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THE 'SI' QUANTITIES AND UNITS – A UNIVERSAL LANGUAGE BRIDGING OVER THE 24 IMEKO TECHNICAL COMMITTEES

Dan Mihai Ştefănescu

Romanian Measurement Society, Bucharest, stefidanro@yahoo.com

Abstract – SI quantities and units are the subject to various IMEKO technical committees, not assigned to a certain TC (e.g. time). On the horizon of the adoption of a new SI, the connection between quantities and units remains the same, and their complexity is noticeable in the three graphical representations given (tree, planetary and subway map), reflecting the significance of the Chinese proverb that *a suggestive picture values more than a thousand of words*.

Keywords: SI, quantities, units, measurement, charts

1. INTRODUCTION

The International System of Quantities and Units (SI) is the most widespread system of measurement units and it is the official one in almost all countries of the world.

Its detalied presentation may be found for example in [1] and [2], where all names, symbols, definitions and inter-relations of the base and derived units are given.

In one form or another, these quantities may be found in the sphere of activity of the 24 IMEKO TCs (Table 1).

2. WHAT HAPPENS WHEN WRONG MEASUREMENT UNITS ARE USED?

The following examples show that using improper measurement units can lead to important material damage and life loss.

2.1. Mass

In July 23, 1983, a Boeing 767 Air Canada jetliner on a long distance route nearly ran out of fuel after someone pumped 22,300 POUNDS of fuel into its tanks rather than 22,300 KILOGRAMS!

2.2. Force

In September 23, 1999 an unusual astronautical accident happened: the space aircraft "Mars Climatic Orbiter" (fortunately without human crew) penetrated the Mars planet atmosphere and disintegrated.

Table 1. IMEKO technical committees (without No. 6 – Vocabulary), their chairs and measurands.

TC	Chair and country	Name	Measurands (fundamental ones with capitals)
1	Holub.cz	Education & Training	all
2	Zagar.at	Photonics	LUMINOUS INTENSITY
3	Kumme.de	Force, Mass, Torque, Density	MASS, Force, Torque, Density
4	Mindykowski.pl	Electrical Quantities	ELECTRIC CURRENT, R, L, C
5	Machado.br	Hardness	Force, Displacement
7	Rossi.it	Science	all
8	Choi.kr	Traceability	all
9	Reader-Harris.uk	Flow	LENGTH, MASS, Volume
10	Catelani.it	Technical Diagnostics	all
11	Borsic.hr	Metrological Infrastructure	all
12	Zvizdic.hr	Thermal & Temperature	THERMODYNAMIC TEMPERATURE
13	Summers.uk	Biology & Medicine	all
14	Takaya.jp	Geometrical Quantities	LENGTH
15	Borbas.hu	Experimental Mechanics	Stress, Strain
16	Woo.kr	Pressure & Vacuum	Pressure
17	Tachi.jp	Robotics	LENGTH, Force, Position
18	Koike.jp	Human Functions	all
19	Lay-Ekuakille.it	Environmental	all
20	Lienesch.de	Energy	Energy, Power
21	Pavese.it	Mathematical Tools	all
22	Ripper.br	Vibration	LENGTH, Velocity, Acceleration
23	Castanheira.pt	Food & Nutrition	all
24	Yim.kr	Chemical	AMOUNT of SUBSTANCE

Fig. 1. Metric error blamed for orbiter loss of Mars Climate Observer, 23 September 1999

When the unmanned vehicle approached Mars a command was transmitted in order to position it on a stationary orbit at an altitude of approx. 150 km, but it was an erroneous command and the spacecraft entered deeply the planet's atmosphere, was overheated and destroyed (Fig. 1).

The reason: two different unit systems were used, the SI (metric) and the imperial ones. NASA stipulated the metric system in the contract, while one of the subcontractors, Lockheed Martin, sent the command in POUND·FORCE instead of NEWTON!

2.3. Length

In March 14, 2014 a French pilot just raised an Airbus A319 to an altitude of 8,000 meters, according to the directives of the flight directors from the Moscow Sheremetyevo airport, when he found himself at an unsafe distance (100 meters) under a TU-95 bomber, which was involved in a squadron dislocation procedure in Belarus.

According to the newspaper Izvestia, the reason was the mismatch of the measurement units: the military aviation measures the flight altitude in METERS, while the civil aviation still uses FEET, not the same "language"!

3. REQUIREMENTS FOR THE 'SI' AND ITS MODERNIZATION

According to Newell [3], a system of units to express all physical measurements must take into consideration all physical quantities and the equations that relate those quantities (i.e. the accepted laws of physics). A simple example is

$$F = m \cdot a = m\,\frac{dv}{dt} = m\,\frac{d^2x}{dt^2}\,, \qquad (1)$$

where force F, mass m, acceleration a, velocity v, length x, and time t are all quantities and the relations are Newton's second law of motion.

Carefully choosing a subset of independent base quantities allows one to derive the remaining quantities as functions of the chosen subset through the accepted laws of physics. The present SI has seven base quantities: *time*, *length*, *mass*, *electric current*, *thermodynamic temperature*, *amount of substance*, and *luminous intensity*.

To fully define the system of units, we must assign a specific reference quantity to each base quantity. The reference quantity can be a specific artifact, as is the case for the base quantity of mass in the present SI, the international prototype of the kilogram (IPK).

Alternatively, in the energy equivalence relations

$$E = h \cdot \nu = m \cdot c^2 = e \cdot V = k \cdot T\,, \qquad (2)$$

the Planck constant h, the speed of light c, the elementary charge e, and the Boltzmann constant k can also be reference quantities since they are invariants with specific values, while frequency is ν, mass m, voltage V and thermodynamic temperature T.

The new SI will also have seven base quantities: *frequency*, *velocity*, *action*, *electric charge*, *heat capacity*, *amount of substance*, and *luminous intensity*, the last two being the same as in the classical SI. Details will be given by other authors during the round table on the New SI.

This "more fundamental SI" [3] will have an increased scalability and accessibility through the chosen set of constants because they appear in various research fields and physical theories.

Anyone with the ability to make appropriate measurements related to the defining constants will be able to realize the kilogram, replacing the last remaining artifact of the classical SI (useful for the everyday practical dissemination of the measurement unit kilogram).

Besides, the new SI will have a fundamental significance, mostly from scientific and theoretical point of view, being based on fundamental physical constants, without any artifacts.

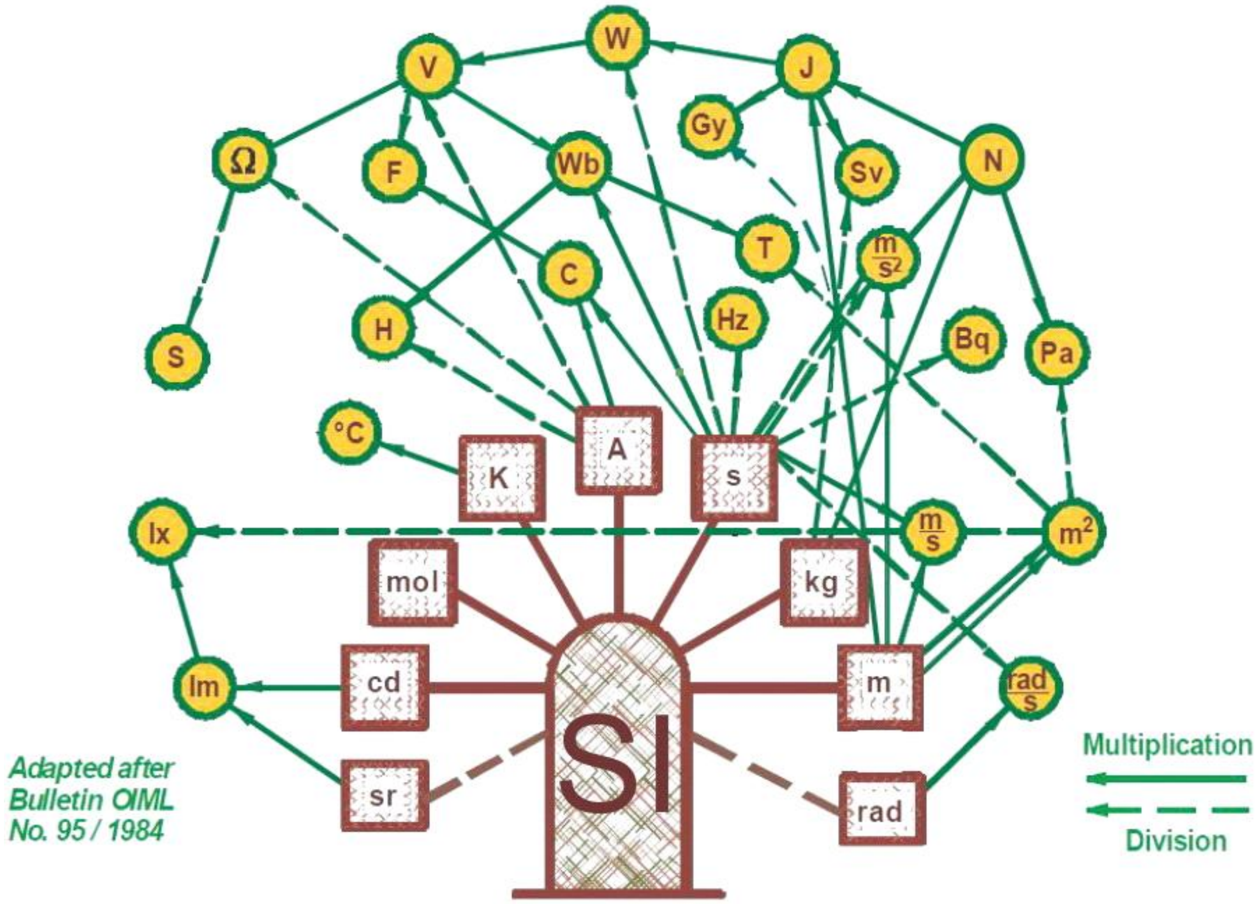

Fig. 2. European "Knowledge Tree" representation of the SI units.

4. GRAPHICAL REPRESENTATIONS OF THE 'SI' QUANTITIES AND UNITS

Three different graphical representations may be considered, in our view [4], as most eloquent and useful for the description of the International System of units.

4.1. Tree representation of the SI units

The "tree" representation originates from an OIML (International Organization of Legal Metrology) idea, first appearing in 1984 in the "OIML Bulletin". The "SI tree" has a trunk whose main branches are the base units, counter-clockwise disposed from right to left: *meter, kilogram, second, ampere, kelvin, mol* and *candela*. Emerging from these base units, placed to form a semicircular contour, a number of derived units are connected, in the form of branches of a tree, resulting in an arborescent representation or chart (Fig. 2).

The following "colour code" has been adopted: brown – for the trunk and the thicker branches with the seven basic units; green – for the thinner branches and the circles that contain the symbols of the derived units. All significant connections are in green: solid lines indicate multiplication, dotted lines mean division.

In this representation, the base units are closer to the roots of the tree, while the derived units are spread throughout the foliage of the tree. It is to be noted that the radian and the steradian are still regarded as "supplementary" units – in accordance with the SI rules valid up to 1995 (the 20th CGPM abolished the supplementary units and decided to consider them as derived units of dimension 1 – see the next repesentations).

4.2. Planetary representation of the SI quantities and units

The "planetary" representation (Fig. 3) was taken over (with permission) from KRISS (Korea Research Institute of Standards and Science) and ROC (Center for Measurement Standards – Industrial Technology Research Institute, Taiwan) respectively, where it is exposed as large sized posters. However, its real origin remains unclear.

In this representation there are seven "planets" along the border of an elliptic field, corresponding to the seven above-mentioned base units (starting counter-clockwise with the Length atop, on the left side, in the same succession as before), and a lot of "satellites", as derived units, "orbiting" inside the ellipse.

Thus, more space is available for representing the derived SI units, their ramification and interconnections are more visible and the whole picture is more intuitive and much richer in information than in the "European SI tree".

The base units appear as blue spheres, and the derived units as smaller green circles. Connections are drawn as green lines for multiplication, yellow lines for division and red lines for other conversions (kelvin to Celsius degrees).

An interesting feature of this representation is that mechanical units are located in the left side of the figure, while the electromagnetic units are situated in the center and others in the right side. Also, the "energetic" quantities (with their units J, W, W/m^2 etc.) are mostly grouped around the center of the ellipse, irrespective of their nature (mechanical, electrical, thermal).

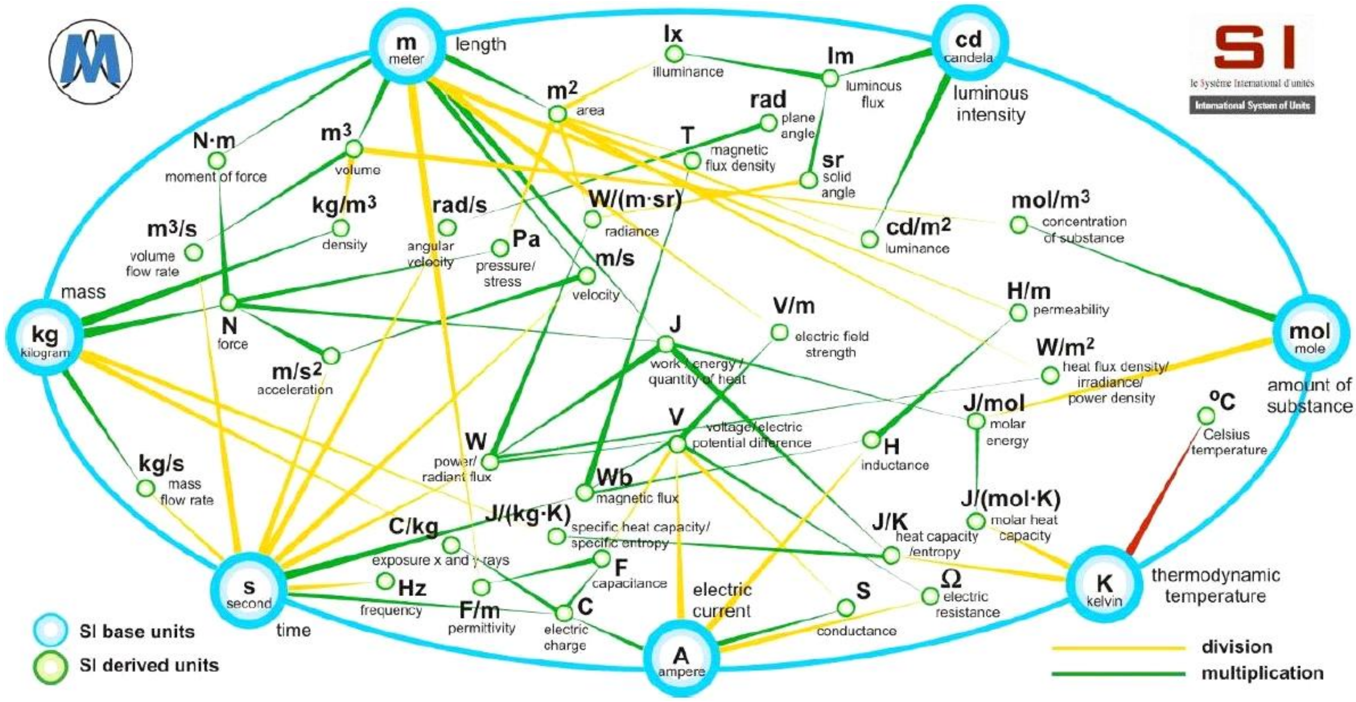

Fig. 3. Asian "Planetary System" representation of the SI quantities and units.

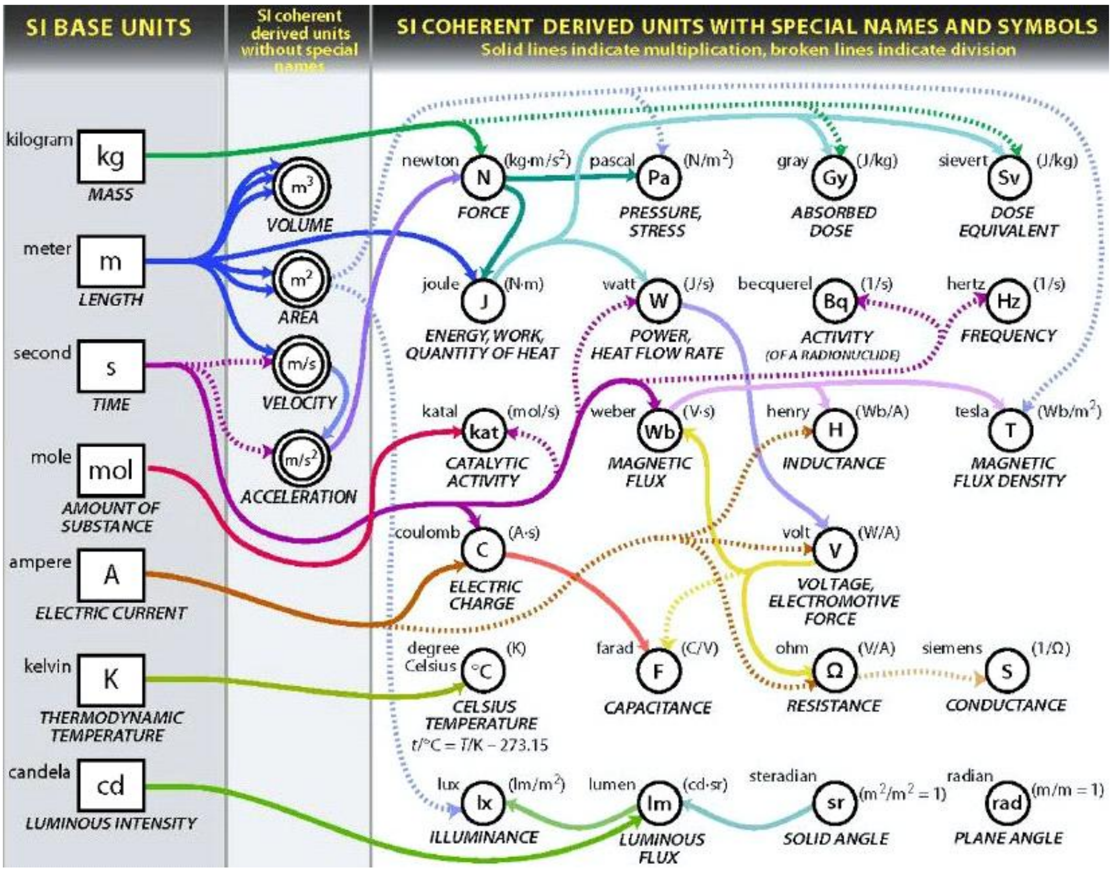

Fig. 4. American "Subway Map" representation of the SI quantities and units.

4.3. *“Subway map” representation of SI quantities & units*

The “subway map” representation (so called by its authors) was posted on Internet by Dr. Barry N. Taylor (22 March 2004), then a second variant was obtained from Paul Trusten, Director of Public Relations, U.S. Metric Association, Inc. (copyright 2006), and finally published, under a similar form (Fig. 4), by NIST (National Institute of Standards and Technology, USA) [5].

This is another kind of “tree”, with multiple inter-connecting lines; the representation has the merit of being highly “transparent”, easily “visible” and with a logic grouping of quantities and units.

The first column is for the SI base units, the second comprises SI derived units without special names (volume, area, velocity, acceleration) and the third displays 22 derived units with special names.

A number of units specific to certain disciplines or chapters of physics are not included (for example, strain, permittivity and permeability, signal level, attenuation, viscosity, thermal conductivity and capacity, entropy, a.o.)

Colours have no distinct significance. Conventions for the connecting lines: solid lines indicate multiplication; dotted lines indicate division.

The rectangular shape of this representation is optimal from the point of view of space usage, and the “information density”. Moreover, the defining equations of the derived units are explicitly given (e.g. Ω = V / A).

5. SOME ENERGETICAL REMARKS CONCERNING ‘SI’ QUANTITIES

A property of a physical quantity is called *intensive* if its value does not depend on the amount of the substance for which it is measured. Intensive quantities are independent of the extension of the system, but, as the name suggests, determine an “intensity” or a “quality” of the system. Examples include: temperature, velocity, pressure, density (or specific gravity), potential, electric resistivity, hardness, elasticity, concentration, etc.

By contrast, a property of a physical quantity is called *extensive* if its value is proportional to the size of the system it describes. Such a property is additive: it can be expressed as the sum of the properties for the separate subsystems that compose the entire system. Examples of extensive properties include: mass, volume, energy, entropy, enthalpy, charge, momentum, number of moles, etc.

Intensive (first term in the equation) and extensive quantities (second term of the equation) are characterized in that together they can form parameter couples having the dimension of an energy. For instance:

mechanical energy = pressure × volume
or tensile stress × elongation,

electric energy = potential × charge,

thermal energy = temperature × entropy.

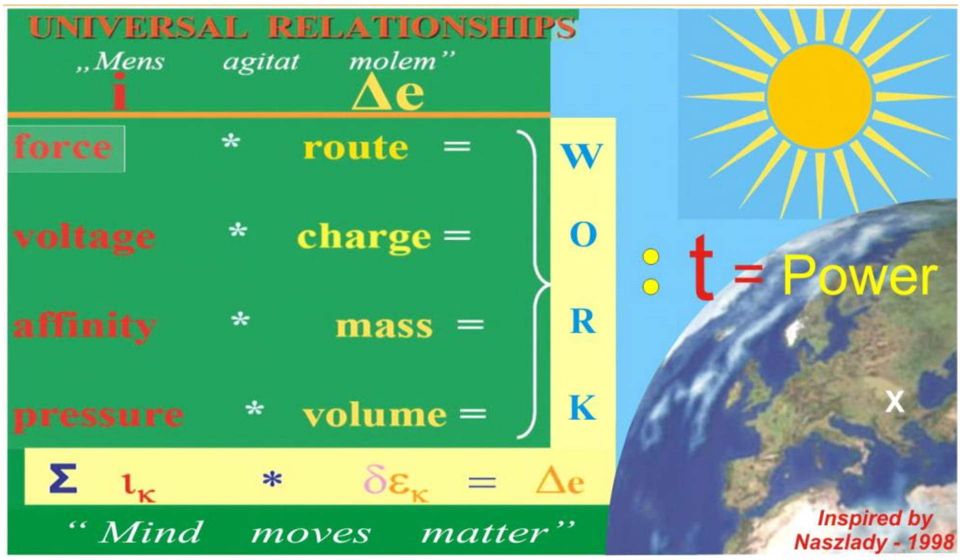

Fig. 5. Different definitions of Work (Energy) and Power.

The global vision of Attila Naszlady (Fig. 5) defines the energy, work and power from four different angles: mechanical, electrical, chemical and thermal, illustrating the various energetic transformations that can take place in the Universe [6].

6. CONCLUSIONS

The paper emphasizes the need to comply with the SI quantities and units, as a common language in worldwide commercial, metrological and scientific relations.

We believe that the three suggestive representations of the SI measurement quantities and units interconnection – the (European) “tree” representation, the (Asian) “planetary” chart and the (American) “subway map” diagram – could be helpful for a better grasping of the nature and peculiarities of the physical quantities.

These representations better highlight the connections between quantities and units, allowing a multidisciplinary and at the same time unitary approach of SI in the economic and industrial sphere, as well as in the IMEKO scientific events.

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Dan Mihai Ştefănescu received his B.S. (1969) in Applied Electronics, M.S. (1983) in Experimental Stress Analysis and PhD *cum laude* (1999) in Electrical Engineering, all from the "Politehnica" University of Bucharest. He worked as Senior Researcher in Measurement Techniques and Head of Metrology and Instrumentation with the National Institute for Aerospace Research in Bucharest from 1969 to 2003. Now he is Senior Consultant for the Romanian Measurement Society. His current research interests are electrical measurement of mechanical quantities, material testing installations, and metrological procedures for multicomponent transducers. Dr. Ştefănescu is a member of the Verband Deutscher Electrotechniker (1987), of the American Society for Experimental Mechanics (1989), member of TC-3 (Measurement of Force, Mass and Torque) and Romanian representative in IMEKO from 1988. He is the author of the Springer "***Handbook of Force Transducers***" (2011).