Berichte aus dem Institut für Meereskunde
an der Christian-Albrechts-Universität Kiel

Nr. 101
1982

# SI-Einheiten in der Ozeanographie

# SI Units in Oceanography

von

Gerold Siedler

DOI 10.3289/IFM_BER_101A

Kopien dieser Arbeit sind erhältlich bei:

Prof. Dr. G. Siedler
Institut für Meereskunde
Abt. Meeresphysik
Düsternbrooker Weg 20
2300 Kiel 1

ISNN 0341-8561

## Inhaltsverzeichnis

Seite

## Tables of Contents

page

## Zusammenfassung

Auf Empfehlung von IAPSO und SCOR sollen in Zukunft SI-Einheiten auch in der Ozeanographie benutzt werden. Die Empfehlungen dazu findet man in:

IAPSO Publication Scientifique No. 31
SUN Report
December 1979
IUGG Publications Office
39ter, rue Gay-Lussac, 75005 Paris

Der Bericht ist in der IfM-Bibliothek vorhanden. Um die Anpassung an das SI-Einheitensystem für deutsch-sprachige Ozeanographen zu erleichtern, wird im folgenden einen Auszug aus dem SUN Report mit Ergänzungen und deutschen Begriffen gegeben. Der hier vorgelegte Text ist im Interesse einer leichten Lesbarkeit gegenüber dem Original gekürzt. Der Leser findet weitere Einzelangaben in der Reproduktion der Seiten 19 bis 55 des SUN Reports, die als Anlage beigefügt sind.

## Abstract

The future use of SI units in oceanography was recommended by IAPSO and SCOR. The recommendations are summarized in:

IAPSO Publication Scientifique No. 31
SUN Report
December 1979
IUGG Publications Office
39ter, rue Gay-Lussac, 75005 Paris

The report is available in the IfM library. In order to facilitate the introduction of the SI units in the German oceanographic community, an extract from the SUN report is given, including some additional remarks and the German names. The text presented here was shortened with respect to the original to facilitate an easy access to the subject. The reader will find more details in the attached reproduction of pages 19 to 55 of the SUN Report.

## 1. Definition der Einheiten
## definition of units

SI = Système International d'Unités.
Beschlossen auf Sitzungen der Conférence Générale des Poids et Mesures (CGPM) zwischen 1948 und 1975.

Die SI-Grundeinheiten bilden ein kohärentes System, d.h. abgeleitete Größen bzw. Einheiten der abgeleiteten Größen entstehen durch Multiplikation von Potenzen der Größen bzw. Einheiten ohne Zusatzfaktor.

Das SI-System enthält 7 Grundeinheiten und 2 ergänzende Einheiten:

### SI-Grundeinheiten
### SI base units

| Größe<br>quantity | Einheit<br>unit | Symbol<br>symbol |
|---|---|---|
| Länge<br>length | Meter<br>metre | m |
| Masse<br>mass | Kilogramm<br>kilogram | kg |
| Zeit<br>time | Sekunde<br>second | s |
| Elektrischer Strom<br>electric current | Ampere<br>ampere | A |
| Thermodynamische Temperatur<br>thermodynamic temperature | Kelvin<br>kelvin | K |
| Stoffmenge<br>amount of substance | Mol<br>mole | mol |
| Lichtstärke<br>luminous intensity | Candela<br>candela | cd |

### SI - ergänzende Einheiten
### SI supplementary units

| Größe<br>quantity | Einheit<br>unit | Symbol<br>symbol |
|---|---|---|
| Ebener Winkel<br>plane angle | Radian<br>radian | rad |
| Raumwinkel<br>solid angle | Steradian<br>steradian | sr |

## Beispiele von SI-abgeleiteten Größen, Bezeichnungen abgeleitet aus Grundeinheiten
## Examples of SI derived units expressed in terms of base units

| Größe<br>quantity | Bezeichnung<br>name | Symbol<br>symbol |
|---|---|---|
| Fläche<br>area | Quadratmeter<br>square metre | $m^2$ |
| Volumen<br>volume | Kubikmeter<br>cubic metre | $m^3$ |
| Geschwindigkeit<br>speed, velocity | Meter pro Sekunde<br>metre per second | m/s |
| Beschleunigung<br>acceleration | Meter pro Sekunde-Quadrat<br>metre per second squared | $m/s^2$ |
| Wellenzahl<br>wave number | 1 pro Meter<br>1 per metre | $m^{-1}$ |
| Dichte<br>density, mass density | Kilogramm pro Kubikmeter<br>kilogram per cubic metre | $kg/m^3$ |
| Stromdichte<br>current density | Ampere pro Quadratmeter<br>ampere per square metre | $A/m^2$ |
| magnetische Feldstärke<br>magnetic field strength | Ampere pro Meter<br>ampere per metre | A/m |
| Stoffmengen-Konzentration<br>amount-of-substance concentration | Mol pro Kubikmeter<br>mole per cubic metre | $mol/m^3$ |
| Spezifisches Volumen<br>specific volume | Kubikmeter pro Kilogramm<br>cubic metre per kilogram | $m^3/kg$ |
| Leuchtdichte<br>luminance | Candela pro Quadratmeter<br>candela per square metre | $cd/m^2$ |

## SI-abgeleitete Größen mit besonderen Bezeichnungen
## SI derived units with special names

| Größe<br>quantitiy | Bezeichnung<br>name | Symbol<br>symbol | In anderen Einheiten<br>in other units | In Si-Einheiten<br>in SI units |
|---|---|---|---|---|
| Frequenz<br>frequency | Hertz<br>hertz | Hz | | $s^{-1}$ |
| Kraft<br>force | Newton<br>newton | N | | $m \cdot kg \cdot s^{-2}$ |
| Druck, Spannung<br>pressure, stress | Pascal<br>pascal | Pa | $N/m^2$ | $m^{-1} \cdot kg \cdot s^{-2}$ |
| Energie, Arbeit, Wärmemenge<br>energy, work, quantity of heat | Joule<br>joule | J | $N \cdot m$ | $m^2 \cdot kg \cdot s^{-2}$ |
| Leistung, Strahlenfluß<br>power, radiant flux | Watt<br>watt | W | J/s | $m^2 \cdot kg \cdot s^{-3}$ |
| Elektrizitätsmenge elektrische Ladung<br>quantitiy of electricity, electric charge | Coulomb<br>coulomb | C | | $s \cdot A$ |
| Spannung, elektrisches Potential, Potentialdifferenz, elektromotorische Kraft<br>electric potential, potential difference, electromotive force | Volt<br>volt | V | W/A | $m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$ |
| Kapazität<br>capacitance | Farad<br>farad | F | C/V | $m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$ |
| Elektrischer Widerstand<br>electric resistance | Ohm<br>ohm | Ω | V/A | $m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$ |
| Leitfähigkeit<br>conductance | Siemens<br>siemens | S | A/V | $m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$ |
| Magnetischer Fluß<br>magnetic flux | Weber<br>weber | Wb | $V \cdot s$ | $m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$ |
| Magnetische Flußdichte, Induktion<br>magnetic flux density | Tesla<br>tesla | T | $Wb/m^2$ | $kg \cdot s^{-2} \cdot A^{-1}$ |
| Induktivität<br>inductance | Henry<br>henry | H | Wb/A | $m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$ |
| Celsius-Temperatur<br>Celsius temperature | Grad Celsius<br>degree Celsius | °C | | K |
| Lichtstrom<br>luminous flux | Lumen<br>lumen | lm | | $cd \cdot sr$ |
| Beleuchtungstärke<br>illuminance | Lux<br>lux | lx | $lm/m^2$ | $m^{-2} \cdot cd \cdot sr$ |
| Aktivität<br>activity | Becquerel<br>becquerel | Bq | | $s^{-1}$ |
| Energiedosis<br>absorbed dose | Gray<br>gray | Gy | J/kg | $m^2 \cdot s^{-2}$ |

## Beispiele von SI-abgeleiteten Größen, Bezeichnung abgeleitet aus besonderer und SI-Einheit
## Examples of SI derived units expressed by means of an association of special names and base units

| Größe<br>quantity | Bezeichnung<br>name | Symbol<br>symbol | In SI-Einheiten<br>in SI units |
|---|---|---|---|
| Dynamische Viskosität<br>dynamic viscosity | Pascalsekunde<br>pascal second | $Pa \cdot s$ | $m^{-1} \cdot kg \cdot s^{-1}$ |
| Drehmoment<br>moment of force | Newton meter<br>metre newton | $N \cdot m$ | $m^2 \cdot kg \cdot s^{-2}$ |
| Oberflächenspannung<br>surface tension | Newton pro Meter<br>newton per metre | $N/m$ | $kg \cdot s^{-2}$ |
| Wärmeflußdichte, Strahlungsflußdichte<br>heat flux density, irradiance | Watt pro Quadratmeter<br>watt per square metre | $W/m^2$ | $kg \cdot s^{-3}$ |
| Wärmekapazität Entropie<br>heat capacity, entropy | Joule pro Kelvin<br>joule per kelvin | $J/K$ | $m^2 \cdot kg \cdot s^{-2} \cdot K^{-1}$ |
| Spezif. Wärmekapazität spezif. Entropie<br>specific heat capacity, specific entropy | Joule pro Kilogramm u. Kelvin<br>joule per kilogram kelvin | $J/(kg \cdot K)$ | $m^2 \cdot s^{-2} \cdot K^{-1}$ |
| Wärmeleitfähigkeit<br>thermal conductivity | Watt pro Meter und Kelvin<br>watt per metre kelvin | $W/(m \cdot K)$ | $m \cdot kg \cdot s^{-3} \cdot K^{-1}$ |
| elektrische Feldstärke<br>electric field strength | Volt pro Meter<br>volt per metre | $V/m$ | $m \cdot kg \cdot s^{-3} \cdot A^{-1}$ |
| elektrische Ladungsdichte<br>electric charge density | Coulomb pro Kubikmeter<br>coulomb per cubic metre | $C/m^3$ | $m^3 \cdot s \cdot A$ |
| Permeabilität<br>permeability | Henry pro Meter<br>henry per metre | $H/m$ | $m \cdot kg \cdot s^{-2} \cdot A^{-2}$ |
| molare Energie<br>molar energy | Joule pro Mol<br>joule per mole | $J/mol$ | $m^2 \cdot kg \cdot s^{-2} \cdot mol^{-1}$ |

## Zusätzlich zu SI benutzte Einheiten
## Units in use with the SI

| Größe<br>quantity | Bezeichnung<br>name | Symbol<br>symbol | In SI-Einheiten<br>in SI units |
|---|---|---|---|
| Zeit<br>time | Minute<br>minute | min | 1 min = 60 s |
| | Stunde<br>hour | h | 1 h = 3 600 s |
| | Tag<br>day | d | 1 d = 86 400 s |
| Ebener Winkel<br>plane angle, arc | Grad<br>degree | ° | $1^\circ = (\pi/180)$ rad |
| | Minute<br>minute | ' | $1' = (\pi/10\ 800)$ rad |
| | Sekunde<br>second | " | $1'' = (\pi/648\ 000)$ rad |
| Masse<br>mass | Tonne<br>tonne | t | 1 t = $10^3$ kg |
| | atomare Masseeinheit<br>unified atomic mass | u | 1 u ≈ $1.660\ 57 \times 10^{-27}$ kg<br>(annähernd) |

## Einheiten, die zeitweise mit SI benutzt werden dürfen
## Units that may be temporarily used together with SI

| Größe<br>quantity | Bezeichnung<br>unit | Symbol<br>symbol | In SI-Einheiten<br>in Si units |
|---|---|---|---|
| Länge<br>length | Seemeile<br>nautical mile | - | 1 Seemeile = 1 852 m<br>(exakt) |
| Druck<br>pressure | Bar<br>bar | bar | 1 bar = $10^5$ Pa<br>(exakt) |
| Schwerebeschleunigung<br>acceleration of free fall | Gal<br>gal | Gal | 1 Gal = $10^{-2}\ \mathrm{m \cdot s^{-2}}$ |
| Aktivität<br>activity | Curie<br>curie | Ci | 1 Ci = $3.7\mathrm{x}10^{10}$ Bq<br>= $3.7\mathrm{x}10^{10}\ \mathrm{s^{-1}}$ |

## Einheiten, von deren Benutzung dringend abgeraten wird
## Units whose use is strongly discouraged

| Größe<br>quantity | Bezeichnung<br>name | Symbol<br>symbol | In SI-Einheiten<br>in SI-units |
|---|---|---|---|
| Länge<br>length | Mikron<br>micron | µ | 1 µ = 1 µm = $10^{-6}$ m |
| Fläche<br>area | Hektar<br>hectare | ha | 1 ha = $10^4$ $m^2$ |
| Volumen<br>volume | Liter<br>litre | l | 1 l = 1 $dm^3$ = $10^{-3}$ $m^3$ |
| Kraft<br>force | Kilopond<br>kilogram-force | kp<br>kgf | 1 kp = 9.806 65 N |
| Druck<br>pressure | Atmosphäre<br>atmosphere, standard atmosphere | atm | 1 atm = 101 325 Pa exakt |
| | Torr<br>torr | - | 1 Torr = (101 325/760) Pa ≈ 133.322 387 Pa (annähernd) |
| | mm Quecksilber<br>conventional mm of mercury | mmHg | 1 mmHg = 133.322 387 Pa |
| Geschwindigkeit<br>velocity | Knoten<br>knot | - | 1 Knoten = (1 852/3 600) m/s ≈ 0.514 m/s (annähernd) |
| Geopotential<br>geopotential | dynamisches Meter<br>dynamic metre | - | 1 dynamisches Meter ≈ 10 $m^2 \cdot s^{-2}$ (annähernd) |
| Energie<br>energy | Kalorie<br>calorie | cal | 1 cal = 4.186 8 J |
| Magnetische Flußdichte, Induktion<br>magnetic flux density | Gamma<br>gamma | γ | 1 γ = $10^{-9}$ T |

## 2. Umwandlung von Einheiten
## unit conversion

Multiplikation von Faktoren $\frac{\text{Größe}}{\text{Einheit}}$ und $\frac{\text{Einheit}}{\text{Einheit}}$

Multiply factors $\frac{\text{quantity}}{\text{unit}}$ and $\frac{\text{unit}}{\text{unit}}$

Beispiel:
$p$ = 100 dbar in SI-Einheiten?

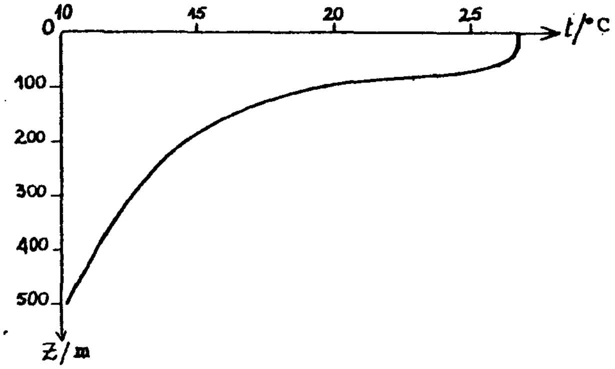
$$\frac{p}{\text{Pa}} = \frac{p}{\text{dbar}}\cdot\frac{\text{dbar}}{\text{bar}}\cdot\frac{\text{bar}}{\text{Pa}} = 100\cdot\frac{1}{10}\cdot 10^5 = 10^6$$

100 dbar = $10^6$ Pa = 1 MPa

## 3. Überschriften in Tabellen, Bezeichnung von Diagramm-Koordinaten
## heading of tables, labelling of graphs

$\frac{\text{Größe}}{\text{Einheit}}$ , $\frac{\text{quantity}}{\text{unit}}$

Beispiel:



## 4. Schriftzeichen
## Printing

Dezimalpunkt im englischen Text.
Dezimalkomma im deutschen Text.

Keine zusätzlichen (Tausender-)Zeichen.
Abstand nach je 3 Ziffern vom Dezimalpunkt.

Zahlen und Einheiten: Senkrechte Schrift.
Größen, Symbole: Kursivschrift.

## 5. Dezimale Vielfache und Teile von SI-Einheiten
## Decimal multiples and sub-multiples of SI units

| Faktor factor | Vorsilbe prefix | Symbol symbol | Faktor factor | Vorsilbe prefix | Symbol 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 |

## 6. Besondere Empfehlungen für die Ozeanographie
## Specific recommendations for oceanography

### Temperatur
### temperature

| | |
|---|---|
| Thermodynamische Temperatur<br>thermodynamic temperature | $T/\mathrm{K}$ |
| Celsius-Temperatur<br>Celsius temperature | $t/{}^\circ\mathrm{C}$ oder $\theta/{}^\circ\mathrm{C}$ |
| Potentielle Temperatur<br>potential temperature | $\theta/{}^\circ\mathrm{C}$ oder $\Theta/{}^\circ\mathrm{C}$ |
| Temperaturintervall,<br>Temperaturdifferenz<br>interval of temperature,<br>difference of temperature | $\Delta T$, $\Delta t$, $\Delta\theta$, $\Delta\Theta$<br>in K oder °C |

Falls Celsius-Temperatur und Zeit im gleichen Text vorkommen, muß für die Zeit t verwendet werden. Eindeutige Bezeichnungen ergeben sich stets mit:

| | |
|---|---|
| Thermodynamische Temperatur | $T/\mathrm{K}$ |
| Celsius-Temperatur | $\theta/{}^\circ\mathrm{C}$ |
| Potentielle Temperatur | $\Theta/{}^\circ\mathrm{C}$ |
| Zeit | $t/\mathrm{s}$ |

## Salzgehalt
## salinity

Die Bezeichnungen $^{o}/oo$, ppm, ppM, ppb sollen nicht mehr benutzt werden, stattdessen:

$S \times 10^3$ oder $S \cdot 10^3$

Der Faktor $10^3$ wird wie eine Einheit benutzt, der Salzgehalt wird mit einem kleinen s oder großen S bezeichnet.

Beispiel:

$s \times 10^3 = 35.000$

oder

$s = 35.000 \times 10^{-3}$

## Chlorinität
## chlorinity

$cl \times 10^3$ oder $cl \cdot 10^3$

## Druck
## pressure

| | |
|---|---|
| Gesamtdruck<br>total pressure | p/Pa, p/MPa |
| Wasserdruck (ohne Atmosphärendruck)<br>sea pressure (excess over atmospheric pressure) | p/MPa |

Beispiel:

Wassertiefe = 100 m
entspricht etwa:
Wasserdruck = 100 dbar = 1 MPa
1 Atmosphäre $\widehat{=}$ 101 325 Pa

### Dichte und abgeleitete Größen
### density and derived quantities

Nur noch dimensionsbehaftete Größen verwenden, nicht relative Dichte.

Also: $\rho/\mathrm{kg} \cdot \mathrm{m}^{-3}$

Größenordnung: $10^3\ \mathrm{kg} \cdot \mathrm{m}^{-3}$

Reihenfolge der Zustandsgrößen ist vorgeschrieben:

$\rho(s, \theta, p)$

Die Zustandsgrößen sollten wie hier in Klammern, nicht als Index geschrieben werden. Angabe ohne Einheiten zulässig. Einheiten sollten hinzugefügt werden, wenn Mehrdeutigkeit möglich ist.

### Spezifisches Volumen
### specific volume

Kehrwert der Dichte:

$\alpha/\mathrm{m}^3 \cdot \mathrm{kg}^{-1}$ oder $v/\mathrm{m}^3 \cdot \mathrm{kg}^{-1}$

Größenordnung: $10^{-3}\mathrm{m}^3 \cdot \mathrm{kg}^{-1}$

### Anomalie des spezifischen Volumens
### specific volume anomaly, steric anomaly

$\delta = \alpha - \alpha^\circ$ mit $\alpha$ = spezif. Volumen der Meerwasserprobe
$\alpha^\circ$ = spezif. Volumen der Referenzwasserprobe (im Text zu definieren)

### Thermostere Anomalie
### thermosteric anomaly

$\Delta(s,t) = \alpha(s,t,p=0) - \alpha^\circ(s^\circ,t^\circ,p=0)$ mit $p$ = Wasserdruck

### $\sigma$

Angabe in SI-Einheiten:

$(\rho - 10^3)/\mathrm{kg} \cdot \mathrm{m}^{-3}$

## Geopotential

Alle Begriffe mit "dynamisch" und das Symbol D sollen nicht mehr verwendet werden, stattdessen:

| | | |
|---|---|---|
| dynamische Tiefe<br>dynamic height | → | Geopotential<br>geopotential |
| Anomalie der dynamischen Tiefe<br>dynamic height anomaly | → | Anomalie des Geopotentials<br>geopotential anomaly |
| Differenz der dynamischen Tiefen<br>dynamic height difference | → | Geopotential-Differenz<br>geopotential difference |
| Niveaufläche<br>equipotential surface | → | Äquipotentialfläche<br>equipotential surface |
| dynamische Topographie der Meeresoberfläche bezogen auf 1000dbar-Fläche<br>dynamic topography at the sea surface relative to 1000 dbar surface | → | (Topographie der) Anomalien des Geopotentials bezogen auf die 10MPa-Fläche<br>(topography of) geopotential anomaly at the sea surface relative to 10-MPa surface |

Einheit des Geopotentials: $m^2/s^2 = J/kg$

1 dynamisches Meter $\approx 10\ m^2s^{-2}$
(annähernd)

# 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 seven Conférences Générales (9th to 15th) that met between 1948 and 1975.

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 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, supplementary units and derived 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

---

[*] 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].

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 may be regarded and used as dimensionally independent from each other.

On the other hand the supplementary units (the radian and the steradian) can be regarded either as base units or as derived units (dimensionless). When regarded as base units, they also are far from being independent from the seven other base units.

## 2.- SI UNITS

### *2.1.- SI Base Units - Definitions and Symbols*

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 metre is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the krypton - 86 atom.*

This definition was legalized by the 11th CGPM (1960).

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 the 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 x $10^{-7}$ 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 $t$, the Working Group proposes (see VI.1/1) the alternative symbol $\theta$ (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 $\theta$ 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 x $10^{-3}$ 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 grams.

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, as amended by the 13th CGPM (1967), reads :

*The candela is the luminous intensity, in the perpendicular direction, of a surface of 1/600 000 square metre of a black body at the temperature of freezing platinum under a pressure of 101 325 newtons per square metre.*

### 2.2.- *SI Supplementary Units*

The Conférence Générale has not yet classified certain units of the International System under either base units or derived units. These SI units are assigned to the second class called "supplementary units", and may be regarded either as base units or as derived units

For the time being this class contains only two, purely geometrical, units : the SI unit of plane angle, the radian, and the SI unit of solid angle, the steradian. These units were adopted by the 11th CGPM (1960).

Table 2

*SI supplementary units*

| Quantity | SI unit | |
|---|---|---|
| | *Name* | *Symbol* |
| plane angle | radian | rad |
| solid angle | steradian | sr |

*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*

### 2.3.- *SI Derived Units*

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

Derived units may therefore be classified under three headings. Some of them are given in Tables 3, 4 and 5.

Table 3

*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, mass 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 | $cd/m^2$ |

## Table 4

*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 | $m^2.s^{-2}$ |

[a] See page 23.

[b] In this expression the steradian (sr) is treated as a base unit.

## Table 5

*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 | $m^2.kg.s^{-2}.mol^{-1}$ |

## 3.- DECIMAL MULTIPLES AND SUB-MULTIPLES OF SI UNITS

SI Prefixes are used to form decimal multiples and sub-multiples of SI units. The list of the prefixes and their symbols is given in Table 6.

Table 6

*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 31/0-1974 [8] of Technical Committee ISO/TC12 "Quantities, units, symbols, conversion factors and conversion tables").

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 x 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:
$c(KCl) = 0.12\ mol/dm^3$
and not $c = 0.12\ mol\ KCl/dm^3$,
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 Comité International des Poids et Mesures (CIPM) agreed (1969) 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 7

### Table 7

*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 ° = (π/180) rad |
| | minute | ' | 1 ' = (1/60)° = (π/10 800) rad |
| | second | " | 1 " = (1/60)' = (π/648 000) rad |
| mass | tonne (3) | t | 1 t = $10^3$ kg |
| | unified atomic mass unit (4) | u | 1 u = 1.660 57 x $10^{-27}$ kg approximately |

NB.- Although the litre is mentioned in the BIPM brochure on the S.I. as being a unit in use with the SI units (except to express the results of high precision measurements), the Working Group prefers not to recommend its use. The litre will therefore be mentioned in Table 9 concerning units whose use is not advisable.

(1) For the other units of time, see the Note at the end of Table 9.

(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 values 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 8.

**Table 8**

*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 x $10^{10}$ Bq<br>= 3.7 x $10^{10}$ $s^{-1}$ |

NB.- Although the knot, hectare, atmosphere are mentioned in the BIPM brochure on the SI as being temporarily accepted with the SI units, the Working Group prefers not to recommend their use. These units will be mentioned therefore in Table 9 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 7 and 8, it is preferable to avoid them and to use instead units of the SI. Some of these units are listed in the following Table 9.

**Table 9**

*Units whose use is strongly discouraged*

| *Quantity* | *Unit* | *Symbol* | *Value in SI unit* |
|---|---|---|---|
| length | micron (1) | μ(1) | 1μ = 1μm = $10^{-6}$ 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 atmosphere (3) | atm | 1 atm = 101 325 Pa exactly |
| | torr (4) | - | 1 torr = (101 325/760) Pa<br>= 133.322 368 Pa approximately |
| | conventional millimetre of mercury (5) | mmHg | 1 mmHg =<br>= 13.595 1 x 9.806 65 Pa<br>= 133.322 387 Pa |
| velocity | knot (6) | - | 1 knot = (1 852/3 600) m/s<br>= 0.514 m/s approximately |
| geopotential | dynamic metre | - | 1 dynamic metre =<br>= 10 $m^2$.$s^{-2}$ approximately |

| *Quantity* | *Unit* | *Symbol* | *Value in SI unit* |
|---|---|---|---|
| energy | calorie (7) | cal | 1 cal = 4.186 8 J |
| magnetic flux density (F. induction magnétique) | gamma | $\gamma$ | 1 $\gamma = 10^{-9}$ 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 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) The numerical value is given for International Table Calorie.

Note.- To the three units of time given in Table 7 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.

$1\ a_{trop} = 365.242\ 20$ 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 abbreviation(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., about 0.999 97 $dm^3$.

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 Q in terms of the unit u chosen :

(6) $Q/u = q$

(7) $Q = q.u$

q being the numerical value.

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

$$l = 5.7 \text{ cm}$$

The second member, 5.7 cm, represents the *measure* or *value* of the quantity *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. :

$$m = 1.318 \text{ x } 10^{-3} \text{ kg}$$

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 q and its symbol Q/u.

According to this equation, we should write :

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

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

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

$$p = 748.95\ \mathrm{mmHg}$$

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

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

We may write then :

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

$$p/\mathrm{bar} = (p/\mathrm{Pa}) \times (\mathrm{Pa/bar}) = 0.998\,518$$

2.- <u>Equations between numerical values</u> .- Let us consider the formula :

$$\rho = f(t)$$

giving the mass density of a body in terms of its temperature. In such a formula, usually established by laboratory measurements, the second member can take various forms, the most classical one being polynomial in $t$ of degree $n$ :

$$\rho = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + \ldots \tag{12}$$

All the terms of this equation have the dimension of a mass density and, consequently, each coefficient $a_i$ has its own dimension, to calculate which requires a knowledge of the units chosen. The choice of $t$, symbol for Celsius temperature, implies that the degree Celsius has been chosen as unit of temperature. The numerical value of $a_0$ gives information on the unit chosen for mass 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 :

$$a_0 = \alpha_0 . \mathrm{kg.m^{-3}} \qquad a_1 = \alpha_1 . \mathrm{kg.m^{-3}.{}^\circ C^{-1}}$$
$$a_2 = \alpha_2 . \mathrm{kg.m^{-3}.{}^\circ C^{-2}} \qquad a_3 = \alpha_3 . \mathrm{kg.m^{-3}.{}^\circ C^{-3}}$$

..............

$\alpha_0, \alpha_1, \alpha_2, \ldots$ being pure numbers.

We obtain then the following *equation between numerical values :*

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

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 (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 10 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 $z$ expressed in metres, the Celsius temperature and the salinity, a dimensionless quantity symbolized here by $s \times 10^3$ i.e. the respective numerical values $z/\mathrm{m}$, $t/°\mathrm{C}$ and $s \times 10^3$. 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 : "z(m)" (which may signify $z$ multiplied by m), "z,m", etc...

Table 10

**Extract of data from a hydrographical station in the Indian Ocean**

| $z/\mathrm{m}$ | $t/°\mathrm{C}$ | $s \times 10^3$ |
|---|---|---|
| 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 $t/°\mathrm{C}$ in terms of depth expressed in meters, $z/\mathrm{m}$. For the same reasons as for Table 10, we place the symbol $z/\mathrm{m}$ on the vertical axis and $t/°\mathrm{C}$ on the horizontal one.

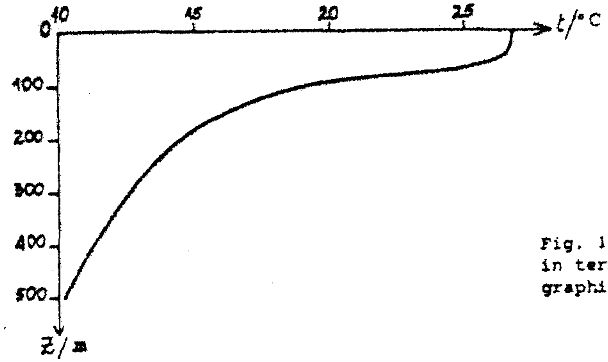


Fig. 1.- Celsius temperature in terms of depth at a hydrographical station

## V. - NUMBERS

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

The decimal sign between digits in a number should be a point on the line (.) in English texts and a comma in French texts ; never 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

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

This chapter was written following correspondance between the members of the Working Group and distributed for comments under the designation of "paper 1" among many members of the Physical Oceanographic Community. Its aim is to examine the specific problems which may arise, in the application to the particular domain of the Physical Sciences of the Ocean, of the SI and related international standard rules concerning terminology and symbols.

We have received a great deal of comment on paper 1, followed by many amendments. The succeeding versions of this paper are dated : February 1976, February 1977, April 1977, April 1978. This latest version has been incorporated, as chapter VII, in the Draft Report dated March 1979.

This draft report was very widely distributed among members of the Physical Oceanography Community, who were asked to send their comments no later than 15 August 1979.

The recent meeting of the Working Group (27-29 August 1979) examined the numerous comments received and made a great number of new amendments to the Draft Report. The present duly amended Draft Report, Part One, and in particular the following proposals will be submitted to the IAPSO for approval.

## 1.- Temperature.-

1.1.- Symbol problems. The international symbols for temperature are $T$ for thermodynamic temperature and $t$ for Celsius temperature [10]. $t$ is also the unique symbol of "time". Now, it could happen that both Celsius temperature and time are found in the same text, or even in the same formula. The Working Group proposes to attribute to Celsius temperature, in addition to $t$ a second symbol $\theta$ (lower case theta), $t$ 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 $\theta$ for temperature. When only one of these quantities appears in a text, this quantity, whether time or Celsius temperature, will be represented by $t$.

1.2.- Potential temperature. - In physical oceanography, this temperature is expressed in degrees Celsius only. We propose to attribute it the two symbols $\theta$ (lower case) and $\Theta$ (capital theta), the latter already used for the same purpose by Sverdrup, Johnson and Fleming in "The Oceans". Potential thermodynamic temperature does not seem to present any interest, its difference from potential Celsius temperature being constant.

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

1.3.- In the tables of Quantities, Units and Symbols to be published in the near future, that of Temperature will mention the following:

Order : quantity, recommended symbol(s) of the quantity, SI unit, symbols of this unit.

Thermodynamic temperature, $T$, kelvin, K

Celsius temperature, $t$, $\theta$, degree Celsius, °C

International Practical Kelvin temperature $T_{68}$, kelvin, K

International Practical Celsius temperature, $t_{68}$, degree Celsius, °C

Interval, difference of temperature, $\Delta t$, $\Delta T$, $\Delta\theta$, kelvin or degree Celsius, K or °C

Potential (Celsius) temperature, $\theta$, $\Theta$, degree Celsius, °C

1.4.- Note for example that in temperature-salinity diagrams, where Celsius temperature is used, $T$ must be replaced by $t$.

## 2.- Chlorinity and Salinity.

These are two dimensionless quantities, the symbols of which are, respectively, $Cl$ and $S$ (and not $Cl$‰ and $S$ ‰).

2.1.- Recommendation. It is proposed that either $s$ or $S$ may be used as a symbol for salinity.

2.2.- Recommendation. The symbol " ‰ ", the use of which is discouraged by many scientific unions, should be abandoned and replaced by $10^{-3}$.

We should write : $s = 35.25 \times 10^{-3} = 0.035\ 25$, or $s \times 10^{3} = 35.25$, the latter representation being particularly suitable for heading tables and as labels on axes of graphs.

However Professor MONTGOMERY proposes that "per mil" is a useful equivalent for $10^{-3}$ (especially in speech) but this opinion does not meet with the approval of the majority of the Working Group.

2.3.- As proposed for " ‰ ", it is recommended that the use in general of symbols such as " % " ($=10^{-2}$), "ppm" ($=10^{-6}$), "ppM" and "ppb" ($= 10^{-9}$) should be given up and replaced by the factor 10 raised to the corresponding power.

2.4.- Proposal for a new definition of Chlorinity and Salinity.- To conform with the international rules related to the SI, these quantities should be defined as the ratio of two masses. Moreover these masses must both be referred to the same unit.

2.4.1.- Proposed definition of chlorinity. This 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 represents 0.328 523 4 times the ratio of the mass of pure reference silver, "Atomgewichtssilber", necessary to precipitate the halides contained in the sample, to the mass of this sample".

2.4.2.- Tentative definition of salinity - Historical - The first definition was given in 1901 by SÖRENSEN and KNUDSEN [12] . Salinity was defined as a conventional quantity expressed in grams per kilogram. Provided it was changed to "kilogram per kilogram", this definition would have been suitable. A direct determination of this quantity, as it is defined, was however difficult and time consuming and practically, this was obtained indirectly by chlorinity and later, by electrical conductivity determination.

When the salinometer has been set up, 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 equals 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 $35 \times 10^{-3}$, 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 $R_{15}$.

The new 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 new definition of salinity on which it is based appeared inacceptable, not only because it is not expressed as the ratio of two masses, but, in addition, the salinity intervenes in its proper definition, the reference sea water sample having a salinity of $35 \times 10^{-3}$.

2.4.3.- New definition of Salinity - Practical Salinity, 1978 - During its meetings, held respectively in May 1977 at Woods Hole Oceanographic Institution, U.S.A. [14], in September 1978 at UNESCO [15], and then at the ad hoc meeting held during the XVIIth IUGG General Assembly, in Canberra, Australia, the Joint Panel on Oceanographic Tables and Standards (JPOTS), sponsored by UNESCO, ICES, SCOR and IAPSO put forward a new suitable definition for Salinity based on the results of work carried out by certain of its members on the relationships between electrical conductivity, chlorinity, salinity and density of sea water. The Panel distinguishes between two slightly different quantities: "Absolute Salinity" and "Practical Salinity, 1978". The wording of the corresponding definitions, as they was presented by JPOTS and adopted by IAPSO, is as follows:

"1. **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 pratice this quantity cannot be measured directly, and a practical salinity is defined for reporting oceanographic observations.

2. **The Practical Saninity** (or Salinity), symbol $S$, is defined in terms of the ratio of the electrical conductivity of the sea water sample at 1 atmosphere (101 325 Pa) and 15°C, to that of a potassium chloride (KCl) solution in which the mass fraction of KCl is 32.435 6 x $10^{-3}$, at the same pressure and temperature (International Practical Temperature Scale, 1968). This ratio $K_{15}$, defines practical salinity of the sample, according to:

$$S \times 10^3 = a_o + a_1 K_{15}^{1/2} + a_2 K_{15} + a_3 K_{15}^{3/2} + a_4 K_{15}^2 + a_5 K_{15}^{5/2}$$

with

$$a_o = 0.008\,0$$
$$a_1 = -\,0.169\,2$$
$$a_2 = 25.385\,1$$
$$a_3 = 14.094\,1$$
$$a_4 = -\,7.026\,1$$
$$a_5 = 2.708\,1$$

$$\Sigma a_i = 35.000\,0$$

$$2 \times 10^{-3} \leqslant S \leqslant 42 \times 10^{-3}$$

Supplementary Statement

The standard KCl solution has the same conductivity at 15°C and 1 standard atmosphere as seawater from the North Atlantic of chlorinity 19.374 0 x $10^{-3}$ and thus provides continuity with previous salinity scales. It was from measurements made on this water, diluted with distilled water or evaporated by weight, that the data giving rise to the above definition of Salinity were obtained. Any oceanic water having a precisely known conductivity ratio of near unity at 15°C and 1 atmosphere with the standard KCl solution is a secondary standard for everyday calibration of oceanographic instruments. All seawaters having the same conductivity ratio have the same practical salinity, and chlorinity is henceforth to be regarded as a separate, independant variable in describing the properties of seawater".

Equations enabling to calculate the practical salinity value under all possible conditions, particularly in terms of temperature (different of 15 °C) and pressure, will be published soon.

The fact that practical salinity is not defined as the ratio of two masses should not arouse any criticism. Since this is a "practical" quantity, we have the right to choose the most convenient definition for it.

## 3.- Pressure

3.1.- In discussing hydrostatic pressure, the word pressure may represent either the total pressure at a point in the ocean or its excess over atmospheric pressure. In both cases the symbol $p$ is commonly used.

To avoid confusion the Working Group proposes that the term "pressure" be reserved for total pressure and that the term "sea pressure" be used for the excess over atmospheric pressure.

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 8) and its decimal multiples, the decibar in particular, should be abandoned as soon as possible.

The "atmosphere" or "standard atmosphere" (see Table 9), 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 to state for example that some data are related to this standard pressure. We should write, for instance :

" $\rho_{max}$ represents the maximal density in terms of temperature of the water free of 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 "density" (mass divided by volume) and "specific gravity" (the ratio of the density of a sea water sample to that of a reference pure water). The "specific volume" was often calculated too as the reciprocal specific gravity. The English equivalent for the French word "densité" was moreover "specific gravity".

To put an end to this confusion the Group recommends the following :

a) density, mass density, symbol $\rho$ , meaning mass divided by volume. Unit : kilogram per cubic metre, symbol kg/m$^3$.
French translation : masse volumique.

b) relative density, symbol $d$, dimensionless, meaning 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 (one standard atmosphere).
Recommended French translation : densité relative.

c) specific volume, symbols $\alpha$, $v$, means the volume divided by the mass.
$\alpha = 1/\rho$ (not $\alpha = 1/d$).
Unit : cubic metre per kilogram, symbol m$^3$/kg
French translation : volume massique.

4.2.- Recommendations.

4.2.1.- The Group recommends giving up once and for all the concept of relative density and using exclusively in the future mass density of sea water expressed preferably in kilograms per cubic metre.

4.2.2.- For the calculation of the mass density of sea water and its related parameters, the Working Group recommends that only pressure, not depth, be used.

4.3.- Notation rules. The following rules proposed for mass density $\rho$ should also be applied to specific volume $\alpha$ and other related parameters which will be mentioned later (specific volume anomaly, thermosteric anomaly).

4.3.1.- The density of sea water samples is not routinely measured, but is calculated from salinity, temperature and pressure by means of empirical tables and formulae.

The symbols and numerical values of these parameters may be indicated in parentheses after the symbol $\rho$ in the compulsory order : $s$, $t$, $p$. Subscripts should preferably not be used. Thus, we should write :

$\rho(s,t,p)$ or $\rho(35.12 \times 10^{-3}, 3.52°C, 28.80 MPa)$,

and preferably not $\rho_{35.12 \times 10^{-3}}$ , 3.52°C, 28.80 MPa.

Symbols and/or numarical values should be separated by commas in English texts and by points in French texts.

In this notation system, the use of the following units is strongly recommended : kilogram per cubic metre (kg.m$^{-3}$) for density, degrees Celsius (°C) for temperature, megapascals (MPa) for pressure. The factor 10$^{-3}$ attached to the salinity value could be considered as the unit of this dimensionless quantity.

Provided that numerical values are written in the recommended order : $s, t, p$, and expressed only with the aforesaid units, these units need not be mentioned. The factor 10$^{-3}$ in the salinity value is therefore deleted.

For example, we may write :

$\rho(35.12 , 3.52 , 28.80)$

for a salinity of 0.035 12, temperature 3.52 °C and pressure 28.80 MPa.

4.3.2.- In cases when one or more of the parameters is or are constant, it/they may be omitted from the parentheses, the constant value of the omitted parameter(s) being stated elsewhere in the text. The order of the remaining parameters should be maintained.

Thus, we should write :

$\rho(s,t)$ , $\rho(s,p)$ , $\rho(t,p)$ , $\rho(t)$ , etc...

In this shortened notation system, and when numerical values are involved, whenever there is a risk of confusion, it is advisable to state the units :

$\rho$(35.28, 28.72 MPa).

N.B.1.- The above rules for abbreviated notation are proposed for reasons of simplicity. However, it is always preferable to use the integral representation, mentioning all the units involved, as well as the numerical value(s) and unit(s) corresponding to constant parameter(s).

N.B.2.- Regarding mass 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 $s = 0$).

4.3.3.- The mass density corresponding to standard or reference conditions may be represented by $\rho°$.

### 4.4.- Abbreviated representation

4.4.1.- Specific Volume Anomaly, proposed symbol $\delta$ or $\delta(s,t,p)$. Following a proposal by Professor Montgomery, we recommend "steric anomaly" as an alternative name.

$$\delta = \alpha - \alpha°$$

$\alpha$ = specific volume in situ of the given sample of sea water,
$\alpha°$ = that of a reference sea water stated in the text.

We recall that there are now two different reference sea water tables corresponding to:

1) $\alpha° = \alpha(35,0,p)$, (Bjerknes, V. & Sandström, J.W.- Dynamic meteorology and hydrography, Pt.I - Statics. Carnegie Institution Washington, Pub. n° 88, 1910).

2) $\alpha° = \alpha(34.85,0,p)$, (Matthews, D.J.- Tables for calculating the specific volume of sea water under pressure.- Copenhague: Conseil permanent international pour l'exploration de la mer, 1938).

4.4.2.- Thermosteric anomaly, proposed symbol $\Delta$ or $\Delta(s,t)$. This term proposed by Professor Montgomery 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 $D$ 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

The Group agrees that to encourage standardization of the scientific spoken and written 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 on the table of "SI units having a special name" distributed by the Bureau International des Poids et Mesures.

In accordance with these principles, the Group voted against the use of the words "sverdrup" and "langley" recently proposed.