / \ (\underline{c} + \underline{d}) - \underline{e}\right] \sin \underline{x}$$

No more than one solidus shall be used in the same expression, unless parentheses are used to eliminate ambiguity.

E.g. :

$(\underline{a}/\underline{b})/\underline{c}$ or $\underline{a}/(b/c)$ but never $\underline{a}/\underline{b}/\underline{c}$.

III - SI UNITS, SYMBOLS AND PREFIXES

DERIVED AND COMPOUND UNITS - BASIC RULES

SOME NON-SI UNITS

1.- Introduction

In 1948 the 9th Conférence Générale des Poids et Mesures (CGPM), by its Resolution 6, instructed the Comité International des Poids et Mesures (CIPM) "to study the establishment of a complete set of rules for units of measurement ; to find out for this purpose, by official enquiry, the opinion prevailing in scientific, technical and educational circles in all countries ; and to make recommendations on the establishment of a practical system of units of measurement suitable for adoption by all signatories to the Metre Convention".

In its present form the International System of Units has been gradually set up by eight Conférences Générales (9th to 17th) that met between 1948 and 1983.

In its Resolution 7, the 9th CGPM already set the general rules of writing the symbols of units. In its Resolution 6 the 10th CGPM (1954) adopted six out of the seven present base units (metre, kilogram, second, ampere, degree Kelvin, that became later on kelvin, and candela) ; symbols of these units were stated in Resolution 12 of the 11th CGPM in 1960. This Conference moreover adopted the names and symbols of the prefixes that help to make multiples and submultiples of units. It also adopted two supplementary units with their symbols as well as a list of special names and symbols for about thirty derived units.

The seventh base unit, the mole, together with its symbol, was adopted in 1971 (14th CGPM) and the list of prefixes was completed by the 12th and 15th CGPM (1964 and 1975).

Nomenclature.- According to Resolution 12 of the 11th CGPM

a) the new system of units must be internationally referred to as "Système International d'Unités" ;

b) its internationally agreed abbreviation is "SI".

The International System of Units (SI) contains the 7 base units, the two supplementary units, the derived units, the symbols of all these units, the prefixes and their symbols. Multiples of these units, made up with these prefixes, do not properly belong to the International System. Prefixes used with the International System are "SI prefixes".

The base units, the supplementary units and the derived units are called "SI units". These SI units form a coherent set of units.*

The multiples of SI units formed by means of SI prefixes do not belong to the coherent system. These multiples of units, that are not derived units, can be referred to as "compound units", an expression used in the International Standards ISO 31/0 [8] and ISO/1000 [9]. The use of such units is, of course, permitted.

Choice of the base units.- The choice of the seven base units and subsequently the division of SI units into three classes,base units, derived units and supplementary units, is somewhat arbitrary, in so far as it is not unequivocally set by physics.

Ideally, the definition of a base unit should be such that this unit remains physically independent from all the other base units, but the choice that was made does not fully meet this requirement. The definition of the ampere, for instance, refers to the metre and the newton. The mole and the candela also are not physically independent from other quantities.

By convention, the seven present base units are regarded and used as dimensionally independent from each other.

2.- SI Units

2.1.- SI Base Units - Definitions and Symbols

---

* The different Resolutions of CGPM that brought about the setting up of SI, as well as the definitions of the base and supplementary units, can be found in a booklet published by the BIPM [1].

Table 1

SI Base Units

Quantity	Name	Symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

Unit of length (metre)

The new definition of the metre adopted by the 17th CGPM (October 1983) is :

> "The metre is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second."

The old international prototype is still kept at the BIPM under the conditions specified by the 1st CGPM (1889).

Unit of mass (kilogram)

> The kilogram is equal to the mass of the international prototype of the kilogram kept since 1889 at the BIPM.

It is the only base unit whose name includes a prefix for historical reasons.

Unit of time (second)

Originally the unit of time, the second, was defined as the fraction 1/86 400 of the mean solar day. A more precise definition based on the tropic year was given in 1960.

Considering that a very precise definition of the unit of time is indispensable for the needs of advanced metrology, the 13th CGPM (1967) decided to replace the definition of the second by the following :

> The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom.

Unit of electric current (ampere)

After the unit called "international" introduced in 1893 and the definition of the "international ampere" in 1908, the 9th CGPM (1948) adopted the following definition for the unit of electric current, the ampere :

> The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between the conductors a force equal to 2×10^{-7} newton per metre of length.

Unit of thermodynamic temperature (kelvin)

The definition of the unit of thermodynamic temperature was given in substance by the 10th CGPM (1954) which selected the triple point of water as fundamental fixed point and assigned to it the temperature 273.16 K by definition. The 13th CGPM (1967) adopted the name "kelvin" (and the symbol K) instead of "degree Kelvin" (symbol °K) and defined the unit of thermodynamic temperature as follows.

> The kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

The same CGPM also decided that the unit "kelvin" and its symbol "K" should be used to express an interval or a difference of temperature.

Note 1.- In addition to the thermodynamic temperature (symbol T), expressed in kelvins, use is also made of Celsius temperature (symbol t) defined by the equation

$$t = T - T_0$$

where T_0 = 273.15 K by definition. The unit "degree Celsius" is equal to the unit "kelvin", but "degree Celsius" is a special name in place of "kelvin" for expressing Celsius temperature. A temperature interval or a Celsius temperature difference can be expressed in degrees Celsius as well as in kelvins.

Thus, the thermodynamic temperature of the triple point of water is 273.16 K which corresponds to the Celsius temperature of 0.01 °C.

Note 2.- To avoid confusion between "time" and "Celsius temperature", both symbolized by _t_, it is recommended (see VI, 2.1, p. 45) to use the alternative symbol _θ_ (lower case theta) for Celsius temperature, _t_ always remaining the unique symbol of time. Thus, when time and Celsius temperature both appear in the same text, we shall use _t_ for time and _θ_ for temperature.

At the present time and in practical use, temperatures are given in the International Practical Temperature Scale of 1968 (amended edition 1975) (IPTS-68). [10].

Unit of amount of substance (mole)

> The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12.
>
> When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

This definition, adopted by the 14th CGPM (1971), specifies at the same time the nature of the quantity whose unit is the mole.

Thus :

1 mole of HgCl has a mass equal to 236.04×10^{-3} kg.

1 mole of a mixture containing 2/3 mole of H_2 and 1/3 mole of O_2 has a mass equal to $12.010\ 3 \times 10^{-3}$ kg.

All units such as the "gram-atom", "gram-molecule", "gram-equivalent", "gram-ion" and "gram-formula" are obsolete.

Thus we must say :

1 mole of Ar and not 1 "gram-atom" of Ar.

Unit of luminous intensity (candela)

The old units of luminous intensity were replaced in 1948 by the "new candle". This decision was adopted by the CIPM in 1946. The 9th CGPM (1948) ratified the decision of the CIPM and gave a new international name, candela, to the unit of luminous intensity. The text of the definition of the candela was amended by the 13th CGPM (1967). A new definition of the candela based on radiometric techniques was adopted by the 16th CGPM (1979) :

> "The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of (1/683) watt per steradian."

2.2.- SI derived units

2.2.1.- Derived units are expressed algebraically in terms of base units by means of the mathematical symbols of multiplication and division.

Table 2

Examples of SI derived units expressed in terms of base units

Quantity	SI unit	
	Name	Symbol
area	square metre	m^2
volume	cubic metre	m^3
speed, velocity	metre per second	m/s
acceleration	metre per second squared	m/s^2
wave number	1 per metre	m^{-1}
density	kilogram per cubic metre	kg/m^3
current density	ampere per square metre	A/m^2
magnetic field strength	ampere per metre	A/m
amount-of-substance concentration	mole per cubic metre	mol/m^3
specific volume	cubic metre per kilogram	m^3/kg
luminance	candela per square metre	cd/m^2

2.2.2.- If for each SI base unit used to form a derived unit we have the same number of multiplications and divisions, this derived unit is "dimensionless" ; it may be expressed by the number 1.

ex. : relative density is a dimensionless quantity and has for unit the number one :

$$(kg \cdot m^{-3})/(kg \cdot m^{-3}) = 1$$

2.2.3.- Several derived units have been given special names and symbols which may themselves be used to express other derived units in a simpler way than in terms of the base units.

Table 3

SI derived units with special names

Quantity	SI unit			
	Name	Symbol	Expression in terms of other units	Expression in terms of SI base units
frequency	hertz	Hz		s^{-1}
force	newton	N		$m.kg.s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1}.kg.s^{-2}$
energy, work, quantity of heat	joule	J	N.m	$m^2.kg.s^{-2}$
power, radiant flux	watt	W	J/s	$m^2.kg.s^{-3}$
quantity of electricity, electric charge	coulomb	C		s.A
electric potential, potential difference, electromotive force	volt	V	W/A	$m^2.kg.s^{-3}.A^{-1}$
capacitance	farad	F	C/V	$m^{-2}.kg^{-1}.s^4.A^2$
electric resistance	ohm	Ω	V/A	$m^2.kg.s^{-3}.A^{-2}$
conductance	siemens	S	A/V	$m^{-2}.kg^{-1}.s^3.A^2$
magnetic flux	weber	Wb	V.s	$m^2.kg.s^{-2}.A^{-1}$
magnetic flux density (F. induction magnétique)	tesla	T	Wb/m^2	$kg.s^{-2}.A^{-1}$
inductance	henry	H	Wb/A	$m^2.kg.s^{-2}.A^{-2}$
Celsius temperature[(a)]	degree Celsius	°C		K
luminous flux	lumen	lm		cd.sr[(b)]
illuminance	lux	lx	lm/m^2	m^{-2}.cd.sr[(b)]
activity (of a radionuclide)	becquerel	Bq		s^{-1}
absorbed dose, specific energy imparted, kerma, absorbed dose index	gray	Gy	J/kg	$m^2.s^{-2}$
dose equivalent, dose equivalent index	sievert	Sv	J/kg	$m^2.s^{-2}$

(a) See page 20.

(b) See 2.2.4., p. 25.

Table 4

Examples of SI derived units expressed by means of an association of special names and base units

Quantity	SI unit		
	Name	Symbol	Expression in terms of SI base units
dynamic viscosity	pascal second	Pa.s	$m^{-1}.kg.s^{-1}$
moment of force	metre newton	N.m	$m^2.kg.s^{-2}$
surface tension	newton per metre	N/m	$kg.s^{-2}$
heat flux density, irradiance	watt per square metre	W/m^2	$kg.s^{-3}$
heat capacity, entropy	joule per kelvin	J/K	$m^2.kg.s^{-2}.K^{-1}$
specific heat capacity, specific entropy	joule per kilogram kelvin	J/(kg.K)	$m^2.s^{-2}.K^{-1}$
thermal conductivity	watt per metre kelvin	W/(m.K)	$m.kg.s^{-3}.K^{-1}$
electric field strength	volt per metre	V/m	$m.kg.s^{-3}.A^{-1}$
electric charge density	coulomb per cubic metre	C/m^3	$m^{-3}.s.A$
permittivity	farad per metre	F/m	$m^{-3}.kg^{-1}.s^4.A^2$
permeability	henry per metre	H/m	$m.kg.s^{-2}.A^{-2}$
molar energy	joule per mole	J/mol	$m^2.kg.s^{-2}.mol^{-1}$

2.2.4.- SI Supplementary Units. This class contains two units, both dimensionless and each having a special name : the radian, SI unit of plane angle (symbol rad) and the steradian, SI unit of solid angle (symbol sr).

At the time of the introduction of the International System, the 11th CGPM (1960, Resolution 12) left open the question of whether to consider these supplementary units as base units or derived units.

Considering that plane angle is generally expressed as the ratio between two lengths and solid angle as the ratio between an area and the square of a length, the CIPM (1980) specified that in the International System the quantities plane angle and solid angle should be considered as dimensionless derived quantities. Therefore, the supplementary units radian and steradian are to be regarded as dimensionless derived units, each having a special name, which may be used or omitted in the expressions for derived units.

Table 5

SI supplementary units

Quantity	SI unit		
	Name	Symbol	Expression in terms of SI base units
plane angle	radian	rad	$(m \cdot m^{-1})$
solid angle	steradian	sr	$(m^2 \cdot m^{-2})$

The radian is the plane angle between two radii of a circle which cut off on the circumference an arc equal in length to the radius.
The steradian is the solid angle which, having its vertex in the centre of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere.

These two definitions are those of International Standards ISO 31/I.

Table 6

Examples of SI derived units formed by using supplementary units

Quantity	SI unit		
	Name	Symbol	Expression in terms of SI base units
angular velocity	radian per second	rad/s	s^{-1}
angular acceleration	radian per second squared	rad/s^2	s^{-2}
radiant intensity	watt per steradian	W/sr	$m^2.kg.s^{-3}$
radiance	watt per square metre steradian	$W/(m^2.sr)$	$kg.s^{-3}$

3.- Decimal multiples and sub-multiples of SI units

SI prefixes are used to form decimal multiples and submultiples of SI units. The list of the prefixes and their symbols is given in Table 7.

Table 7

SI prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{18}	exa	E	10^{-1}	deci	d
10^{15}	peta	P	10^{-2}	centi	c
10^{12}	tera	T	10^{-3}	milli	m
10^{9}	giga	G	10^{-6}	micro	µ
10^{6}	mega	M	10^{-9}	nano	n
10^{3}	kilo	k	10^{-12}	pico	p
10^{2}	hecto	h	10^{-15}	femto	f
10^{1}	deca	da	10^{-18}	atto	a

We saw earlier that units formed by use of these prefixes do not belong to the coherent system.

4.- Recommendations for using SI units and SI prefixes

The general principle ruling the writing of unit symbols had already been adopted by the 9th CGPM (1948), namely :

Roman (upright) type, in general lower case, is used for symbols of units ; however if the symbols are derived from proper names, capital roman type is used (for the first letter).

These symbols are not followed by a fullstop (period). The unit symbols do not change in the plural.

for example :	metre	m
	second	s
	hertz	Hz
	5 m	but not 5 ms

The International Organization for Standardization (ISO) has issued additional recommendations with the aim of securing uniformity in the use of units, in particular those of the International System (see International Standards ISO 31/0-1981 [8]).

According to these recommendations :

(a) The product of two or more units may be indicated in any of the following ways, noting it is essential to use either a space or a point to separate the units,

for example : N•m, N.m, N m or N × m.

(b) A solidus (oblique stroke, /), a horizontal line, or negative powers may be used to express a derived unit formed from two others by division,

for example : m/s, $\frac{m}{s}$, $m.s^{-1}$ or $m\ s^{-1}$.

(c) The solidus must not be repeated on the same line unless ambiguity is avoided by parentheses. In complicated cases, negative powers should be used,

for example : m/s^2 or $m.s^{-2}$ but not : m/s/s

$m.kg/(s^3/A) = m.kg.s^{-3}.A$

ISO also recommends the following rules for the use of SI prefixes :

(a) Prefix symbols are printed in lower case roman (upright) type without spacing between the prefix symbol and the unit symbol.

(b) A combination of prefix and symbol for a unit is regarded as a single symbol which may be raised to a power without the use of brackets,

for example : 1 cm^2 always means $(0.01\ m)^2$ and never 0.01 m^2

(c) Compound prefixes, formed by the juxtaposition of two or more SI prefixes, are not to be used,

for example : 1 nm but not 1 mμm

Finally, the following rules concerning the symbols and units should be observed :

(a) The symbol of a unit which is not preceded by a numerical value should be replaced by the name of the unit written in full,

for example, we must write : "the unit of mass is the kilogram", but not "the unit of mass is the kg".

(b) The association of symbols and names of units to form the symbol of a derived unit is discouraged.

The symbol of a derived or compound unit must be regarded as a single term and should not be split,

for example : to express an amount-of-substance concentration we write :

$\underline{c}$(KCl) = 0.12 mol/dm^3

and not $\underline{c}$ = 0.12 mol KCl/dm^3,

the unit mol/dm^3 being a single term and the term (KCl) qualifying the quantity and not the unit.

5.- Units outside the International System (SI)

In principle, only the units belonging to the SI are to be used to express the results of physical measurements.

However, the CIPM (1969) agreed that certain units outside the SI, either for their practical importance or because of force of habit, may be used with the SI or temporarily maintained.

Combination of some of these units with SI units in order to form compound units should be used only in very limited cases.

The units outside the SI are divided into three categories :

1 - units used with the SI ;
2 - units that may be temporarily used together with the SI ;
3 - those to be strongly discouraged.

The three following tables present the units of each of the above categories. They are modelled on those corresponding to the BIPM brochure on the SI, adapting them to physical oceanography. These tables are followed by explanations and, when need be, comments made by the Working Group.

5.1.- Units in use with the SI. These units are grouped in the following Table 8.

Table 8

Units in use with the SI

Quantity	Unit	Symbol	Value in SI unit
time(1)	minute	min	1 min = 60 s
	hour	h	1 h = 60 min = 3 600 s
	day	d	1 d = 86 400 s
plane angle, arc(2)	degree	°	$1° = (\pi/180)$ rad
	minute	'	$1' = (1/60)° = (\pi/10\ 800)$ rad
	second	"	$1'' = (1/60)' = (\pi/648\ 000)$ rad
mass	tonne(3)	t	$1\ t = 10^3$ kg
	unified atomic mass unit(4)	u	$1\ u = 1.660\ 57 \times 10^{-27}$ kg approximately

NB.- Although the litre is mentioned in the BIPM brochure on the SI as being a unit in use with the SI units (except to express the results of high precision measurements), its use is not recommended. The litre will therefore be mentioned in Table 10 concerning units whose use is not advisable.

(1) For the other units of time, see the Note at the end of Table 10.

(2) For fractions of angles or arcs smaller than the second, the decimal fractions of the second may be used.

The value of a plane angle or arc can be expressed in the following different forms :

a) 5°38'16.4"
b) 5° + 38' + 16.4"
c) 5° 38.274'
d) 338.274'

Form d) which consists in reducing the expression of the angle to a decimal number of minutes is particularly suitable for calculating distances on nautical charts, because 1' of latitude represents approximately 1 nautical mile.

Decimal fractions of degrees and seconds are scarcely used.

(3) In some English-speaking countries, this unit is called "metric ton".

(4) The unified atomic mass unit is equal to the fraction 1/12 of the mass of an atom of the nuclide ^{12}C. Its value, in kilogram, is obtained experimentally.

5.2.- Units that may be temporarily used together with the SI. Some of these units are grouped in the following Table 9.

Table 9

Units that may be temporarily used with the SI

Quantity	Unit	Symbol	Value in SI unit
length	nautical mile[1]	-	1 nautical mile = 1 852 m exactly
pressure	bar	bar	1 bar = 10^5 Pa exactly
acceleration of free fall	gal[2]	Gal	1 Gal = 10^{-2} m.s^{-2}
activity of radionuclides	curie[3]	Ci	1 Ci = 3.7×10^{10} Bq = 3.7×10^{10} s^{-1}

NB.- Although the knot, hectare, atmosphere are mentioned in the BIPM brochure on the SI as being temporarily accepted with the SI units, their use are not recommended. These units will be mentioned therefore in Table 10 concerning those units whose use is discouraged.

(1) This conventional value was adopted by the First International Hydrographic Conference, Monaco, 1929, under the name "International nautical mile".

(2) The gal is a special unit used in geodesy and geophysics to express the acceleration due to gravity.

(3) The curie is a special unit used in nuclear physics to express activity of radionuclides.

5.3.- Units whose use is strongly discouraged. As regards units outside the SI which are not included in the Tables 8 and 9, it is preferable to avoid them and to use instead units of the SI. Some of these units are listed in the following Table 10.

Table 10

Units whose use is strongly discouraged

Quantity	Unit	Symbol	Value in SI unit
length	micron[(1)]	μ[(1)]	1 μ = 1 μm = 10^{-6} m
area	hectare	ha	1 ha = 10^4 m^2
volume	litre[(2)]	l	1 l = 1 dm^3 = 10^{-3} m^{-3}
force	kilogram-force	kgf	1 kgf = 9.806 65 N
pressure	atmosphere, standard atmosphère[(3)]	atm	1 atm = 101 325 Pa exactly
	torr[(4)]	-	1 torr = (101 325/760)Pa = 133.322 368 Pa approximately
	conventional millimetre of mercury[(5)]	mmHg	1 mmHg = 13.595 1 × 9.806 65 Pa = 133.322 387 Pa
velocity	knot[(6)]	-	1 knot = (1 852/3 600) m/s = 0.514 m/s approximately
geopotential	dynamic metre	-	1 dynamic metre = 10 $m^2.s^{-2}$ approximately
energy	calorie[(7)]	cal	
magnetic flux density (F. induction magnētique)	gamma	γ	1 γ = 10^{-9} T

(1) This unit and its symbol, μ, were withdrawn from SI by the 13th CGPM, Resolution 7, in 1967. For the same unit of length, the name and symbol are now "micrometre" and "μm".

(2) See the following section 5.3.1 : "Abandonment of the litre".

(3) It is recommended that "standard atmosphere" or "atmosphere" should no longer be used as pressure unit. This term could be retained to represent the standard value of 101 325 Pa. It is very convenient for example to say that certain data have been reduced to the pressure of "one standard atmosphere (101 325 Pa)".

(4) We may take : 1 torr = 1 mmHg = 133.322 4 Pa.

(5) This unit (symbol mmHg, not mm Hg) is a convenient unit when using a mercury barometer to read a pressure. However it is recommended that the final results are given in pascals.

(6) The knot represents the velocity of water flow covering 1 nautical mile per hour.

(7) Several "calories" have been in use :

- a calorie labelled "at 15 °C" : 1 cal_{15} = 4.185 5 J (value adopted by the CIPM in 1950 (Procès-Verbaux CIPM, 22, 1950, pp. 79-80) ;

- a calorie labelled "IT" (International Table) : 1 cal_{IT} = 4.186 8 J (5th International Conference on the Properties of Steam, London, 1956) ;

- a calorie labelled "thermochemical" : 1 cal_{th} = 4.184 J.

Note.- To the three units of time given in Table 8 the units week, month, year and century can be added, but they have no precise definitions. Their use should, as far as possible, be avoided, but could be convenient in certain circumstances, e.g. to measure geological durations.

Month and year have not been given symbols by the CGPM, but ISO has attributed to year the symbol "a" (neither "y" nor "yr"). For greater precision, this symbol could be followed by a subscript which specifies the kind of year concerned, for example : "a_{trop}" for a tropic year.

$$1\ a_{trop} = 365.242\ 20\ \text{d approximately}$$

In general if unit(s) such as week, month, century are to be used in a text, it is recommended not to use symbols but rather the full name(s) of this/these unit(s), or abbreviations(s) stated in the text.

5.3.1.- Abandonment of the "litre" for scientific uses. For a long time (1901-1964) the litre was defined as the volume occupied by 1 kilogram of water at its maximal density, i.e., 1.000 028 dm^3.

This definition, which created two units of volume : the litre and the cubic decimetre, of very close but not strictly equal values, was very inconvenient, especially for precise measurements, because of the risks of confusion between them.

Resolution 6 of the 12th CGPM, (1964), put an end to this situation by rescinding this definition and by deciding that the litre would thereafter be considered as synonymous with the cubic decimetre.

This Resolution ends with the recommendation that the word litre should not be used any longer to express results of high precision measurements of volume.

When high precision is required, particularly in physical oceanography, there is now a risk of confusion between data referring to the litre before and after the change of definition. This risk of confusion will disappear if only the cubic decimetre is used, its definition having the advantage of being perfectly clear.

IV.- NUMERICAL VALUES OF PHYSICAL QUANTITIES

Let us recall the equations (6) and (7) (see I.3) which serve to express the measure of a physical quantity $\underline{Q}$ in terms of the unit u chosen :

(6) $\underline{Q}/u = \underline{q}$

(7) $\underline{Q} = \underline{q} \cdot u$

$\underline{q}$ being the numerical value.

Equation (7) is the one most frequently used ; e.g :

$\underline{l} = 5.7$ cm

The right hand side, 5.7 cm, represents the measure or value of the quantity $\underline{l}$ expressed with the centimetre as unit and 5.7 the numerical value of this quantity.

A distinction must therefore be made between the value of a quantity and its numerical value, these two terms having different meanings.

Frequently, the numerical value appears in the form of a number multiplied by a power (positive or negative) of ten ; e.g. :

$\underline{m} = 1.318 \times 10^{-3}$ kg

The spaces left between the different elements of the equation should be observed.

In section I.3, we have already dealt with equation (6) which establishes an equality between the numerical value $\underline{q}$ and its symbol $\underline{Q}/u$.

According to this equation, we should write :

$\underline{l}/\mathrm{cm} = 5.7$; $\underline{m}/\mathrm{kg} = 1.318 \times 10^{-3}$

To represent the numerical value of a quantity $\underline{Q}$ by its symbol $\underline{Q}/u$, is a fairly recent practice, and presents advantages some of which we shall indicate.

1.- Unit conversions.- As an example, atmospheric pressure observed in a laboratory by means of the mercury barometer is equal, all corrections having been made, to :

$$\underline{p} = 748.95 \text{ mmHg}$$

Let us calculate the numerical value of this pressure, first in pascals and then in bars. We have :

$$\underline{p}/\text{mmHg} = 748.95$$
$$\text{mmHg}/\text{Pa} = 133.322\ 387$$
$$\text{Pa}/\text{bar} = 1 \times 10^{-5}$$

We may write then :

$$\underline{p}/\text{Pa} = (\underline{p}/\text{mmHg}) \times (\text{mmHg}/\text{Pa}) = 748.95 \times 133.322\ 387 = 0.998\ 518 \times 10^5$$

$$\underline{p}/\text{bar} = (\underline{p}/\text{Pa}) \times (\text{Pa}/\text{bar}) = 0.998\ 518$$

2.- Equations between numerical values.- Let us consider the formula :

$$\underline{\rho} = f(\underline{t})$$

giving the density of a body in terms of its temperature. In such a formula, usually established by laboratory measurements, the right hand side can take various forms, a common one being a polynomial in $\underline{t}$ of degree n :

$$\underline{\rho} = \underline{a}_0 + \underline{a}_1\underline{t} + \underline{a}_2\underline{t}^2 + \underline{a}_3\underline{t}^3 + \ldots \tag{12}$$

All the terms of this equation have the dimension of a density and, consequently, each coefficient $\underline{a}_i$ has its own dimension, to calculate which requires a knowledge of the units chosen. The choice of $\underline{t}$, symbol for Celsius temperature, implies that the degree Celsius has been chosen as unit of temperature. The numerical value of $\underline{a}_0$ gives information on the unit chosen for density. E.g., in the case of pure water, if this numerical value is close to 1000, the unit is kilogram per cubic metre. Let us suppose that this is so in equation (12). We shall get :

$\underline{a}_0 = \alpha_0 . \mathrm{kg.m^{-3}}$ $\underline{a}_1 = \alpha_1 . \mathrm{kg.m^{-3}.^\circ C^{-1}}$

$\underline{a}_2 = \alpha_2 . \mathrm{kg.m^{-3}.^\circ C^{-2}}$ $\underline{a}_3 = \alpha_3 . \mathrm{kg.m^{-3}.^\circ C^{-3}}$

....

α_0, α_1, α_2, ... being pure numbers.

We obtain then the following <u>equation between numerical values</u>

$$\underline{\rho}/(\mathrm{kg.m^{-3}}) = \alpha_0 + \alpha_1 \underline{t}/^\circ\mathrm{C} + \alpha_2 \underline{t}^2/^\circ\mathrm{C}^2 + \alpha_3 \underline{t}^3/^\circ\mathrm{C}^3 + \ldots$$

This equation is dimensionally homogenous, all the terms having the dimension zero. All the units here are clearly indicated and any change of unit becomes simpler.

Such a notation, using symbols of numerical value ($\underline{Q}$/u) requires of course a strict observation of the rules established for printing and writing quantity and unit symbols, enabling us to differentiate the quantity symbols (in italic) from those of units (in roman type).

3.- <u>The heading of tables of numerical values</u>.- The following Table 11 reproduces a part of the results of the observations made on 1962.08.20, aboard the "Commandant Robert Giraud", at the Hydrographic Station n° 315 in the Indian Ocean. The three columns contain the respective numerical values of the depth $\underline{Z}$ expressed in metres, the Celsius temperature and the salinity, a dimensionless quantity symbolized here by $\underline{S}$ i.e. the respective numerical values $\underline{Z}$/m, $\underline{t}$/°C and $\underline{S}$. It is natural, therefore, that these symbols head their respective columns. This way of acting seems preferable to all others used in the past, such as : "$\underline{Z}$ (m)" (which may signify $\underline{Z}$ multiplied by m), "$\underline{Z}$,m", etc.

Table 11

Extract of data from a hydrographical station in the Indian Ocean

$\underline{Z}$/m	$\underline{t}$/°C	$\underline{S}$
0	26.71	35.410
20	26.72	35.390
50	26.68	35.400
100	20.07	35.254
150	16.59	35.229
200	14.25	35.183
300	12.75	35.104
500	10.27	34.951

4.- The labelling of graphs.- Below, Fig. 1 represents the numerical values of Celsius temperature $\underline{t}$/°C in terms of depth expressed in meters, $\underline{Z}$/m. For the same reasons as for Table 11 we place the symbols $\underline{Z}$/m on the vertical axis and $\underline{t}$/°C on the horizontal one.

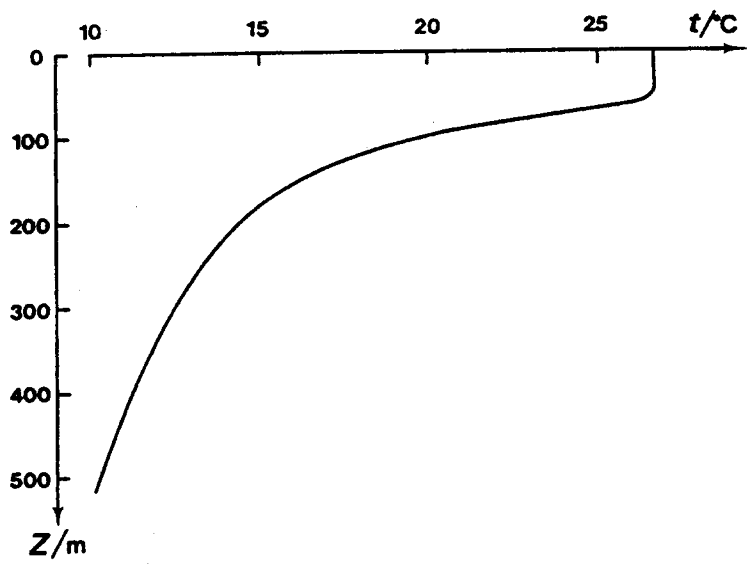

Fig. 1.- Celsius temperature in terms of depth at a hydrographical station

V.- NUMBERS

1.- Writing and printing of numbers.- Numbers should be printed in upright type.

The preferred decimal sign between digits in a number is a dot on the line (.). In French texts, a comma on the line (,) is used. Never use a centred dot (·) which could be used as a multiplication sign.

When the decimal sign is placed before the first digit of a number, a zero should always be placed before the decimal sign, e.g. :

0.037 72 not .037 72

2.- Writing and printing long numbers.- To facilitate the reading of long numbers, the digits may be grouped in threes about the decimal sign, but no point or comma should ever be used except for the decimal sign.

3 517. 175 27 0.001 37

Note : For a better understanding of this document, we have kept up the use of the dot on the line as a decimal sign.

VI - SPECIFIC RECOMMENDATIONS FOR THE FIELD OF PHYSICAL SCIENCES OF OCEAN

Two very important changes have been proposed in September 1980 in the field of Oceanographic Quantities and Symbols by the Joint Panel on Oceanographic Tables and Standards (JPOTS), a panel sponsored by Unesco, ICES, SCOR and IAPSO. These proposals then received the approval of the international oceanographic organizations. The following problems were concerned :

1) the definition of a new salinity, "Practical Salinity of 1978", as a function of conductivity, to replace the Salinity defined at the beginning of this century by Sörensen and Knudsen [12] as a function of chlorinity ;

2) a new "Equation of State of Sea Water of 1980", concerning in particular the quantities "density" and "specific volume" which are fundamental in dynamics.

1.- Chlorinity and salinity

These are two dimensionless quantities, the symbols of which are, respectively, $\underline{Cl}$ and $\underline{S}$.

1.1.- Recommendation. Until the IAPSO General Assembly in Canberra (December 1979), both chlorinity and salinity were expressed as "o/oo".

The IAPSO SUN-WG recommended in 1979 that the use of "o/oo" should be discouraged and replaced 10^{-3}.

At the same time, by analogy, the Working Group recommended that the use in general of symbols such as "%" (= 10^{-2}), "p.p.m." (= 10^{-6}), "ppM" and "ppb" (= 10^{-9}) should be abandonned and replaced by factor 10 raised to the corresponding power.

1.2.- Proposal for a new definition of chlorinity and salinity. In order to conform with the international rules regarding the SI, these quantities should be defined as the ratio of two masses. Moreover these masses must both be referred to the same unit.

1.3.- Definition of chlorinity. The definition is the one given by J.P. Jacobsen and M. Knudsen [11], slightly amended as follows :

> "the chlorinity of a sample of sea water, symbol Cl, represents 0.328 523 4 times the ratio of the mass of pure reference silver, "Atomsgewichtssilber", necessary to precipitate the halides contained in the sample of sea water to the mass of this sample".

1.4.- First definition of salinity. This definition was given in 1901 by Sörensen and Knudsen [12]. Salinity was defined as a conventional quantity as follows :

> "the Salinity of a sample of sea water, symbol S, represents the total mass of solid material dissolved in a sample of sea water divided by the mass of this sample, when all the carbonate has been converted into oxide, the bromine and iodine replaced by chlorine and all organic matter completely oxidized".

A direct determination of this quantity, thus defined, was however difficult and time-consuming and in practice, it was obtained indirectly by chlorinity, and later by electrical conductivity determinations.

1.5.- Standard sea water. One standard sea water, "Eau normale", the chlorinity of which deviates little from 19.375×10^{-3} and is known with the highest precision, serves as reference to obtain, by chemical titration and with a precision considered sufficient at the time, the chlorinity of any sample of sea water. This standard sea water is prepared and titrated by a specialised laboratory the IAPSO Standard Sea Water Service and then distributed in sealed ampulas throughout the world for the purpose of oceanographic research. Its mean chlorinity, 19.375×10^{-3}, corresponds to a salinity equal to 35.000×10^{-3}.

The passage from chlorinity to salinity is achieved with the help of a first order Cl polynomial.

1.6.- Second definition of salinity. When the salinometer had been developed, enabling salinity to be obtained by conductivity measurement both more quickly and with more precision, a second definition was adopted by the main International Organizations of Physical Oceanography, according to which the salinity of a sea water sample is derived from a fifth order polynomial in R_{15}, this last symbol designating the ratio of the electrical conductivity of the sample to that of a reference sample having a salinity equal to 35×10^{-3}, both conductivity measurements being made at 15 °C and under a pressure of one standard atmosphere [13].

In October 1966, the first edition of the International Oceanographic Tables was published jointly by Unesco and the National Institute of Oceanography of Great Britain, in which Table Ia presents a rapid calculation of salinity in terms of the measured value $\underline{R}_{15}$.

The technique for determining salinity, with the help of the salinometer and the new table, has been of great service to oceanographers by making measurements more convenient and more precise than before. However the definition of salinity on which it is based has created problems which are discussed fully in [17].

1.7.- Third definition of salinity. - Practical Salinity of 1978. During meetings held respectively in May 1977 at Woods Hole Oceanographic Institution,U.S.A. [14] and in September 1978 at Unesco [15], the Joint Panel on Oceanographic Tables and Standards (JPOTS) decided to launch some important work on the relationships existing between "electrical conductivity", "chlorinity", "salinity" (first and second definitions) and "density" of sea water, in the hope of arriving at a new highly reproducible and precise definition of salinity. At the same time a new and more precise Equation of State of sea water was to be developed. Measurements for these investigations have been made in at least two different laboratories, using different methods ; the results obtained in both instances coincide very closely.

Finally, at a meeting held by JPOTS from 1 to 5 September 1980 in Sidney, B.C., Canada [16], the terms of the definition of "Practical Salinity 1978" and the algorithm enabling its calculation at every temperature and pressure value over the oceanographic range of values, were adopted. All papers dealing with this question have been published in Unesco technical papers in marine science, n° 37, 1981 [17].

In the course of the same JPOTS meeting the "International Equation of State of Sea Water 1980" was adopted. All papers published on this topic have appeared in Unesco technical papers in marine science, 38, 1981 [18].

Lastly, Unesco has just published, as n° 39 of Unesco technical papers in marine science, 1981 [19], the third volume of the International Oceanographic Tables", first published in 1966 and re-edited in 1971.

This third volume of international oceanographic tables makes it possible to obtain practical salinity

- from the measured value of the conductivity ratio $\underline{R}_{15}$ and inversely,
- from the conductivity ratio $\underline{R}_t$ and inversely,

R_t being the ratio of the conductivity of sea water at temperature t to that of normal water at the same temperature. t can have any value between − 2 and 35 °C. It must be equal for both liquids, at a precision of ± 0.1 °C.

The full definition of the Practical Salinity 1978, for sea water is :

a) Absolute Salinity, symbol S_A, is defined as the ratio of mass of dissolved material in sea water to the mass of sea water. In practice, this quantity cannot be measured directly and a Practical Salinity is defined for reporting oceanographic observations.

b) The Practical Salinity, symbol S, of a sample of sea water, is defined in terms of the ratio K_{15} of the electrical conductivity of the seawater sample at the temperature of 15 °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

$$\begin{aligned} a_0 &= 0.008\ 0 \\ a_1 &= -\ 0.169\ 2 \\ a_2 &= 25.385\ 1 \\ a_3 &= 14.094\ 1 \\ a_4 &= -\ 7.026\ 1 \\ a_5 &= 2.708\ 1 \\ \Sigma a_i &= 35.000\ 0 \end{aligned}$$

$$2 < S < 42$$

This equation is valid for a Practical Salinity S from 2 to 42.

This quantity has only one symbol, S, and for a considerable time it should be called "practical salinity" in full, and not "salinity". However, once all possibility of confusion has disappeared, after a sufficient lapse of time, or when it becomes quite clear from the text that practical salinity is concerned, it will be quite acceptable to speak simply of "salinity".

As a consequence of the definition, any oceanic water having a precisely known conductivity ratio of near unity at 15 °C with the KCl solution can be secondary standard for routine calibration of oceanographic instruments. However it is not recommended that individual laboratories prepare secondary standards directly against the KCl. On the contrary, the use of Standard Sea Water now calibrated additionally with its conductivity ratio is strongly recommended. 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.

It will be noticed that when calculating Practical Salinity with the help of the definition equation (1) above, the values obtained are 1 000 times greater in comparison with those calculated with the help of former definitions (salinity in terms of chlorinity).

In fact the definition of Practical Salinity was obtained in two stages. At the first stage, Practical Salinity was defined by the equation (1), in which the left hand side ($\underline{S}$ =) was multiplied by 10^3, ($\underline{S} \times 10^3 = \ldots\ldots$), and the value of $\underline{K}_{15}$ exactly equal to 1 corresponded to a Practical Salinity exactly equal to 35×10^{-3}. The values obtained were thus of the same order of magnitude as those obtained with the help of the former definitions. A typical value of Practical Salinity was, for instance, 0.035 123 or 35.123×10^{-3}. As the same factor 10^{-3} was attributed to all these numerical values of Practical Salinity, it was decided, at the second stage, that for convenience sake this factor should purely and simply be eliminated. Instead of writing in the above example, $\underline{S} = 35.123 \times 10^{-3}$, we shall simply write $\underline{S} = 35.123$, a value 1 000 times greater. We have then, as definition equation, equation (1) in which the factor 10^3 has disappeared from the left hand side.

If a comparison is to be made between the values obtained, for the same sample of seawater, from Practical Salinity, Salinity deduced from Chlorinity and Absolute Salinity, it will be necessary to begin by dividing by 1 000 the value of Practical Salinity. The high numerical value attributed to this new Salinity will, moreover, have the advantage of avoiding all possibility of confusion in future between Practical Salinity and those preceding it.

Finally, it should be remembered that when passing to Practical Salinity, the mean value for Standard Sea Water passes from 35×10^{-3} to 35.

It will be noticed that the Practical Salinity being the ratio of two electrical conductivities, its unit is "dimensionless" and it may be expressed by the number 1.

The Practical Salinity of Sea Water 1978, as well as the Equation of State of Sea Water 1980 have both been endorsed by the main Physical Oceanographic Organizations throughout the world.

2.- Temperature

2.1.- Problems of symbols. The international symbols for temperature are T for thermodynamic temperature and t for Celsius temperature [10]. t is also the only symbol for "time". Now it could happen that both Celsius temperature and time are found in the same text, or even in the same formula. It is recommended therefore to attribute to Celsius temperature, in addition to t, a second symbol θ (lower case theta), t always remaining the unique symbol for time. Thus, when time and Celsius temperature both appear in the same text, we shall use t for time and θ for temperature. When only one of these quantities appears in a text, this quantity, whether time or Celsius temperature will be represented by t.

2.2.- Table of temperature.- Order : quantity, recommended symbol(s) of the quantity, SI unit, symbol of this unit.

Thermodynamic temperature, T, kelvin, K.
Celsius temperature, t, θ, degree Celsius, °C.
International Practical Kelvin temperature, T, kelvin, K.
International Practical Celsius temperature, t, degree Celsius, °C.
Interval, difference of temperature, Δt, ΔT, $\Delta \theta$, kelvin or degree Celsius, K or °C.
Potential (Celsius) temperature, Θ (capital theta), degree Celsius, °C.

2.3.- In physical oceanography, potential temperature is expressed in degree Celsius only. It is proposed that the symbol Θ (capital theta) should be attributed to it. Potential thermodynamic temperature does not seem to present any interest, its difference from potential Celsius temperature being constant.

$$T \text{ (potential)} - \Theta = T_0 = 273.15 \text{ K.}$$

2.4.- Note. In temperature-practical salinity diagrams, where Celsius temperature is used, T must be replaced by t.

3.- Pressure

Symbol p, SI unit pascal, Pa, recommended unit (for dynamics) MPa, megapascal.

3.1.- Several terms are used in measurements of pressure :

a) atmospheric pressure, symbol $\underline{p}_a$. This quantity varies in time and space over the oceanic surface.

b) standard pressure or standard atmosphere, symbol $\underline{p}^{\circ}$, standard value for atmospheric pressure

$$\underline{p}^{\circ} = 101\ 325 \text{ Pa exactly.}$$

c) pressure, symbol $\underline{p}$, is the total pressure at one point of the ocean.

d) sea pressure, symbol $\underline{p}_s$, excess of total pressure at one point of the ocean over the atmosphere pressure at the vertical sea surface point.

$$\underline{p}_s = \underline{p} - \underline{p}_a$$

At sea surface, $\underline{p}_s = 0$.

3.2.- Only the pascal and its decimal multiples, formed by means of SI prefixes, should be used as pressure unit. For sea pressure the megapascal is recommended.

The "bar" (see Table 9) and its decimal multiples, the decibar in particular, should be abandoned as soon as possible.

The "atmosphere" or "standard atmosphere" (see Table 10), symbol "atm", should no longer be used as pressure unit.

This term could, nevertheless, be kept to represent the standard pressure of 101 325 Pa. This is very convenient for stating, for example, that some data are related to this standard pressure. We should write, for instance :

"$\underline{\rho}_{max}$ represents the maximal density in terms of temperature of the water free from dissolved atmospheric gases under the standard pressure of 101 325 Pa (one standard atmosphere)".

4.- Density, specific gravity, specific volume

4.1.- Terminology. In the past there has been some confusion in oceanographic literature between the two quantities relating to sea/pure water, "density" (mass divided by volume) and "specific gravity" (the ratio of the density of a sea/pure water sample to that of a reference pure water). The "specific volume" was also often calculated as the reciprocal "specific gravity". The English equivalent for the French word "densité" was moreover "specific gravity" :

a) <u>density</u>, symbol $\underline{\rho}$. The term "density" is chosen to represent the quantity mass divided by volume. Unit : kilogram per cubic metre, symbol : $kg.m^{-3}$.

French translation : "masse volumique".

b) <u>relative density</u>, symbol $\underline{d}$, dimensionless, means the ratio of the density of a substance under stated physical conditions to that of pure water at 4 °C, free of dissolved atmospheric gases, under a pressure of 101 325 Pa (standard pressure).

Recommended French translation : "densité relative".

c) <u>specific volume</u>, symbols $\underline{\alpha}$, $\underline{v}$, means volume divided by mass.

$$\underline{\alpha} = 1/\underline{\rho} \text{ (not } 1/\underline{d}\text{)}.$$

Unit : cubic metre per kilogram, symbol m^3/kg.

French translation : "volume massique".

4.2.- <u>Recommendations</u>

4.2.1.- It is recommended that the concept of relative density should be abandoned once and for all and that in future only density of sea/pure water, expressed in kilograms per cubic metre should be used exclusively.

4.2.2.- To calculate density of sea/pure water and its related parameters, it is recommended that only pressure, not depth, be used.

4.3.- <u>Terms of variation of density of sea water</u>. Sea water density varies in terms of the following five quantities :

1) practical salinity, 2) temperature, 3) pressure, 4) isotopic composition and 5) dissolved atmospheric gases content.

But its isotopic composition is practically constant for the whole world ocean, and the density is generally observed in a saturation condition in dissolved atmospheric gases. Thus, at least for very high precision determinations, sea water varies in terms of only three of the main quantities : 1) practical salinity, 2) temperature, 3) pressure. By international agreement numerical values of sea water density in terms of practical salinity, temperature and pressure are calculated from the International Equation of State of Sea Water, 1980. (See : <u>Unesco technical papers in marine science</u>, n° 38, 1981. [18]).

4.4.- Reference values for sea/pure water density. The density corresponding to standard or reference conditions may be represented by ρ°. Those corresponding to the maximum density (in terms of temperature) may be represented by ρ_{max} or $\rho(max)$.

4.5.- New recommended reference liquids for density determination. This is the SMOW (Standard Mean Ocean Water), which is distilled oceanic water stored at and distributed by the International Atomic Energy Agency (IAEA). Its isotopic composition is perfectly known and its maximum density value is :

$$\rho^\circ = \rho_{max}\ (\text{SMOW}) = (999.975 + \varepsilon)\ \text{kg.m}^{-3}.$$

where 999.975 kg.m^{-3} is the provisional value adopted for ρ° and ε kg.m^{-3}, the correction to be added once its international high level determination, now in process, has been completed. ε should not exceed, in absolute value, 3×10^{-3} [20].

4.5.1.- Notation rules. The following rules proposed for density ρ should also be applied to other quantities which are function of the three main parameters : 1) practical salinity, 2) temperature, 3) pressure, as for example : specific volume, steric anomaly, electrical conductivity ...

a) To state that such a quantity is given in terms of the three main parameters : practical salinity, temperature, pressure, symbols and/or values of these parameters may be indicated in parentheses, after the symbol ρ in the following compulsory order : S, t, p.

Subscripts should be avoided.

Thus we should write :

$\rho(S, t, p)$ or $\rho(35.12, 3.52\ °\text{C}, 18.80\ \text{MPa})$.

in preference to :

$\rho_{S,\ t,\ p}$ or $\rho_{35.12,\ 3.52\ °\text{C},\ 18.80\ \text{MPa}}$.

b) When values are used, the corresponding units should be indicated.

c) Symbols and/or values should be separated by commas, when the decimal sign is a point, and reciprocally.

d) The three parameters can be represented partly by symbol(s), partly by value(s) :

$$\rho(S, 3.52\ °C, 18.80\ MPa).$$

e) In this notation system the use of the following units is strongly recommended : kilogram per cubic metre ($kg.m^{-3}$) for density, degree Celsius (°C) for temperature, megapascal (MPa) for pressure.

f) Provided that values are written in the recommended order : S, t, p, and expressed only with the aforesaid units, these units need not be mentioned.

We may write for example :

$$\rho(35.12, 3.52, 28.80)$$

for a sea water of practical salinity 35.12, temperature 3.52 °C and a pressure of 28.80 MPa.

N.B. - Regarding density (and related parameters such as specific volume), pure water cannot always be considered as a sea water having a nil salinity. The use of the above notation is recommended, but for sea water only, never for pure water (for which $S = 0$).

4.6.- Abbreviated representation.

4.6.1.- Representation of density. The values of density of sea water, expressed in kilograms per cubic metre, with an accuracy of 1×10^{-3} may consist of six or seven significant digits. In writing, this can be simplified with the help of two parameters.

a) Knudsen's parameter, σ (σ_t for sea surface water). This corresponds to relative density :

For example if $d = \rho/\rho max = 1.028\ 723$,

we wish to obtain an abbreviated value, but as precise as this density. By writing :

$$\sigma = (d - 1) \times 10^3 = 28.723$$

we reduce this value to a number with only three decimals, which is more convenient.

b) Recent parameter, γ.

Here we start with the numerical value of density.

$$\rho = 1\ 029.725\ kg.m^{-3}$$

which is abbreviated as follows :

$$\underline{\gamma} = \underline{\rho} - 1\ 000\ \mathrm{kg.m^{-3}} = 29.725\ \mathrm{kg.m^{-3}}$$

which is undoubtedly more convenient. It is clearly distinguishable from $\underline{\sigma}$ by having unit $\mathrm{kg.m^{-3}}$.

c) It is recommended that the use of $\underline{\sigma}$ be given up in favour of the symbol $\underline{\gamma}$ related to the idea of density. In case this symbol $\underline{\gamma}$ has already been employed in the text, any other symbol may be used, but its meaning must be explicitly stated.

4.6.2.- Specific volume anomaly (abbreviated value), symbol $\underline{\delta}$ or $\underline{\delta}(\underline{S}, \underline{t}, \underline{p})$. "Steric anomaly" is recommended as an alternative name.

$\underline{\delta} = \underline{\alpha}(\underline{S}, \underline{t}, \underline{p}) - \underline{\alpha}(35.0, 0, \underline{p})$ with

$\underline{\alpha}(\underline{S}, \underline{t}, \underline{p})$ is specific volume in situ of the given sample of sea water.

$\underline{\alpha}(35.0, 0, \underline{p})$ is that of a reference sea water of practical salinity 35.0, temperature 0 °C, and the same pressure.

4.6.3.- Thermosteric anomaly, symbol $\underline{\Delta}$ or $\underline{\Delta}(\underline{S}, \underline{t})$. This term represents the steric anomaly, but with sea pressure set equal to zero.

5.- Geopotential

It is recommended that the terminology "dynamic height" and "dynamic depth", the symbol $\underline{D}$ and the unit "dynamic metre" be abandoned and only the words "geopotential", "geopotential difference", "equipotential surface" be used.

The geopotential unit will be m^2/s^2 = J/kg without any particular name.

6.- Special name for SI oceanographic units

To encourage standardization of the spoken and written scientific language, no unit of an oceanographic character should receive a special name, unfamiliar to scientists in other disciplines. Such a name should first of all be sanctioned by the Conférence Générale des Poids et Mesures (General Conference of Weights and Measures) and appear in the table of "SI units having a special name", distributed by the Bureau International des Poids et Mesures.

In accordance with these principles, the words "sverdrup" and "langley" recently proposed should not be used.

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PART II

TABLES OF QUANTITIES, UNITS AND SYMBOLS IN VARIOUS DIVISIONS OF THE PHYSICAL SCIENCES OF THE OCEAN

Column 1 : Quantity
Column 2 : Symbol(s) of the quantity
Column 3 : Definition of the quantity and remarks
Column 4 : SI unit, symbol
Column 5 : Recommended unit

Column 1.- For certain quantities the French term is mentioned, preceded by "F", after the English term.

Column 2.- For each quantity, one or more principal symbol(s) is/are proposed without any distinction between them. They are, then, on an equal footing.

These principal symbols may be followed by one or more alternative symbol(s), grouped in parentheses. As far as possible, the use of a principal symbol is preferable.

Column 3.- Definition of the quantity is given only when needed. The brief definition is intended to identify the quantity clearly.

Column 4.- The symbol 1 is assigned, as SI unit, to non-dimensional quantities.

Column 5.- This column is introduced as appropriate (in Table II.5 - Marine Geophysics), to indicate a recommended unit. In certain cases, recommended units are given in Column 4.

TABLE II.1

FUNDAMENTAL QUANTITIES OF SEA WATER

Prepared by M. MENACHÉ

Revised by G. GIRARD

Quantity	Symbol	Definition and remarks	SI unit, symbol
Thermodynamic temperature	$\underline{T}$		kelvin, K
Celsius temperature	$\underline{t}$, $\underline{\theta}$	$\underline{t} = \underline{T} - \underline{T}_0$ where $\underline{T}_0$ = 273.15 K by definition. $\underline{T}$ and $\underline{t}$ are the respective international symbols for thermodynamic temperature and Celsius temperature. $\underline{t}$ being also the generally agreed symbol for time, $\underline{\theta}$ is proposed as alternative symbol for Celsius temperature. Thus, when both time and temperature appear in a text, $\underline{t}$ should symbolize time and $\underline{\theta}$, Celsius temperature. When only one of these two quantities appears in a text, this quantity, whether time or Celsius temperature, will be symbolized by $\underline{t}$.	
International Practical Kelvin temperature	$\underline{T}_{68}$	Temperature given by the International Practical Temperature Scale of 1968 (IPTS-68). It is now the best approximation of the thermodynamic temperature.	kelvin, K
International Practical Celsius temperature	$\underline{t}_{68}$	Celsius temperature given by the IPTS-68 $\underline{t}_{68} = \underline{T}_{68} - 273.15$ K	degree Celsius, °C

Quantity	Symbol	Definition and remarks	SI unit, symbol
Interval, difference of temperature	$\Delta \underline{T}$, $\Delta \underline{t}$		kelvin, K or degree Celsius, °C
Potential (Celsius) temperature	$\underline{\theta}$	N.B.- Potential Kelvin temperature is rarely used in physical oceanography.	degree Celsius, °C
Pressure	$\underline{p}$	Total pressure at a point of the ocean. Recommended unit	pascal, Pa MPa
Atmospheric pressure	$\underline{p}_a$		pascal, Pa
Standard (or reference) pressure, 1 standard atmosphere F. pression normale (ou de référence), 1 atmosphère normale	$\underline{p}^{\circ}$	$\underline{p}^{\circ}$ = 101 325 Pa exactly Remark 1.- The use of terms "atmosphere", or "standard atmosphere" as unit of pressure (with the symbol "atm") is strongly discouraged (see table 10, part I). Remark 2.- Standard atmosphere is generally used as synonymous of standard pressure, for definition of certain fundamental oceanographic quantities (such as practical salinity, density, ...), definitions which need the greatest possible accuracy.	pascal, Pa

Quantity	Symbol	Definition and remarks	SI unit, symbol
Sea pressure	$\underline{p}_s$	Excess of total pressure at a point of the ocean over the atmospheric pressure at the vertical sea surface point : $\underline{p}_s = \underline{p} - \underline{p}_a$	pascal, Pa
		Recommended unit	MPa
		Remark 1.- For sea surface we have : sea pressure = 0 total pressure = $\underline{p} = \underline{p}_a$	
Chlorinity	$\underline{Cl}$	See VI. 1, p. 40.	1
Absolute Salinity, 1978	$\underline{S}_A$	See definition, VI, 1.7, p. 43.	1
Practical Salinity, 1978	$\underline{S}$	See definition, VI, 1.7, p. 43. Note.- Numerical values of Practical Salinity are ranged from 2 to 42.	1
Electrical resistivity	$\underline{\rho}$		ohm.metre, Ω.m
Electrical conductivity	$\underline{C}, \underline{\gamma}$	$\underline{C} = \underline{\rho}^{-1}$, where $\underline{\rho}$ is electrical resistivity.	siemens per metre, $S.m^{-1} = \Omega^{-1}.m^{-1}$
Electrical conductivity of sea water as a function of practical salinity, temperature, sea pressure	$\underline{C}(\underline{S},\underline{t},\underline{p})$	Conductivity of a sea water sample having Practical Salinity, $\underline{S}$, temperature $\underline{t}$, at sea pressure $\underline{p}_s$.	$\Omega^{-1}.m^{-1}$

Quantity	Symbol	Definition and remarks	SI unit, symbol
		This kind of representation is valid with the same rules for any oceanographical quantity which is a function of the three main parameters : Practical Salinity, temperature, pressure. For detailed rules for simplifying this system of notation, see VI, 4.5.1, Notation rules, p. 48.	
	$\underline{K}_{15}$	Ratio of the conductivity of a sample of sea water to that of a Reference Potassium Chloride (KCl) solution, in which the mass fraction of KCl is 32.435 6 × 10^{-3}, both conductivities being measured at the same temperature 15 °C and the standard pressure $\underline{p}^{\circ}$ = 101 325 Pa. Very high precision measurements of $\underline{K}_{15}$, obtained with the help of the reference KCl solution, served as a basis for the definition of Practical Salinity in terms of the ratio $\underline{K}_{15}$, for $2 < \underline{S} < 42$.	1
Conductivity Ratio for sea water at 15 °C	$\underline{R}_{15}$	$\underline{R}_{15} = \underline{C}(\underline{S}, 15, 0)/\underline{C}(35, 15, 0)$ Ratio of the conductivity of a sample of sea water of which Practical Salinity $\underline{S}$ is to be determined, to that of a standard sea water (or a second sea water sample), having Practical Salinity equal (or corrected) to 35, both conductivities being measured at 15 °C and standard pressure.	1

Quantity	Symbol	Definition and remarks	SI unit, symbol
		The conductivity ratio $\underline{R}_{15}$ is used above all for routine measurements carried out with the help of laboratory salinometers maintained at a constant temperature (15 ± 0.002) °C, the atmospheric pressure being supposed constant. According to the definition of Practical Salinity, for a Practical Salinity exactly equal to 35, we have $\underline{K}_{15} = \underline{R}_{15} = 1$. It suffices therefore, in the definition equation (1) to replace $\underline{K}_{15}$ by $\underline{R}_{15}$ to obtain Practical Salinity in terms of $\underline{R}_{15}$. Conversion of $\underline{R}_{15}$ to Practical Salinity is obtained by the International Oceanographic Tables, vol. 3, <u>Unesco technical papers in marine science</u>, n° 39, Unesco, 1981 (tables Ia and Ib).	
Conductivity Ratio at temperature $\underline{t}$	$\underline{R}_{\underline{t}}$	$\underline{R}_{\underline{t}} = \underline{C}(\underline{S}, \underline{t}, 0)/\underline{C}(35, \underline{t}, 0)$. Ratio of the conductivity of a sea water sample of Practical Salinity $\underline{S}$ to be determined, to that of a standard sea water (or a second water sample) for which Practical Salinity is equal	1

Quantity	Symbol	Definition and remarks	SI unit, symbol
		(or corrected) to 35, both conductivities being measured at the same temperature *t* and standard pressure. R_t is generally used for Practical Salinity measurements in the laboratory with salinometers maintained at any temperature *t* constant to ± 0.002 K. Conversion of R_t to Practical Salinity is obtained by the International Oceanographic Tables, vol. 3, *Unesco technical papers in marine science*, n° 39, Unesco 1981, (tables Ia, Ib, IIa, IIb). R_t is also used for calculation of Practical Salinity from *in situ* measurements.	
in situ conductivity ratio	R	$R = C(\text{in situ}, p)/C(35, 15, 0)$ Ratio of the *in situ* electrical conductivity of sea water at sea pressure p_s, to the conductivity of a standard sea water (or a second sea water) having Practical Salinity equal (or corrected) to 35.000 at temperature of (15 ± 0.002) °C at sea pressure nil.	1

Quantity	Symbol	Definition and remarks	SI unit, symbol
	R_p	$R_p = C(\text{in situ}, p)/C(S, t, 0)$ Ratio of the in situ conductivity, at sea pressure p_s of a sea water sample, to the conductivity of the same sample at the same temperature, but at sea pressure nil. Formulas for the calculation of R_p in terms of p, t and R, are given in Unesco technical papers in marine science, n° 37, p. 142.	1
	r_t	$r_t = C(35, t, 0)/C(35, 15, 0)$ Ratio of the conductivity of a reference sea water having a Practical Salinity of 35, at temperature t and sea pressure nil, to its conductivity at 15 °C and the same sea pressure nil. Formulas for the calculation of r_t in terms of t are given in the Unesco technical papers in marine science, n° 37, p. 142-143. Calculation of Practical Salinity For a given sea water sample the following formula : $R = R_t\ R_p\ r_t$	1

Quantity	Symbol	Definition and remarks	SI unit, symbol
		allows the calculation of $\underline{R_t}$, which in turn is converted into Practical Salinity by the help of the *International Oceanographic Tables*, vol. 3, mentioned above. Usually the CTD (conductivity, temperature, depth) cell is equipped with a computer for calculating the values of Practical Salinity and temperature in terms of the depth.	

TABLE II.2

PHYSICAL PROPERTIES OF PURE AND SEA WATER

Prepared by M. MENACHÉ

Revised by G. GIRARD

Quantity	Symbol	Definition and remarks	SI unit, symbol
Density, (mass, absolute density) (F. masse volumique)	$\underline{\rho}$	mass divided by volume. Remark.- Density of sea water varies in terms of the 5 following quantities : 1) Practical salinity ; 2) temperature ; 3) pressure ; 4) isotopic composition and 5) dissolved atmospheric gas content. For sea water, isotopic composition is practically constant for the whole World Ocean and density is generally observed at the condition of saturation in dissolved atmospheric gases. Thus sea water varies in terms of only three of the main quantities : 1) Practical salinity ; 2) temperature ; 3) pressure. By international agreement, numerical values of sea water density in terms of Practical salinity, temperature, pressure are calculated from the "International Equation of State of Sea Water, 1980". See Unesco technical papers in marine science, n° 38, 1981.	$kg.m^{-3}$
Density of sea water as a function of Practical salinity, temperature, pressure	$\underline{\rho}(\underline{S},\underline{t},\underline{p})$	This kind of representation is valid with the same rules for any oceanographical quantity which is a function of the three main parameters : 1) Practical salinity, 2) temperature, 3) pressure.	$kg.m^{-3}$

Quantity	Symbol	Definition and remarks	SI unit, symbol
		For detailed rules for simplifying this system of notation, see VI, 4.5.1., Notation rules, p. 48.	
Maximum density of pure water	$\rho(max)$, ρ_{max}	Maximum value in terms of temperature of the density of a pure water sample for given values of isotopic composition, pressure and dissolved atmospheric gas content.	$kg.m^{-3}$
Temperature of maximum density	$t(max)$, t_{max}	For pure water, $t(max) = (3.98_5 \pm 0.00_5)$ °C	°C
Relative density (F. densité relative)	d	$d = \rho/\rho'$ ρ being the density of a sea/pure water, and ρ' that of reference liquid, under conditions that should be specified for both liquids. For most data available on sea/pure water, relative density corresponds to $\rho' = \rho_{max}(BIPM) = 999.972\ kg.m^{-3}$. This is the average result of several series of high level precision determinations carried out at the beginning of this century on a bidistilled BIPM (Bureau International des Poids et Mesures) tap water, the isotopic composition of which is unknown, free of dissolved gases, at the standard pressure of 101 325 Pa. At that time, isotopes had not yet been discovered.	1

Quantity	Symbol	Definition and remarks	SI unit, symbol
		This particular value, which is not linked to a well-defined isotopic composition, is of no more interest and could be considered obsolete. Even the use of relative density is no longer recommended.	
New reference value for sea/pure water density determination	$\underline{\rho}°$, $\underline{\rho}_{max}$(SMOW)	SMOW (Standard Mean Ocean Water) is the newly accepted reference liquid for water density determination. It is distilled oceanic water, stored at and distributed by the International Atomic Energy Agency (IAEA), having the following characteristics : (D/H) (SMOW) = $(155.76 \pm 0.05)10^{-6}$ $(^{18}O/^{16}O)$(SMOW) = $(2\ 005.20 \pm 0.45)10^{-6}$ $\underline{\rho}_{max}$(SMOW) = $\underline{\rho}°$ = $(999.975 + \underline{\varepsilon})kg.m^{-3}$, where 999.975 $kg.m^{-3}$ is the provisional value adopted for $\underline{\rho}°$, and $\underline{\varepsilon}$ $kg.m^{-3}$ the correction to be added once its international high level determination, now in process, has been completed. $\underline{\varepsilon}$ should not exceed, in absolute value, 3×10^{-3}. (See Recommended reference materials for realization of physico-chemical properties, section density. Pure and applied chemistry, 45, 1976, p. 1-9).	$kg.m^{-3}$

Quantity	Symbol	Definition and remarks	SI unit, symbol
Knudsen's parameter for sea water relative density, relative density excess (F. excès de densité relative)	σ	$\sigma = (d - 1) \times 10^3$ with $d = \rho/\rho_{max}(\mathrm{BIPM}) = \rho/(999.972\ \mathrm{kg.m^{-3}})$ The parameter σ also represents the numerical value of the density difference $(\rho - \rho_{max}(\mathrm{BIPM}))$ $\sigma = \rho/(\mathrm{kg.m^{-3}}) - 999.972$. The use of this parameter, σ, is no longer recommended.	1
Knudsen's parameter of sea surface water relative density	σ_t	σ_t represents the parameter σ applied to a sea surface water, the temperature of which is t. The use of this parameter, σ_t, is strongly discouraged.	1
Density excess. (F. excès de masse volumique)	γ	$\gamma = \rho - 1000\ \mathrm{kg.m^{-3}}$. The use of γ instead of σ is recommended.	$\mathrm{kg.m^{-3}}$
Specific volume (F. volume massique)	α, (v)	$\alpha = 1/\rho$	$\mathrm{m^3.kg^{-1}}$
Specific volume anomaly, steric anomaly (F. anomalie de volume massique)	δ	$\delta = \alpha - \alpha°$ where α is specific volume of a sample of sea water and $\alpha°$, that of a reference sea water clearly stated.	$\mathrm{m^3.kg^{-1}}$

Quantity	Symbol	Definition and remarks	SI unit, symbol
Thermosteric anomaly (F. anomalie thermostérique)	$\Delta(S,t)$	This quantity represents the steric anomaly, but with the sea pressure set equal to zero.	$m^3.kg^{-1}$
Cubic thermal expansion coefficient, thermal expansibility	α_V	$\alpha_V = (1/V)\ dV/dT$ (V = volume)	K^{-1}
Relative pressure coefficient (F. coefficient de pression relative)	α_p	$\alpha_p = (1/p)\ dp/dT$ (p = pressure)	K^{-1}
Compressibility	κ	$\kappa = (-1/V)dV/dp$	Pa^{-1}
Coefficient of friction (F. coefficient de frottement, facteur de frottement)	μ, (f)	Ratio of frictional force to normal force, for a sliding body.	1
Surface tension (F. tension superficielle)	γ, (σ)	Force perpendicular to a line element in a surface divided by the length of the line element.	$N.m^{-1}$
Viscosity, (dynamic viscosity)	η, (μ)	$\tau_{x,z} = \eta dv/dz$ where $\tau_{x,z}$ is the shear stress in sea water moving with a velocity gradient dv/dz perpendicular to the plane of shear. $v_z = 0$ for laminar flow.	Pa.s

Quantity	Symbol	Definition and remarks	SI unit, symbol
Kinematic viscosity	$\underline{v}$	$\underline{v} = \underline{\eta}/\underline{\rho}$ where $\underline{\eta}$ is dynamic viscosity and $\underline{\rho}$ density.	$m^2.s^{-1}$
Heat flow rate (F. flux thermique)	$\underline{\Phi}$	Rate of heat flow across a surface.	W
Density of heat flow rate (F. densité de flux thermique)	$\underline{q}$, ϕ	Heat flow rate divided by area.	$W.m^{-2}$
Thermal conductivity (F. conductivité thermique)	$\underline{\lambda}$, $\underline{k}$	Density of heat flow rate divided by temperature gradient.	$W.m^{-1}.K^{-1}$
Coefficient of heat transfer (F. coefficient de transmission thermique)	$\underline{h}$,($\underline{K}$)	Density of heat flow rate divided by temperature difference.	$W.m^{-2}.K^{-1}$
Thermal insulance (F. isolation thermique)	$\underline{M}$	Temperature difference divided by density of heat flow rate.	$m^2.K.W^{-1}$
Thermal resistance	$\underline{R}$	Temperature difference divided by heat flow rate.	$K.W^{-1}$
Thermal conductance (F. conductance thermique)	$\underline{G}$	$\underline{G} = 1/\underline{R}$	$W.K^{-1}$

Quantity	Symbol	Definition and remarks	SI unit, symbol
Heat capacity (F. capacité thermique)	C	$C = dQ/dT$ when an increase dQ of heat leads to an increase dT of temperature.	$J.K^{-1}$
Specific heat capacity (F. chaleur massique, capacité thermique massique)	c	Heat capacity divided by mass.	$J.kg^{-1}.K^{-1}$
Specific heat capacity at :			
constant pressure	c_p		$J.kg^{-1}\ K^{-1}$
constant volume	c_V		$J.kg^{-1}\ K^{-1}$
saturation	c_s		$J.kg^{-1}\ K^{-1}$
Molar heat capacity	C_m	Heat capacity divided by amount of substance.	$J\ K^{-1}mol^{-1}$
Thermal diffusity (F. diffusité thermique)	a, (α, k)	$a = \lambda/\rho\ c_p$ where λ is thermal conductivity, ρ density and c_p specific heat capacity at constant pressure.	$m^2.s^{-1}$
Electric resistance (to direct current)	R	Electric potential difference divided by current when there is no electromotive force in the conductor.	$\Omega = V.A^{-1}$

Quantity	Symbol	Definition and remarks	SI unit, symbol
Electric conductance (to direct current)	$\underline{G}$	$\underline{G} = 1/\underline{R}$	$S = \Omega^{-1}$
Refractive index	$\underline{n}$		1
Velocity of sound (in sea water) (F. vitesse du son (dans l'eau de mer))	$\underline{c}$		$m.s^{-1}$

TABLE II.3

DYNAMICAL OCEANOGRAPHY

Prepared by B. SAINT-GUILY

Revised by J. GONELLA

Quantity	Symbol	Definition and remarks	SI unit, symbol
Velocity	v,u,w,c	length divided by time.	$m.s^{-1}$
Acceleration	a	velocity divided by time squared.	$m.s^{-2}$
Density (F. masse volumique)	ρ	mass divided by volume.	$kg.m^{-3}$
Specific volume (F. volume massique)	α,v	volume divided by mass.	$m^3.kg^{-1}$
Momentum (F. quantité de mouvement)	q	mass multiplied by velocity.	$m.kg.s^{-1}$
Force	F	mass multiplied by acceleration.	newton, N (1 N = 1 $m.kg.s^{-2}$)
Pressure	p	force divided by area.	pascal, Pa (1 Pa = 1 $N.m^{-2}$ = 1 $m^{-1}.kg.s^{-2}$)
Normal stress (F. contrainte ou tension normale)	σ	force divided by area.	Pa
Shear stress (F. contrainte ou tension tangentielle)	τ	force divided by area.	Pa
Energy, work, heat	E,W,(A) Q	Force multiplied by displacement in the direction of the force.	joule, J (1 J = 1 N.m)

Quantity	Symbol	Definition and remarks	SI unit, symbol
Potential energy	E_p, V, Φ		J
Kinetic energy	E_k, K		J
Power	P	energy divided by time.	watt, W (1 W = 1 $J.s^{-1}$)
Mass flow rate (F. débit-masse)	q_m	Mass crossing a surface divided by time	$kg.s^{-1}$
Volume flow rate (F. débit-volume)	q_V	Volume crossing a surface divided by time	$m^3.s^{-1}$
(dynamic) Viscosity	η, (μ)	Shear stress divided by velocity gradient	Pa.s
Kinematic viscosity	ν	Dynamic viscosity divided by density	$m^2.s^{-1}$
Frequency	ν	Number of cycles divided by time	hertz, Hz (1 Hz = 1 s^{-1})
Angular velocity	ω, Ω	$\omega = d\theta/dt$ where θ = plane angle (radian)	s^{-1}
Compressibility	κ	$\kappa = (1/V)\ (dV/dp)$ where V = volume ; p = pressure	Pa^{-1}
Coriolis parameter	f	$f = 2\ \omega \sin \phi$ where ω = angular velocity of the earth rotation, ϕ = latitude	s^{-1}

Quantity	Symbol	Definition and remarks	SI unit, symbol
Rossby number	R_o	$R_o = U/f.l$ where U = velocity of a current f = Coriolis parameter l = horizontal length	1
Ekman number	E	$E = \nu/f.h^2$ where ν = kinematic viscosity f = Coriolis parameter h = vertical length	1
Specific volume anomaly	δ	$\delta = \alpha(S,t,p) - \alpha(35,0,p)$ where $\alpha(S,t,p)$ = specific volume of a sea water sample having salinity S, temperature t and pressure p ; and, $\alpha(35,0,p)$ = those of a reference sea water having S = 35, t = 0 °C and the same value of p	$m^3.kg^{-1}$
Geopotential	Φ	(potential) energy divided by mass	$m^2.s^{-2}$ (= $J.kg^{-1}$)
Equipotential surface		Surface of constant geopotential	
Geopotential distance	$\Delta\Phi$	Geopotential difference between two geometric levels (assuming hydrostatic pressure)	$m^2.s^{-2}$
Standard geopotential distance (F. distance géopotentielle normale)	$\Delta\Phi_s$	$\Delta\Phi_s = \int_{p_1}^{p_2} \alpha(35,0,p)\, dp$ p_1 and p_2 being 2 isobaric surfaces (assuming hydrostatic pressure)	$m^2.s^{-2}$

Quantity	Symbol	Definition and remarks	SI unit, symbol
Geopotential anomaly	$\underline{D}$	$\underline{D} = \int_{\underline{p}_1}^{\underline{p}_2} \underline{\delta}\, d\underline{p}$ (assuming hydrostatic pressure)	$m^2.s^{-2}$
Vorticity (F. tourbillon)	$\underline{\zeta}$	Curl of velocity	s^{-1}
Absolute vorticity	$\underline{\zeta}_a$	$\underline{\zeta}_a = \underline{\zeta} + \underline{f}$ where $\underline{\zeta}$ = vertical component of vorticity $\underline{f}$ = Coriolis parameter	s^{-1}
Potential vorticity	$\underline{\zeta}_p$	Absolute vorticity divided by the thickness of the fluid layer $\underline{\zeta}_p = \underline{\zeta}_a/\underline{h}$	$m^{-1}.s^{-1}$
Adiabatic temperature gradient	$\underline{\Gamma}$	$\underline{\Gamma} = \underline{\alpha}_V\, \underline{g}\, \underline{T}/\underline{c}_p$ where $\underline{\alpha}_V$ = cubic thermal expansion coefficient $\underline{g}$ = acceleration due to gravity $\underline{T}$ = thermodynamic temperature $\underline{c}_p$ = specific heat capacity at constant pressure	m^{-1} K
Stability (without compressibility correction)	$\underline{E}$	$\underline{E} = -(1/\underline{\rho})\left(\frac{\partial\underline{\rho}}{\partial\underline{S}}\frac{\partial\underline{S}}{\partial\underline{z}} + \frac{\partial\underline{\rho}}{\partial\underline{t}}\left[\frac{\partial\underline{t}}{\partial\underline{z}} + \Gamma\right]\right)$ where : $\underline{\rho}$ = density $\underline{S}$ = salinity $\underline{t}$ = temperature $\underline{\Gamma}$ = adiabatic temperature gradient $\underline{z}$ = depth	m^{-1}

Quantity	Symbol	Definition and remarks	SI unit, symbol
Väisälä frequency	N	$N = (g.E)^{\frac{1}{2}}$ where : g = acceleration due to gravity E = stability	s^{-1}
External radius of deformation (F. rayon externe de déformation)	r_e	$r_e = (g.H)^{\frac{1}{2}}/f$ where : H = sea depth f = Coriolis parameter	m
Inertial radius (F. rayon d'inertie)	r	$r = U/f$ where : U = velocity of the current f = Coriolis parameter	m
Internal radius of deformation	r_i	$r_i = N.h/f$ where : N = Väisälä frequency h = thickness of the water layer f = Coriolis parameter	m
Equatorial internal radius of deformation (F. rayon interne équatorial de déformation)	r_o	$r_o = (N.h.R/2\omega)^{\frac{1}{2}}$ where : N = Väisälä frequency h = thickness of the water layer ω = angular velocity of the earth rotation R = radius of the earth rotation	m
Equatorial inertial radius (F. rayon d'inertie équatorial)	r_e	$r_e = (U.R/2\omega)^{\frac{1}{2}}$ where : U = velocity of the current	m

Quantity	Symbol	Definition and remarks	SI unit, symbol
Ekman depth	$\underline{D}$	Ekman boundary layer thickness $\underline{D} = (2\,\underline{\nu}/\underline{f})^{\frac{1}{2}}$, instead of $\pi\,(2\,\underline{\nu}/\underline{f})^{\frac{1}{2}}$ where : $\underline{\nu}$ = kinematic viscosity, $\underline{f}$ = Coriolis parameter	m
Coriolis acceleration	$\underline{a}_c$	Complementary acceleration due to earth's rotation (should replace Coriolis force)	$m.s^{-2}$
Coriolis period	$\underline{T}_c$	$\underline{T}_c = 2\,\pi/\underline{f}$ (should replace inertial period)	s
Eddy viscosity		Kinematic turbulent viscosity, horizontal or vertical, has no proper definition	$m^2.s^{-1}$

TABLE II.4

OPTICAL OCEANOGRAPHY

Table prepared by André MOREL, Chairman of the I.A.P.S.O. Working Group on Optical Oceanography, with the help of the Working Group members

INTRODUCTION

This table presents fundamental terms describing the transfer of radiative energy in natural (sea and lake) waters and relevant optical properties of this medium. The table is divided into four parts :

(1) fundamental quantities ; (2) radiant energy in natural waters ; (3) material characteristics ; and (4) inherent optical properties of natural water.

The present terminology respects the rules of the "Système International d'Unités", and consequently, Quantities, Symbols, and Units in Part 1 are transcribed from the table ISO 31/6 (E) (International Organization for Standardization, 1980) dealing with light and related electromagnetic radiations. Quantities in Part 3 are based partly on the same ISO Table and also on the more detailed nomenclature developed by the Commission Internationale de l'Eclairage (1970).

Parts 2 and 4 deal more specifically with quantities and parameters belonging to optical oceanography. Basically, this vocabulary derives from and complements a previous terminology recommended by the Committee on Radiant Energy in the Sea, set up by IAPO (International Association of Physical Oceanography) and published by its chairman, N.G. Jerlov, in 1964.

As in ISO Table, the statements in the definition column are given merely for identification ; they are not intended to be complete and perfect definitions.

The quantities considered concern unpolarized radiation. Only radiometric quantities are considered and the luminous (or photometric) quantities are not defined. For photosynthesis and aquatic primary production studies, radiant energy must be evaluated in terms of radiometric quantities and not in terms of photometric quantities. For such studies, the radiometric quantities are adequately expressed as amount of quanta (or Einstein = $\underline{N}$ quanta, where $\underline{N}$ is the Avogadro number) within a given spectral range according to UNESCO recommendations (1966).

The convention has been adopted that if a quantity is used to describe monochromatic radiation, its name can be preceded by the adjective "spectral". This adjective is used to designate quantities that are functions of wavelength (or frequency) or are spectral concentration (dimension of a derivative with respect to wavelength). The functional dependence may be indicated by a subscript ($\underline{\lambda}$, or $\underline{\nu}$) or preferably as an argument put in parentheses.

Quantity	Symbol	Definition and remarks	SI unit, symbol
		1. Fundamental Quantities	
Wavelength (F. longueur d'onde)	λ	Distance between two successive points of a periodic wave in the direction of propagation, for which the oscillation has the same phase. Note : The wavelength of monochromatic radiant energy depends on the refractive index of the medium. Unless otherwise stated, values of wavelength are those *in vacuo*. Recommended units : nm (= 10^{-9} m) and µm (= 10^{-6} m)	m
Wave number (F. nombre d'onde)	σ	$\sigma = 1/\lambda$	m^{-1}
Circular wave number (F. nombre d'onde angulaire)	k, κ	$k = 2\pi/\lambda$	m^{-1}
Frequency	ν	Number of cycles divided by time.	Hz
Refractive index (F. indice de réfraction)	n	The ratio of the velocity of electromagnetic radiation *in vacuo*, to the phase velocity of electromagnetic radiation of a specified frequency in a medium.	1
Photon	γ	A photon is a quantum of electromagnetic radiation which has an energy equal to the product of the frequency of the radiation by	J

Quantity	Symbol	Definition and remarks	SI unit, symbol
		the Plank's constant $\underline{h}$ (Quantum is entity of energy postulated in quantum theory). With : $\underline{h} = (6.626\ 176 \pm 0.000\ 036) \times 10^{-34}\ J.Hz^{-1}$	
Quantity of radiant energy (F. Quantité d'énergie rayonnante)	$\underline{W},\underline{Q}$	Energy emitted, transferred or received as radiation	J
Radiant flux (F. flux énergétique)	$\underline{\Phi},\underline{F}$	The time rate of flow of radiant energy. Relation : $\underline{\Phi} = d\underline{W}/d\underline{t}$. Where $\underline{t}$ is time. Note : The symbol $\underline{\Phi}$, rather than $\underline{F}$ recommended by IAPO has been adopted by the International Organization for Standardization (ISO) and by the International Association of Meteorology and Atmospheric Physics (IAMAP).	W
Radiant intensity (of a source in a given direction) (F. intensité énergétique ...)	$\underline{I}$	The radiant flux emitted by a point source, or by an element of an extended source, in an infinitesimal cone containing the given direction, divided by that element of solid angle. Relation : $\underline{I} = d\underline{\Phi}/d\underline{\omega}$, where $\underline{\omega}$ is solid angle. Note : For a source which is not a point source, the quotient of the radiant flux received at an elementary surface and the solid angle which this surface subtends at	$W.sr^{-1}$

Quantity	Symbol	Definition and remarks	SI unit, symbol
		any point of the source, when this quotient is taken to the limit as the distance between the surface and the source tends toward infinity.	
Radiance (F. luminance énergétique)	$\underline{L}$	At a point of a surface, the radiant flux in a given direction and in an element of solid angle, divided by that element of solid angle and by the projected area (projected on a plane perpendicular to the given direction). Relation : $\underline{L}(\underline{\theta},\underline{\Phi}) = d^2\underline{\Phi}/d\underline{A}\ \cos\underline{\theta}\ d\underline{\omega}$. Where $\underline{A}$ is area.	$W.m^{-2}.sr^{-1}$
Irradiance (at a point of a surface) (F. éclairement ...)	$\underline{E}$	The radiant flux incident on an infinitesimal element of a surface containing the point under consideration, divided by the area of that element. Relation : $\underline{E} = d\underline{\Phi}/d\underline{A}$.	$W.m^{-2}$
Radiant exitance (at a point of a surface) (F. exitance ...)	$\underline{M}$	The radiant flux emitted by an infinitesimal element of a surface containing the point under consideration, divided by the area of that element. Relation : $\underline{M} = d\underline{\Phi}/d\underline{A}$.	$W.m^{-2}$
Radiant exposure (irradiation at a point of a surface) (F. exposition énergétique ...)	$\underline{H}$	The product of an irradiance and its duration. Relation : $\underline{H} = d\underline{W}/d\underline{A} = \underline{E}.\underline{t}$ for constant irradiance, $\underline{E}$; for variable irradiance, $\underline{E}(\underline{t})$: $\underline{H} = \int_{\underline{t}_1}^{\underline{t}_2} \underline{E}(\underline{t})\ d\underline{t}$ where $\underline{t}$ is time and $(\underline{t}_2 - \underline{t}_1)$ is the duration.	$J.m^{-2}$

Quantity	Symbol	Definition and remarks	SI unit, symbol
		2. Radiant energy in natural waters	
Downward irradiance (F. éclairement énergétique descendant)	$\underline{E}_d$	The radiant flux on an infinitesimal element of the upper face (i.e. facing zenith) of a horizontal surface containing the point being considered, divided by the area of the element. Alternatively, downward irradiance is the integral of the radiance, weighted by the cosine of the zenith angle ($\underline{\theta}$), over the upper hemisphere. Relation : $\underline{E}_d = d\underline{\Phi}/d\underline{A}$ $= \int_{\underline{\phi}=0}^{2\pi} \int_{\underline{\theta}=0}^{\pi/2} \underline{L}(\underline{\theta},\underline{\phi}) \cos\underline{\theta} \sin\underline{\theta}\ d\underline{\theta}\ d\underline{\phi}$ where $\underline{\phi}$ is the azimuthal angle.	$W.m^{-2}$
Upward irradiance (F. éclairement énergétique ascendant)	$\underline{E}_u$	The radiant flux incident on an infinitesimal element of the lower face (i.e. facing nadir) of a horizontal surface containing the point being considered, divided by the area of the element. Alternatively, upward irradiance is the integral of the radiance, weighted by the cosine of the nadir angle, $(\pi-\underline{\theta})$, over the lower hemisphere. Relation : $\underline{E}_u = d\underline{\Phi}/d\underline{A}$ $= \int_{\underline{\phi}=0}^{2\pi} \int_{\underline{\theta}=\pi}^{\pi/2} \underline{L}(\underline{\theta},\underline{\phi}) \cos\underline{\theta} \sin\underline{\theta}\ d\underline{\theta}\ d\underline{\phi}$	$W.m^{-2}$

Quantity	Symbol	Definition and remarks	SI unit, symbol
Downward vector irradiance, net (downward) irradiance (F. éclairement vectoriel (ou net) descendant)	$\vec{\underline{E}}$	The net irradiance or the modulus of the vector is given as the difference between the downward and upward irradiance, with a horizontal plane as reference. Alternatively, the net irradiance is the integral of the radiance, over all directions, weighted by the cosine of the zenith angle $(\underline{\theta})$. Relation : $\vec{\underline{E}} = (\underline{E}_d - \underline{E}_u)\,\vec{\underline{Z}}$ where $\vec{\underline{Z}}$ is the unit vector in the direction of the nadir and $\underline{E}_d - \underline{E}_u = \int_{4\pi} \underline{L}(\underline{\theta},\underline{\phi}) \cos\underline{\theta}\, d\underline{\omega}$ $= \int_{\underline{\phi}=0}^{2\pi} \int_{\underline{\theta}=0}^{\pi} \underline{L}(\underline{\theta},\underline{\phi}) \cos\underline{\theta} \sin\underline{\theta}\, d\underline{\theta}\, d\underline{\phi}$	$W.m^{-2}$
Scalar irradiance (F. éclairement scalaire)	$\overset{\circ}{\underline{E}}, \underline{E}_o$	The integral of radiance distribution at a point over all directions about the point. Relation : $\overset{\circ}{\underline{E}} = \int_{4\pi} \underline{L}(\underline{\theta},\underline{\phi})\, d\underline{\omega}$ $= \int_{\underline{\phi}=0}^{2\pi} \int_{\underline{\theta}=0}^{\pi} \underline{L}(\underline{\theta},\underline{\phi}) \sin\underline{\theta}\, d\underline{\theta}\, d\underline{\phi}$	$W.m^{-2}$
Downward and upward scalar irradiance (F. éclairement scalaire descendant et ascendant)	$\overset{\circ}{\underline{E}}_d, \overset{\circ}{\underline{E}}_u$ or $\underline{E}_{od}, \underline{E}_{ou}$	The integral of the radiance distribution at a point over the upper and the lower hemisphere, respectively. Relations : $\overset{\circ}{\underline{E}}_d = \int_{\underline{\phi}=0}^{2\pi} \int_{\underline{\theta}=0}^{\pi/2} \underline{L}(\underline{\theta},\underline{\phi}) \sin\underline{\theta}\, d\underline{\theta}\, d\underline{\phi}$ $\overset{\circ}{\underline{E}}_u = \int_{\underline{\phi}=0}^{2\pi} \int_{\underline{\theta}=\pi/2}^{\pi} \underline{L}(\underline{\theta},\underline{\phi}) \sin\underline{\theta}\, d\underline{\theta}\, d\underline{\phi}$ $\overset{\circ}{\underline{E}} = \overset{\circ}{\underline{E}}_d + \overset{\circ}{\underline{E}}_u$	

Quantity	Symbol	Definition and remarks	SI unit, symbol
Spherical irradiance (F. éclairement sphérique)	$\underline{E}_s$	Limit of the ratio of radiant flux onto a spherical surface to the area of the surface, as the radius of the sphere tends toward zero with its center fixed. Relations : $\underline{E}_s = \underline{\Phi}_s/4\pi\underline{r}^2$, $\underline{\Phi}_s$ being the radiant flux onto the sphere of radius $\underline{r}$, and : $\underline{E}_s = (1/4)\ \overset{\circ}{\underline{E}}$	$W.m^{-2}$
Average cosines (F. cosinus moyens)	$\bar{\mu}, \bar{\mu}_d, \bar{\mu}_u$	The ratio of the net (downward) irradiance to scalar irradiance. Relation : $\bar{\mu} = \frac{\vec{E}}{\overset{\circ}{E}} = \frac{E_d - E_u}{\overset{\circ}{E}}$ Note : Average cosines for the upper and the lower hemisphere can be defined in a similar way : $\bar{\mu}_d = \frac{E_d}{\overset{\circ}{E}_d}$; $\bar{\mu}_u = \frac{E_u}{\overset{\circ}{E}_u}$	1
Vertical attenuation coefficient of a radiometric ($\underline{X}$) quantity (such as any of the radiances or irradiances defined above) (F. coefficient d'atténuation verticale ...)	$\underline{K}$	Vertical gradient of the napierian logarithm of the quantity. Relation : $\underline{K} = -\frac{d\ln(\underline{X})}{d\underline{z}} = -\frac{1}{\underline{X}}\frac{d\underline{X}}{d\underline{z}}$ ($\underline{z}$ = depth) the negative sign originates from the orientation toward nadir of the vertical (depth) axis.	m^{-1}

Quantity	Symbol	Definition and remarks	SI unit, symbol
Irradiance ratio (F. réflectance, rapport d'éclairement)	$\underline{R}$	The ratio of the upward to the downward irradiance at a given depth in the sea. Relation : $\underline{R} = \underline{E}_u/\underline{E}_d$	1
Asymptotic radiance distribution ; Asymptotic radiative regime (F. distribution asymptotique des luminances énergétiques ; régime asymptotique)		The radiance distribution which is the limit of the distribution in the hydrosphere, as the (geometrical or optical) depth increases infinitely and with the proviso that the water is optically homogeneous. This asymptotic distribution is symetrical around the vertical axis, independent of the radiance distribution above the surface and exclusively dependent on the inherent optical properties. In the asymptotic radiative regime (which corresponds to the asymptotic radiance distribution) • $\underline{\bar{\mu}}, \underline{\bar{\mu}}_d, \underline{\bar{\mu}}_u$ and $\underline{R}$ become constant and depth-independent • The various $\underline{K}$ coefficients for the various radiometric quantities take the same and constant value, also depth-independent. The subscripts ∞ or lim are often associated with the above mentioned symbols to indicate that these quantities are considered in their asymptotic values.	

Quantity	Symbol	Definition and remarks	SI unit, symbol
		3. Material characteristics	
		3.1 General characteristics	
Emissivity (F. émissivité)	$\underline{\varepsilon}$	The ratio of the radiant exitance of a surface to that of a black body at the same temperature. Relation : $\underline{\varepsilon} = \underline{M}/\underline{M}_{\text{black body}}$	1
Absorptance (F. facteur d'absorption)	$\underline{A}$	The ratio of the radiant flux ($\underline{\Phi}_a$) lost from a beam by means of absorption, to the incident flux ($\underline{\Phi}_o$). Relation : $\underline{A} = \underline{\Phi}_a/\underline{\Phi}_o$	1
Scatterance (F. facteur de diffusion)	$\underline{B}$	The ratio of the radiant flux ($\underline{\Phi}_b$) scattered from a beam, to the incident flux ($\underline{\Phi}_o$). Relation : $\underline{B} = \underline{\Phi}_b/\underline{\Phi}_o$	1
Forward scatterance	$\underline{B}_f$	The ratio of the radiant flux scattered through angles 0 - 90° from a beam to the incident flux.	1
Backward scatterance	$\underline{B}_b$	The ratio of the radiant flux scattered through angles 90 - 180° from a beam to the incident flux.	1
Attenuance (F. facteur d'atténuation)	$\underline{C}$	The ratio of the radiant flux lost from a beam of infinitesimal width by means of absorption and scattering to the incident flux. Relation : $\underline{C} = \underline{A} + \underline{B}$	1

Quantity	Symbol	Definition and remarks	SI unit, symbol
Reflectance (F. facteur de réflexion)	$\underline{\rho}$	The ratio of the reflected radiant flux to the incident radiant flux. Note : Irradiance ratio, $\underline{R}$, is a particular case of reflectance $\underline{\rho}$, defined under specified conditions (horizontal plane, see above).	1
Transmittance (F. facteur de transmission)	$\underline{T}$	The ratio of the transmitted ($\underline{\Phi}_t$) radiant flux to the incident radiant flux (in either irradiance or radiance form). Relation : $\underline{T} = \underline{\Phi}_t/\underline{\Phi}_o$ Note : for a beam : $1 - \underline{C} = \underline{T}$ (beam transmittance).	1
		3.2. Particle characteristics	
Efficiency factor for absorption (F. (facteur d') efficacité d'absorption)	$\underline{Q}_a$	The ratio of the radiant flux absorbed within a particle to the radiant flux incident onto the geometrical cross section of this particle. (The geometrical cross section of a particle is the projected area of this particle in the direction of propagation of the incident radiation).	1
Efficiency factor for scattering (F. (facteur d') efficacité de diffusion)	$\underline{Q}_b$	The ratio of the radiant flux scattered from a particle to the radiant flux incident onto the geometrical cross section of this particle.	1

Quantity	Symbol	Definition and remarks	SI unit, symbol
Efficiency factor for attenuation (F. (facteur d') efficacité d'atténuation)	$\underline{Q}_c$	The ratio of the radiant flux absorbed within and scattered from a particle to the radiant flux incident onto the geometrical cross section of this particle. Relation : $\underline{Q}_c = \underline{Q}_a + \underline{Q}_b$ Note : The cross sections of the particle for absorption, scattering and attenuation are the product of the geometrical cross section, respectively, by $\underline{Q}_a$, $\underline{Q}_b$ and $\underline{Q}_c$.	1

4. Inherent optical properties of natural waters

Quantity	Symbol	Definition and remarks	SI unit, symbol
		4.1. Coefficients	
Absorption coefficient (F. coefficient d'absorption)	$\underline{a}$	The absorptance of an infinitesimally thin layer of the medium normal to the beam, divided by the thickness ($\Delta\underline{r}$) of the layer. Relation : $\underline{a} = - \Delta\underline{A}/\Delta\underline{r} = - \frac{\Delta\underline{\Phi}_a}{\underline{\Phi}_o} / \Delta\underline{r}$ Note 1 : for homogeneous medium of finite thickness $\underline{r}$ $\underline{a} = - \frac{1}{\underline{r}} \ln (1 - \underline{A})$ Note 2 : for passive medium (no internal source) $\text{div}\, \vec{\underline{E}} = - \underline{a}\, \underline{E}_o$ and for practical applications (i.e. negligible horizontal gradients) $d\vec{\underline{E}} / d\underline{z} = - \underline{a}\, \underline{E}_o$	m^{-1}

Quantity	Symbol	Definition and remarks	SI unit, symbol
Volume scattering function (F. coefficient angulaire de diffusion)	$\beta(\theta)$	The radiant intensity, from a volume element in a given direction, per unit of irradiance on the cross section of the volume and per unit volume (V). Relation : $\beta(\theta) = dI(\theta) \,/\, E\, dV$ Convention : $\theta = 0$ for the direction of propagation of the incident beam (plane waves).	$m^{-1}sr^{-1}$
Total scattering coefficient (F. coefficient total de diffusion)	b	The scatterance of an infinitesimally thin layer of the medium normal to the beam, divided by the thickness (Δr) of the layer. Relation : $b = \Delta B \,/\, \Delta r = -\frac{\Delta\Phi_b}{\Phi_o} / \Delta r$ Note 1 : an alternative definition is : the total scattering coefficient is the integral over all directions of the volume scattering function. Relation : $b = \int_{4\pi} \beta(\theta)\, d\omega$ and for scattering with rotational symetry $b = 2\pi \int_0^{\pi} \beta(\theta) \sin\theta \, d\theta$ Note 2 : for homogeneous medium of finite thickness r $b = -\frac{1}{r} \ln (1 - B)$	m^{-1}

Quantity	Symbol	Definition and remarks	SI unit, symbol
Forward scattering coefficient (F. coefficient de diffusion avant)	$\underline{b}_f$	The coefficient which relates to forward scatterance Relation : $\underline{b}_f = 2\pi \int_o^{\pi/2} \underline{\beta}(\underline{\theta}) \sin\underline{\theta}\, d\underline{\theta}$	m^{-1}
Backward scattering coefficient (F. coefficient de rétrodiffusion)	$\underline{b}_b$	The coefficient which relates to backward scatterance Relation : $\underline{b}_b = 2\pi \int_{\pi/2}^{\pi} \underline{\beta}(\underline{\theta}) \sin\underline{\theta}\, d\underline{\theta}$	m^{-1}
(Total) Attenuation coefficient (F. coefficient (total) d'atténuation)	$\underline{c}$	The attenuance of an infinitesimally thin layer of the medium normal to the beam, divided by the thickness ($\Delta\underline{r}$) of the layer. Relation : $\underline{c} = -\Delta\underline{C}/\Delta\underline{r} = -\frac{\Delta\underline{\Phi}_c}{\underline{\Phi}_o} / \Delta\underline{r}$ and $\underline{c} = \underline{a} + \underline{b}$ for homogeneous layer of finite thickness $\underline{r}$: $\underline{c} = -1/\underline{r} \ln (1 - \underline{C})$	m^{-1}
		4.2. <u>Dimensionless parameters</u>	
Probability of photon survival	$\underline{\omega}, \underline{\tilde{\omega}}$	The ratio of the scattering coefficient to the attenuation coefficient. Relation : $\underline{\tilde{\omega}} = \underline{b}/\underline{c}$ <u>Note</u> : this quantity is also called "single scattering albedo"	1

Quantity	Symbol	Definition and remarks	SI unit, symbol
Absorption number	$\bar{a}$, $\tilde{a}$	The ratio of the absorption coefficient to the attenuation coefficient. Relation : $\bar{a} = a/c$ $= 1 - \bar{\omega}$ Note : this quantity is the probability of photon disappearance.	1
Normalized volume scattering function	$\bar{\beta}(\theta)$, $\tilde{\beta}(\theta)$	The dimensionless function obtained by dividing the volume scattering function by the total scattering coefficient (its integral over all solid angle is 1). Relation : $\bar{\beta}(\theta) = \frac{1}{b} \beta(\theta)$ and $\int_{4\pi} \bar{\beta}(\theta)\, d\omega \equiv 1$ Note : the phase function, $P(\theta)$, is related to $\bar{\beta}(\theta)$ by : $P(\theta) = 4\pi\, \bar{\beta}(\theta)$ and $\int_{4\pi} P(\theta)\, d\omega \equiv 4\pi$. Its integral over all directions is 4π.	sr^{-1}
Forward and backward scattering ratio	$\bar{b_f}$, $\bar{b_b}$ or $\tilde{b_f}$, $\tilde{b_b}$	The ratio of the forward or the backward scattering coefficient to the total scattering coefficient. Relations : $\bar{b_f} = b_f/b$ $\bar{b_b} = b_b/b$	1

Quantity	Symbol	Definition and remarks	SI unit, symbol
Optical length (or depth, or thickness) (F. épaisseur ou profondeur optique)	τ	The geometrical length of a path multiplied with the (total) attenuation coefficient associated with the path. Relation : $\tau = c \cdot l$ or, for an inhomogeneous medium, where c varies along the pathlength : $\tau = \int_0^l c(l)\, dl$ Note 1 : Despite the words "length" or "depth", these quantities are dimensionless. Note 2 : Similar dimensionless quantities are obtained by multiplying a depth interval, Δz, with the various vertical attenuation coefficients, K. No name and no symbol is proposed.	1

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TABLE II.5

MARINE GEOPHYSICS

Prepared by M. YASUI

Revised by G. GRAU

Quantity	Symbol	Definition and remarks	SI unit, symbol	Recommended unit
		A. GRAVITY		
Acceleration of free fall, acceleration due to gravity (F. accélération due à la pesanteur)	g	It is strongly advisable to retain temporarily the use of "milligal" (symbol mGal) as unit. Given the present precision of the corrections to be applied to sea measurements in order to take into account the ship's movements, numerical values expressed in this unit have a non-significant decimal part. 1 Gal = 1×10^{-2} $m.s^{-2}$ 1 mGal = 1×10^{-5} $m.s^{-2}$	$m.s^{-2}$	mGal
Normal acceleration due to gravity	g_n, γ	Two slightly different values for normal acceleration due to gravity are proposed using two slightly different reference ellipsoids adopted in succession by IUGG : 1) in 1967 : $g_n(1967)/\text{mGal} = 978\ 031.9$ $(1 + 0.005\ 302\ 4 \sin^2\phi$ $- 0.000\ 005\ 9 \sin^2 2\phi)$ 2) and in 1980 : $g_n(1980)/\text{mGal} = 978\ 032.7$ $(1 + 0.005\ 302\ 4 \sin^2\phi$ $- 0.000\ 005\ 8 \sin^2 2\phi)$ ϕ being the latitude. It is therefore necessary to state the reference system chosen, by mentioning e.g. the year of adoption in parentheses attached to the symbol : $g_n(1967)$, $g_n(1980)$.	$m.s^{-2}$	mGal

Quantity	Symbol	Definition and remarks	SI unit, symbol	Recommended unit
Free-air anomaly (F. anomalie à l'air libre)	$\Delta\underline{g}'$, $(\Delta\underline{g}_F)$	$\Delta\underline{g}' = \underline{g} - \underline{g}_n$	$m.s^{-2}$	mGal
Bouguer anomaly	$\Delta\underline{g}''$, $(\Delta\underline{g}_B)$	Sum of free air anomaly and correction calculated under the assumption that sea water having density value of 1 030 $kg.m^{-3}$ is replaced by crustal rocks having a density value of 2 670 $kg.m^{-3}$.	$m.s^{-2}$	mGal
		B. GEOMAGNETISM AND PALEOMAGNETISM		
Geomagnetic field strength (F. champ magnétique terrestre)	$\underline{H}$		$A.m^{-1}$	
Geomagnetic flux density, geomagnetic induction (F. induction géomagnétique)	$\underline{B}$	Density of magnetic flux of geomagnetic field.	tesla T	nT

Quantity	Symbol	Definition and remarks	SI unit, symbol	Recommended unit
IAGA International Geomagnetic Reference Field (IGRF)	$\underline{B}_I$	Geomagnetic field derived by the formula representing a finite series of spherical harmonic functions which was authorized by IAGA in 1968.	T	nT
Geomagnetic anomaly (F. anomalie géomagnétique)	$\Delta\underline{B}$	Difference between the observed geomagnetic flux density and those derived from the IGRF.	T	nT
Magnetization (F. aimantation)	$\underline{M}, \underline{H}_I$	Magnetic moment induced by polarizing magnetic substance divided by volume of this substance.	$A.m^{-1}$	
Magnetic susceptibility	$\underline{\chi}$	Ratio of the induced magnetization to geomagnetic field strength.	1	
Inclination (F. inclinaison)	$\underline{I}$	Angle between vertical direction and that of geomagnetic field. Use preferably the "degree" (°) and its fractions "minute" (') and "second" ("), as far as these units are used in latitudinal system. $1° = (\pi/180)$; $1' = (1/60)°$ $= (\pi/10\ 800)$rad ; $1'' = (1/60)' = (1/3\ 600)°$ $= (\pi/648\ 000)$rad.	rad	

Quantity	Symbol	Definition and remarks	SI unit, symbol	Recommended unit
Declination (F. déclinaison)	$\underline{D}$	Angle between the geomagnetic and geographic meridians. As for inclination, use preferably the "degree", "minute" and "second".	rad	
		C. TERRESTRIAL HEAT FLOW		
Geothermal gradient (F. gradient géothermique	$\partial\underline{T}/\partial\underline{z}$, $\partial\underline{t}/\partial\underline{z}$ ($\partial\underline{\Theta}/\partial\underline{z}$)	Rate of increase of temperature with depth within the earth.	$K.m^{-1}$	
Terrestrial heat flow, geothermal flux (F. flux de chaleur terrestre)	$\underline{q}$, ($\underline{\phi}$)	Dissipation of geothermal energy through the unit cross section of surface of the earth during the unit time.	$W.m^{-2}$	$mW.m^{-2}$
Thermal conductivity (F. conductivité thermique)	$\underline{k}$	Rate of heat energy passing through the unit cross section during the unit time under the unit thermal gradient by means of molecular conduction. Tabulation of "$\underline{\lambda}$" as symbol of the quantity is reserved because of foreseen confusion with wavelength.	$W.m^{-1}.K^{-1}$	
Specific heat capacity (F. chaleur massique, capacité thermique massique	$\underline{c}$	Heat capacity divided by mass. $\underline{c}_p$: at constant pressure $\underline{c}_V$: at constant volume $\underline{c}_s$: at saturation	$J.kg^{-1}.K^{-1}$	$mJ.kg^{-1}.K^{-1}$

Quantity	Symbol	Definition and remarks	SI unit, symbol	Recommended unit
Thermal diffusivity (F. diffusivité thermique)	$\underline{K}$, $\underline{a}$	$\underline{K} = \underline{k}/\underline{\rho}\ \underline{c}_{\underline{p}}$	$m^2.s^{-1}$	
Heat generation (F. production d'énergie)	$\underline{A}$	Heat production in the unit volume during the unit time.	$W.m^{-3}$	$nW.m^{-3}$
Permeability of a medium to water (F. perméabilité d'un milieu à l'eau)	$\underline{k}$	Volume flow rate of water having unit viscosity, across unit cross section through porous medium of unit thickness under unit pressure difference.	m^2	
		D. EXPLOSION SEISMOLOGY		
Velocity of compressional waves. (F. vitesse de propagation des ondes de compression)	$\underline{v}_{\underline{p}}$		$m.s^{-1}$	$km.s^{-1}$
Velocity of shear waves (F. vitesse de propagation des ondes de cisaillement)	$\underline{v}_{\underline{s}}$		$m.s^{-1}$	$km.s^{-1}$

Quantity	Symbol	Definition and remarks	SI unit, symbol	Recommended unit
		E. MISCELLANEOUS		
Density (F. masse volumique)	ρ	Mass divided by volume.	$kg.m^{-3}$	$kg.m^{-3}$
Rate of sedimentation (F. vitesse de sédimentation)	(v)	Quotient of the interval length of core between dated samples by the time difference of dating. The SI unit is too small to be of any use in this respect. Advise preferably use as unit : $mm/(1\ 000\ a) = \mu m.a^{-1}$.	$m.s^{-1}$	$m.a^{-1}$

TABLE II.6

MARINE GEOCHEMISTRY
CHEMICAL OCEANOGRAPHY

Prepared by P.J. WANGERSKY

Revised by J.D. BURTON

Quantity	Symbol	Definition and remarks	SI unit, symbol
Relative atomic mass of an element	A_r	The ratio of the average mass per atom of an element to 1/12 of the mass of an atom of nuclide ^{12}C. Formerly called atomic weight.	1
Relative molecular mass of a substance	M_r	The ratio of the average mass per molecule or specified entity of a substance to 1/12 of the mass of an atom of nuclide ^{12}C. Formerly called molecular weight.	1
Molar mass	M	Mass divided by amount of substance.	$kg.mol^{-1}$
Molar volume	V_m	Volume divided by amount of substance.	$m^3.mol^{-1}$
Molar internal energy	U_m	Internal energy divided by amount of substance.	$J.mol^{-1}$
Molar enthalpy	H_m	Enthalpy divided by amount of substance.	$J.mol^{-1}$
Molar heat capacity	C_m	Heat capacity divided by amount of substance.	$J.mol^{-1}K^{-1}$
	$C_{m,p}$	At constant pressure.	
	$C_{m,V}$	At constant volume.	
Molar entropy	S_m	Entropy divided by amount of substance.	$J.mol^{-1}K^{-1}$
Amount-of-substance concentration of component B	c_B,[B]	Amount of substance of component B divided by volume of the mixture. (See Note 2)	$mol.m^{-3}$
		Recommended unit	$mol.dm^{-3}$

Quantity	Symbol	Definition and remarks	SI unit, symbol
Amount-of-substance of component B per mass of solution	$\underline{M}_B$	Amount of substance of component B divided by the mass of solution, sea water in particular.	$mol.kg^{-1}$
Mass concentration of component B	$\underline{\rho}_B$	Mass of B divided by the volume of the mixture. Recommended unit	$kg.m^{-3}$ $g.dm^{-3}$
Mole fraction of component B	$\underline{x}_B$	Ratio of the amount of substance of component B to the amount of substance of the mixture.	1
Mass fraction of component B	$\underline{w}_B$	Ratio of the mass of component B to the mass of the mixture.	1
Volume fraction of component B	$\underline{\phi}_B$	Ratio of the volume of component B to the volume of the mixture.	1
Mole ratio of solute component B	$\underline{r}_B$	Ratio of the amount of substance of solute component B to the amount of substance of the solvent.	1
Molality of solute component B	$\underline{m}_B$	The amount of substance of solute component B in a solution divided by the mass of the solvent.	$mol.kg^{-1}$
Alkalinity (of sea water)	$\underline{A}$	Amount of hydrogen ion necessary to neutralize the anions of the weak acids divided by the volume of sea water Recommended unit	$mol.m^{-3}$ $mol.dm^{-3}$

Quantity	Symbol	Definition and remarks	SI unit, symbol
Chemical potential of component B	μ_B	For a mixture with components B, C, ... $\mu_B = (\delta G/\delta n_B)_{T,p,n_C...}$, where n_B, n_C, ... are the amount of substance of B, C, ... respectively and G is the Gibbs function.	$J.mol^{-1}$
Absolute activity of component B	λ_B	$\lambda_B = \exp(\mu_B/RT)$	1
Partial pressure of component B	p_B	For a gaseous mixture, $p_B = x_B p$ where p is the pressure.	Pa
Activity of solute component B	a_B	For a solution, a_B is proportional to the absolute activity λ_B, the proportionality factor, which is a function of temperature and pressure only, being determined by the condition that at constant temperature and pressure, a_B divided by the molality ratio m_B/m^θ tends to 1 for infinite dilution. m^θ is a reference molality, usually 1 $mol.kg^{-1}$.	
Activity coefficient of solute component B	γ_B	For a solution, $\gamma_B = a_B/(m_B/m^\theta)$ (See Note 3).	1

Quantity	Symbol	Definition and remarks	SI unit, symbol
Osmotic pressure	Π	The excess pressure required to maintain osmotic equilibrium between a solution and the pure solvent separated by a membrane permeable only to the solvent.	Pa
Stoichiometric number of component B	ν_B	The integers or simple fractions occuring in the standard expression for a chemical reaction $0 = \Sigma \nu_B B$, where the symbol B indicates the molecules or atoms involved in the reactions. In the present formulation the stoichiometric numbers for reactants are negative and those for products are positive.	1
Partition function	Q, Z	The sum of the quantities $\exp(-E_i/kT)$ over all quantum states i, where E_i is the energy of state i.	1
Diffusion coefficient	D	$n_B \langle \nu_B \rangle = - D$ gradient n_B, where n_B is the local molecular concentration of component B in the mixture and $\langle \nu_B \rangle$ is the local average velocity of the molecules B.	$m^2.s^{-1}$
Elementary charge	e	The electric charge of a proton.	coulomb C
Charge number of an ion	z	The ratio of the charge of an ion to the elementary charge.	1

Quantity	Symbol	Definition and remarks	SI unit, symbol
Degree of dissociation	α	The ratio of the number of dissociated molecules to the total number of molecules.	1
Electrolytic conductivity	γ, X, K, σ	The electrolytic current density divided by the electric field strength. Formerly called "specific conductance".	siemens per metre, $S.m^{-1}$
Molar conductivity	Λ_m	Conductivity divided by amount-of-substance concentration.	$S.m^2mol^{-1}$
Transport number	t	The ratio of the current carried by a specific kind of ions to the total current.	1

Notes.

1. For reporting concentrations of radioactive nuclides, radioactivity is generally used rather than amount of substance or mass. The SI unit is $Bq.m^{-3}$ or $Bq.kg^{-1}$.

2. With the use of the mole as the unit of amount of substance, such units as gram-atom and gram-molecule have become obsolete. For concentrations of dissolved gases units such as millilitre or cubic centimetre per litre at reference temperature and pressure should also be discarded. Such concentrations should henceforth be reported uniformly in moles per cubic decimetre, or in moles per kilogram of solution.

3. The activity coefficient on a concentration basis (y_B) will be used in addition to γ_B which is on a molality basis.

TABLES OF CONVERSION FACTORS

For each quantity the first line gives, in the following order : name of the quantity, comma, its recommended symbol(s), comma, symbol of its SI unit.

After the first line a list of the units of the same quantity which do not belong to the SI is given in the following order : name of the unit, comma, its symbol (when existing), and finally the conversion factor giving its value in the SI unit.

In rare cases, for certain physical quantities, name and symbol are replaced by an abbreviation only.

For dimensionless quantities the number 1 represents the SI unit.

II.7.- Dynamical Oceanography

Prepared by B. SAINT-GUILY

1. length, l	m
nautical mile	1 nautical mile = 1 852 m exactly
2. velocity, v, u, w, c	$m.s^{-1}$
knot (should not be used)	1 knot = 0.514 $m.s^{-1}$
3. geopotential, Φ	$m^2.s^{-2} = J.kg^{-1}$
dynamic metre	1 dynamic metre = 10 $m^2.s^{-2}$

II.8.- Marine Geophysics

Prepared by M. YASUI

1. acceleration due to gravity, g	$m.s^{-2}$
milligal, mGal	1 mGal = 1 x 10^{-5} $m.s^{-2}$
2. geomagnetic flux density, B	T
gamma, γ	1 γ = 1 nT = 10^{-9} T
3. magnetization, M, H_1	$A.m^{-1}$
emu/cm^3	1 emu/cm^3 = 10^3 $A.m^{-1}$ (emu = 1 × 10^{-3} $A.m^2$ = unit of magnetic moment)
4. inclination, I ; declination, D	rad
degree, °	1 ° = (π/180)rad
minute, '	1' = (1/60)° = (π/10 800)rad
second, "	1" = (1/60)' = (π/648 000)rad
5. heat energy, Q	J
I.T. calorie = International Table calorie, cal_{IT}	1 cal_{IT} = 4.186 8 J [For definition, see ISO 31/IV]
15 °C calorie, cal_{15}	1 cal_{15} = 4.185 5 J
thermochemical calorie, cal_{th}	1 cal_{th} = 4.184 J exactly [For definition, see ISO 31/IV]
6. terrestrial heat flow	$W.m^{-2}$
q, (ϕ)	
HFU	1 HFU = 41.86 × 10^{-3} $W.m^{-2}$

7. thermal conductivity, *k*	$W.m^{-1}.K^{-1}$
$cal_{IT}.s^{-1}.cm^{-1}.K^{-1}$	1 $cal_{IT}.s^{-1}.cm^{-1}.K^{-1}$ = 418.68 $W.m^{-1}.K^{-1}$ exactly
8. specific heat capacity, *c*	$J.kg^{-1}.K^{-1}$
$cal_{IT}.g^{-1}.K^{-1}$	1 $cal_{IT}.g^{-1}.K^{-1}$ = 4 186.8 $J.kg^{-1}.K^{-1}$ exactly
9. heat generation, *A*	$W.m^{-3}$
HGU	1 HGU = 10^{-13} $cal_{IT}.cm^{-3}.s^{-1}$ = $4.186\ 8 \times 10^{-7}.W.m^{-3}$
10. Permeability (of a medium to water), *k*	m^2
darcy	1 darcy = $0.986\ 9 \times 10^{-12}$ m^2

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24	Seventh report of the joint panel on oceanographic tables and standards, Grenoble, 2-5 September 1975; sponsored by Unesco, ICES, SCOR, IAPSO	1976	WG 10
25	Marine science programme for the Red Sea: Recommendations of the workshop held in Bremerhaven, FRG, 22-23 October 1974; sponsored by the Deutsche Forschungsgemeinschaft and Unesco	1976	—
26	Marine science in the Gulf area-Report of a consultative meeting, Paris, 11-14 November 1975	1976	—
27	Collected reports of the joint panel on oceanographic tables and standards, 1964-1969	1976	WG 10
28	Eighth report of the joint panel on oceanographic tables and standards, Woods Hole, U.S.A., sponsored by Unesco, ICES, SCOR, IAPSO	1978	WG 10
29	Committee for the preparation of CLOFETA-Report of the first meeting, Paris, 16-18 January 1978	1979	—
30	Ninth report of the joint panel on oceanographic tables and standards, Unesco, Paris, 11-13 September 1978	1979	—
31	Coastal lagoon survey (1976-1978)	1980	—
32	Coastal lagoon research, present and future. Report and guidelines of a seminar, Duke University Marine Laboratory, Beaufort, NC, U.S.A. August 1978. (Unesco, IABO).	1981	—
33	Coastal lagoon research, present and future. Proceedings of a seminar, Duke University, August 1978. (Unesco, IABO).	1981	—
34	The carbon budget of the oceans. Report of a meeting, Paris, 12-13 November 1979	1980	WG 62
35	Determination of chlorophyll in seawater. Report of intercalibration tests sponsored by SCOR and carried out by C.J. Lorenzen and S.W. Jeffrey, CSIRO Cronulla, N.S.W., Australia, September-October 1978	1980	—
36	The practical salinity scale 1978 and the international equation of state of seawater 1980. Tenth report of the Joint Panel on Oceanographic Tables and Standards, (JPOTS). Sidney, B.C., Canada, 1-5 September 1980. Sponsored by Unesco, ICES, SCOR, IAPSO. Available in Ar, Ch, F, R, S	1981	WG 10
37	Background papers and supporting data on the Pratical Salinity Scale 1978.	1981	WG 10
38	Background papers and supporting data on the International Equation of State of Seawater 1980.	1981	WH 10
39	International Oceanographic Tables, Vol. 3	1981	WG 10
40	International Oceanographic Tables, Vol. 4. (To be published)	1982	WG 10
41	Ocean-Atmosphere Materials exchange (OAMEX) Report of SCOR Working Group 44, Unesco, Paris, 14-16 November 1979	1982	WG 44
42	Carbon dioxide sub-group of the joint panel on oceanographic tables and standards. Report of a meeting Miami, Florida, 21-23 September 1981 sponsored by Unesco, ICES, SCOR, IAPSO	1983	—
43	International Symposium on Coastal lagoons Bordeaux, France, 8-14 September 1981 Available in F and S	1982	—
44	Algorithms for computation of fundamental properties of seawater. Endorsed by Unesco/SCOR/ICES/IAPSO Joint Panel on Oceanographic Tables and Standards and SCOR Working Group 51.	1983	—

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3	Report on the intercalibration measurements in Copenhagen, 9-13 June 1965. Organized by ICES	1966	—
4	Incorporated with Nos. 1,8 and 14 in No. 27	1966	WG 10
5	Report of the second meeting of the joint group of experts on photosynthetic radiant energy held at Kauizawa, 15-19 August 1966. Sponsored by Unesco, SCOR, IAPO	1966	WG 15
6	Report of a meeting of the joint group of experts on radiocarbon estimation of primary production held at Copenhagen, 24-26 October 1966. Sponsored by Unesco, SCOR, ICES	1967	WG 20
7	Report of the second meeting of the Committee for the Check-List of the Fishes of the North Eastern Atlantic and on the Mediterranean, London, 20-22 April 1967	1968	—
8	Incorporated with Nos. 1, 4 and 14 in No. 27	1968	WG 10
9	Report on intercalibration measurements, Leningrad, 24-28 May 1966 and Copenhagen, September 1966; organized by ICES	1969	—
10	Guide to the Indian Ocean Biological Centre (IOBC), Cochin (India), by the Unesco Curator 1967-1969 (Dr. J. Tranter)	1969	—
11	An intercomparison of some current meters, report on an experiment at WHOI Mooring Site "D", 16-24 July 1967 by the Working Group on Continuous Current Velocity Measurements. Sponsored by SCOR, IAPSO and Unesco	1969	WG 21
12	Check-List of the Fishes of the North-Eastern Atlantic and of the Mediterranean (report of the third meeting of the Committee, Hamburg, April 1969)	1969	—
13	Technical report of sea trials conducted by the working group on photosynthetic radiant energy, Gulf of California, May 1968; sponsored by SCOR, IAPSO, Unesco	1969	WG 15
14	Incorporated with Nos. 1, 4 and 8 in No. 27	1970	WG 10
15	Monitoring life in the ocean, sponsored by SCOR, ACMRR, Unesco, IBP/PM	1973	WG 29
16	Sixth report of the joint panel on oceanographic tables and standards, Kiel, 24-26 January 1973; sponsored by Unesco, ICES, SCOR, IAPSO	1974	WG 10
17	An intercomparison of some current meters, report on an experiment of Research Vessel Akademic Kurchatov, March-April 1970, by the Working Group on Current Velocity Measurements; sponsored by SCOR, IAPSO, Unesco	1974	WG 21
18	A review of methods used for quantitative phytoplankton studies; sponsored by SCOR, Unesco	1974	WG 33
20	Ichthyoplankton. Report of the CICAR Ichthyoplankton Workshop-*Also published in Spanish*	1975	—
21	An intercomparison of open sea tidal pressure sensors. Report of SCOR Working Group 27: "Tides of the open sea"	1975	WG 27
22	European sub-regional co-operation in oceanography. Report of Working Group sponsored by the Unesco Scientific Co-operation Bureau for Europe and the Division of Marine Sciences	1975	—
23	An intercomparison of some currents meters, III. Report on an experiment carried out from the Research Vessel Atlantis II. August-September 1972, by the Working Group on Continuous Velocity Measurements: sponsored by SCOR, IAPSO and Unesco	1975	WG 21