AN ONTOLOGY ON PROPERTY

FOR PHYSICAL, CHEMICAL, AND BIOLOGICAL SYSTEMS

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To my Wife

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(1922-2004)

ABSTRACT

Current metrological literature, including the *International vocabulary of metrology - Basic and general concepts and asssociated terms* (*VIM3* 2007), presents a special language slowly evolved and sometimes without consistent use of the procedures of terminological work; furthermore, nominal properties are excluded by definition. Both deficiencies create problems in fields, such as laboratory medicine, which have to report results of all types of property, preferably in a unified systematic syntax and format.

The present text aims at forming a domain ontology around "property", with intensional definitions and systematic terms, mainly using the terminological tools - with some additions - provided by the *International Standards ISO 704, 1087-1*, and *10241*.

"System" and "component" are defined, "quantity" is discussed, and the generic concept "property" is given as 'inherent state- or process-descriptive feature of a system including any pertinent components'. Previously, the term 'kind-of-quantity' and quasi-synonyms have been used as primitives; the proposed definition of "kind-of-property" is 'common defining aspect of mutually comparable properties'. "Examination procedure", "examination method", "examination principle", and "examination" are defined, avoiding the term 'test'. The need to distinguish between instances of "characteristic", "property", "type of characteristic", "kind-of-property", and "property value" is emphasized; the latter is defined together with "property value scale". These fundamental concepts are presented in a diagram, and the effect of adding essential characteristics to give expanded definitions is exemplified. Substitution usually leads to unwieldy definitions, but reveals any circularity as does exhaustive consecutive listing of defining concepts.

The top concept <property> may be generically divided according to many terminological dimensions, especially regarding which operators are allowed among the four sets $=$, $\neq$; $<$, $>$; $+$, $-$; and $\times$, $:$. The coordinate concepts defined are termed by the respective modifiers 'nominal', 'ordinal', 'differential', and 'rational' before '... property'. Other possibilities are given, especially the stepwise division into "nominal property" and "quantity"; "ordinal quantity" and "unitary quantity"; "differential unitary quantity" and "rational unitary quantity". As top concepts, <kind-of-property>, <examination procedure>, <examination>, <property value>, and <property value scale> are i.a. divided homologously to <property>. The term 'observation' and the modifiers 'qualitative', 'semiquantitative', and 'quantitative' are avoided.

"Metrological unit" and "system of metrological units" are defined together with a number of specific concepts. Some problems with characteristics of "SI unit" are discussed and an alternative system shown. The conceptions of "metrological dimension" are outlined, leading to a definition and specific concepts.

The generally accepted *IUPAC/IFCC* syntax for designations of instantiated properties is 'System(specification)--Component(specification); kind-of-property(specification)', and "dedicated kind-of-property" is defined as 'kind-of-property with given sort of system and any pertinent sorts of component'. The related systematic terms may be generated according to *ENV 1614* using generative patterns from *ENV 12264*. The elements of the appellation and examination result of a singular rational property are diagrammed. Finally, the possibilities of representing properties and their results by the formalisms of relation and function from Set Theory and Object-Oriented Analysis are exemplified.

PREFACE

Following graduation in Medicine from the *University of Copenhagen* 1951, a wish to acquire a better fundament in chemistry led to my postgraduate studies in organic chemistry, biochemistry, and physical chemistry, the latter subject under Professor *J.A. Christiansen* (1898-1969) and senior lecturer Dr *E. Güntelberg* (1885-1962). Ever since, the topic of Quantities and Units has occupied a part of my professional life.

Encouraged by colleagues in the *Danish Society for Clinical Chemistry and Clinical Physiology* (DSCCCP) - and often in collaboration with my colleague and friend, Dr *Kjeld Jørgensen* - a series of lectures, articles, and book chapters on quantities and units in clinical chemistry were presented from 1957 onwards in Danish, Nordic, and international professional fora and texts. The publications were applications, adaptations, and extensions of the recommendations by the *International Union of Pure and Applied Chemistry (IUPAC), Commission on Symbols and Physicochemical Terminology*, and by International Standards from the *International Organization for Standardization (ISO)/Technical Committee 12 on Quantities and Units.*

Eventually, a proposed set of *Recommendations 1966 (R-66)* were approved by the *IUPAC Commission on Clinical Chemistry* and by the *Council of the International Federation of Clinical Chemistry (IFCC)*. These recommendations were incorporated in a larger monograph by Dybkær and Jørgensen in 1967 [39].

Three important issues were:

- firstly, the increased biochemical insight gained by preferring quantities based on "amount of substance" with the unit "mole" over those based on "mass" with the unit "kilogram";
- secondly, the greater ease of comparing routine results for concentrations if a denominator for amount of system is chosen, i.e. litre or kilogram; and
- thirdly, the increased information content and unambiguous data transmission obtained by using systematic terms for properties examined in clinical chemistry and other laboratory disciplines.

Later, through work on the revisions of the 1984 and 1993 editions of the *International vocabulary of basic and general terms in metrology (VIM)*, I slowly realized the necessity of applying the rules and procedures of terminology work to provide coherent concept systems facilitating appropriate definitions and systematic terms. The present monograph is the outcome of these considerations concerning some central concepts in metrology.

In this context, for the initial formative stages of the present text, Diploma engineer *Heidi Suonuuti* (Helsinki, FI), former chairman of the *ISO*

Technical Committee 37 on Terminology and other language resources, has been an invaluable, kind, and expert influence.

During all these years, I have had the great privilege of being a member of national, regional, and international specialist groups for which terminology has been a significant or even main concern, either in a general sense or specifically related to metrology or my specialty Laboratory Medicine[1]. The listing raises fond memories of many intensive and instructive, humorous, and heated discussions with colleagues who became friends.

My participation in the discussions and work within these bodies obviously has been an important influence on this monograph. The involved eminent and dedicated scientists, however, should in no way be held responsible for any mistakes or deficiencies in this text.

Not all of these colleagues can be thanked here by name, but besides Dr *Kjeld Jørgensen* mentioned above I should specifically offer my sincere gratitude to Professor *Robert Zender* (†) (Chaux-de-Fonds, CH), Dr *J. Christopher Rigg* (Langhaven, NL), and Dr *Henrik A. Olesen* (Copenhagen, DK) - all major players in the field of properties and units in laboratory medicine, a subject that many would think esoteric, some essential.

My work on this subject obviously would not have been possible without some pied-à-terre, and thanks for excellent facilities and professionally stimulating climates are due to the administrations, department heads, and colleagues of the *Copenhagen University Institute of General Pathology* (later *Medical Microbiology*), the *Departments of Clinical Chemistry* at *The Old Peoples Town* (*De Gamles By*) and *Frederiksberg Hospital*.

The composition of this monograph has been made in my *Department of Standardization in Laboratory Medicine* at the *H:S Kommunehospitalet* (now abol-

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[1] During the last four decades, in various intervals, the set of groups includes:
- *CEN/TC 140 In Vitro Diagnostic Medical Devices/WG 4 on Reference Systems*,
- *CEN/TC 251 Medical Informatics/WG 2 Health Care Terminology, Informatics, and Knowledge Bases*,
- *DSCCCP Committee on Quantities and Units* (DK),
- *IFCC Expert Panel* (later *Committee*) *on Quantities and Units*,
- *ISO/TC 212 Clinical Laboratory Testing and In Vitro Diagnostic Test Systems/WG 2 on Reference Systems*,
- *ISO/Technical Advisory Group 4 Metrology/WG on the International vocabulary of basic and general terms in metrology (VIM)*,
- *IUB/IUPAC Committee on Biochemical Nomenclature*,
- *IUB/IUPAC Joint Commission on Biochemical Nomenclature*,
- *IUPAC Commission* (later *Subcommittee*) *on Nomenclature, Properties, and Units* jointly with the *IFCC Committee* (of the same name),
- *IUPAC Commission on Quantities and Units* jointly with the *IFCC Committee* (of the same name),
- *IUPAC/IFCC Joint Working Party on the Compendium of terminology and nomenclature in clinical chemistry*,
- *IUPAC Interdivisional Committee on Nomenclature and Symbols*,
- *Joint Committee for Guides in Metrology/WG 2 on the VIM*, and
- *Lykeion* (DK).

ished) and the *H:S* (now *REGION H*) *Frederiksberg Hospital* of the *Copenhagen University Hospital*, and thanks are offered to their administrations for the generous overhead provided. Special thanks for computer graphics are due to Draughtsmen Mr *Thierry Wieleman* and Mr *Benny Rosenfeld* who ably gave my sketched figures a professional appearance.

Finally, I am most grateful for the many years of skilful secretarial assistance, critical help, and steadfast friendship of correspondent, medical secretary Ms *Inger Danielsen*.

NOTE

This work to a large extent is identical with my thesis for Doctor of Medical Sciences, which was published in APMIS (Acta Pathologica, Microbiologica et Immunologica Scandinavica) 2004;112(Suppl 117):1-210, publicly defended, and accepted by the Faculty of Health Sciences at the University of Copenhagen (Denmark) 2004. This new text is not to be regarded as a thesis.

Many editorial changes have been introduced, mainly in response to new wording in International Standards and the third edition of the International Vocabulary of Metrology. Some technical modifications are due to an evolution in the author's views.

2009-04
R. Dybkaer

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FIGURES

Figures are numbered according to section of appearance.

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TABLES

Tables are numbered according to section of appearance.

ABBREVIATIONS

ASTM	American Society for Testing and Materials
BIPM	Bureau international des poids et mesures International Bureau of Weights and Measures
CCQM	Comité consultatif pour la quantité de matière Consultative Committee for Amount of Substance
CCU	Comité consultatif des unités Consultative Committee for Units
CEN	Comité Européen de Normalisation European Committee for Standardization
CGPM	Conférence générale des poids et mesures General Conference on Weights and Measures
CIPM	Comité international des poids et mesures International Committee for Weights and Measures
COD	The concise Oxford dictionary of current English, 1991
DIN	Deutsches Institut für Normung e.V.
DIS	Draft International Standard (of ISO)
EN	European Standard (of CEN)
ENV	European prestandard (of CEN)
EOQC	European Organization for Quality
IEC	International Electrotechnical Commission
IFCC	International Federation of Clinical Chemistry (and Laboratory Medicine)
ISA	International Society of Andrology
ISO	International Organization for Standardization
ISTH	International Society of Thrombosis and Haemostasis
IUPAC	International Union of Pure and Applied Chemistry
IUPAP	International Union of Pure and Applied Physics
JCGM	Joint Committee for Guides in Metrology
NCCLS	National Committee for Clinical Laboratory Standards, US
NPU	Nomenclature, Properties, and Units (code by IFCC/IUPAC)
OIML	Organisation Internationale de Métrologie Légale International Organization of Legal Metrology .
R-66	Quantities and units in clinical chemistry, 1967 [39]
SI	Système international d'unités International System of Units
VIM	International vocabulary of metrology, 1993 [7] or 2007 [132]
WAPS	World Association of (Anatomic and Clinical) Pathology Societies
WHA	World Health Assembly
WHO	World Health Organization

1 HISTORICAL INTRODUCTION

'- nothing lives if it is not properly placed in its historical context and tied to the dates that form the skeleton of its history'.
Maurice Danloux-Dumesnils, 1969 [28]

The ability of an individual continuously to examine internal and external signals by means of the senses and to compare the outcome with remembered or recorded previous instances in order to react advantageously is a prerequisite to survival and well-being of individual and society.

When the object of examination is the overt appearance of another human being and the purpose is diagnosis with a view to alleviate his or her distress, we have the inception of health care as performed by a mother on her child or of medicine as practiced by a witch-doctor on a customer.

The examination of a person's excreta opens a new door to diagnosis as when Egyptian priests under *Akhenaten* (*Imhotep IV*) three and a half millenia ago used grain as a herbal sensor for urinary growth-promoting hormone to reveal pregnancy; or when Indian clinicians two millenia before our time noticed that ants are partial to 'honey-urine' from diabetics.

The more formal examination of the patient's urine - the so-called uroscopy - was heralded by *Hippocrates of Kos* (460-377) who related the formation of bubbles in the urine to renal disease [51]. (We now know that the sign is caused by an abnormally high protein excretion.)

Such serendipitous discoveries were slowly supplemented by experimental clinical chemistry introduced by the Swiss physician and alchymist *Philippus Aureolus Theophrastus Bombastus von Hohenheim* (1493-1541), alias *Paracelsus*, who extolled the importance of 'iatrochemistry' in shedding light upon medical problems as follows.

> 'Chemistry solves for us the secrets of therapy, physiology and pathology. Without chemistry we are trudging in darkness'.
>
> (after *I.M. Kolthoff* [90])

The next three centuries saw important progress in 'qualitative' examinations - first of inorganic elements, later of organic compounds - such as when *Robert Boyle* (GB, 1627-1691) in 1684 examined human blood for chloride [12] and *William Hyde Wollaston* (GB, 1766-1828) in 1810 found the amino acid cystine in human bladder stones [127].

'Quantitative' examinations of properties with many possible values are sometimes achieved by subjective judgement of a single person or a panel of assessors, e.g. for winetasting, but are mostly performed by measuring instruments, which have been evolved during the last two centuries for, e.g., gravimetry, volumetry, and spectrometry, culminating in present-day big, 'automated', multichannel, self-calibrating, self-controlling, artificial-intelligent electromechanical, and electronic diagnostic machines or small, sophisticated, disposable measuring devices.

The operation of such complex and often expensive equipment elicited a need for medical laboratories with specialized dedicated personnel. The first were established during the eighteen hundreds, especially in the hospitals of German speaking Europe. Around 1900, small medical department laboratories were common and fifty years later they had grown to become huge, centralized, independent departments to accommodate specialists and equipment providing daily results in the thousands. Today, technological advances and miniaturization permit considerable decentralization to aid 'point-of-need examinations' - usually called 'point-of-care testing' (POCT) - whether at the hospital bed, in general practice, or by the patient himself.

Fundamental to all communication about the outcome of an examination is a comparison with a conventionally accepted reference, either in the form of a procedure or a standard, and ancient examples of weights and measures were used by the Babylonians and Egyptians thousands of years ago. Today, most of the measurement units that are universally accepted - although not fully implemented - constitute the *Système International d'Unités* (*SI*) [6] which is predominantly used for data in science and technology.

NOTE 1 - The SI has been developed from the *Convention du Mètre*, adopted in Paris 1875-05-20, which was itself based upon the *Metric System* of an originally 'natural system' of units suggested by the French diplomat *Charles Maurice Talleyrand-Périgord* (1754-1838), vainly in 1790 and with some success in 1799 [28].

In some cases, an SI unit is not applicable and off-system units, such as the *WHO* international units for some biological substances, are defined independently [129].

NOTE 2 - Another example of an off-system unit - albeit for a difficultly measurable, 'soft' property - was proposed by *Mr Tim Daw* in a letter to The Times (1996-07-08) defining one milliHelen, as the amount of beauty needed to launch one ship. *Mr Daw* must be a devotee of *Homer*.

The expression of a measurement result generally needs a number, and our present conventional number system is a combination of ancient ideas. The early Egyptian had a decimal system of counting; the Sumerians used a positional notation in writing sexagesimal numbers; around the year 200 A.D. the Indians had symbols for the integers zero to nine, and about 1200 they had real decimal positional notation for fractions. In Europe, the Western Arabic number symbols were modified and adopted, the Scot *John Napier* (1550-1617) introduced the decimal sign, and the Dutchman *Simon Stevin* (1548-1620) introduced the comma and gave a fundamental description of the whole system and its use [29].

The expansion and diversification of Laboratory Medicine around the middle of the last century was pioneered by various types of professional - e.g. physicians, chemists, biochemists, pharmacists, chemical engineers, and physicists. Consequently, the unambiguous exchange of laboratory data and information became more difficult due to a cornucopia of terms, local conventions, and unsystematic ad hoc vocabularies. This development was not only inconvenient, but sometimes exposed patients to risk due to inadvertent misinterpretation of transmitted 'unfamiliar' data.

NOTE 3 - The concept "laboratory medicine" is used here in the sense of 'branch of medicine providing the health care system with laboratory results and related information and advice pertaining to the clinical state and treatment of health care recipients' [38].

To improve this unfortunate situation - and following a decade of studies centred in Copenhagen [27, 35, 36] - a monograph was prepared in 1967 [39], incorporating a *Recommendation 1966* (here sometimes abbreviated *R-66*) from the joint *Commission on Quantities and Units (in Clinical Chemistry)* of the *International Union of Pure and Applied Chemistry* (*IUPAC*) and of the *International Federation for Clinical Chemistry* (*IFCC*). The treatise emphasized the need for a metrological and physico-chemical view of the properties examined in the clinical laboratories. It also embraced and extended the special metrological language elaborated by several international scientific bodies, and foremost the *Technical Committee on Quantities, Units, Symbols, Conversion Factors, and Conversion Tables of the International Organization for Standardization* (*ISO/TC 12*) as presented in the *ISO* 31-series, currently under revision [64], and that of the *IUPAC Division of Physical Chemistry*, now also in a new edition of *'The Green Book'* [82].

The monograph, including *R-66*, was timely both because metrological concepts were scantly known among the heterogeneous group of practitioners of Laboratory Medicine, and because the metrological basic documents did not cover all needs of the medical laboratory, being restricted to "physical quantities" also called "measurable quantities" and ignoring other important forms of properties.

The document further suggested a new systematic syntax and format for the names of the properties of systems being measured or otherwise examined in the medical laboratories.

During the following three decades, many updated and expanded recommendations in the field of Laboratory Medicine have adhered to the same principles [e.g. 61, 83, 84, 85, 86]. Throughout, however, there has been uncertainty about definitions and terms for some concepts related to "quantity" that are central to the special language of metrology.

NOTE 4 - "Special language" is defined in the *International Standard ISO 1087-1 "Terminology Work - Vocabulary - Part 1: Theory and application"* as 'language used in a subject field and characterized by the use of specific linguistic means of expression' [72-3.1.3]. A more nourishing (and somewhat circular) definition of "language for special purposes (LSP)" is given by *Picht & Draskau*: 'formalized and codified variety of language, used for special purposes and in a legitimate context - that is to say, with the function of communicating information of a specialist nature at any level - at the highest level of complexity, between initiate experts, and, at lower levels of complexity, with the aim of informing or initiating other interested parties, in the most economic, precise and unambiguous terms possible' [110]. A useful discussion of the approaches to and the characteristics, relations, and uses of "LSP" is found in a thesis by *Høy* [59].

The uncertainty is still present in spite of the appearance of three editions of the *International vocabulary of metrology* [7, 9, 132]. (*VIM2* will indicate the second edition from 1993, *VIM3* the third edition from 2007 and 2008), and a review by *Thor* [120] of the *ISO 31-0 "Quantities and units - General principles"* [64].

Besides the simple term 'quantity' [28, 29, 38, 39, 61, 64, 82, 83, 84, 85, 86, 131, 132], the set of terms for closely related concepts includes the complex terms

- 'kind-of-quantity' [22, 37, 39, 61, 83, 84, 86, 131, 132] (often written without hyphens [33, 39, 132]);
- 'physical quantity' [64];
- 'measurable quantity' [7, 9];
- 'quantity in a general sense' [7, 120];
- 'quantities of the same kind' [7, 64, 120];
- 'category of quantities' [7, 64, 120]; and
- 'particular quantity' [7].

The problems increase when concepts for the group of 'qualitative' properties that are not accepted as quantities, but which form important items of medical laboratory reports, have to be meshed with the concepts surrounding "quantity".

The following terminological study of the concepts involved was therefore undertaken with a view to form concept systems and consequent definitions and partially systematic terms for a central part of the professional or special language of metrology used in describing states and processes of physical, chemical, and biological systems, including a contribution to the standing discussion on a consistent nomenclature for requesting and reporting examinations in Laboratory Medicine.

In other words, the aim is to fashion and describe a domain ontology related to the top concept "property".

NOTE 5 - The concept "ontology" is here taken to have one of the emerging meanings of 'characteristics, definitions, terms, and relationships of the significant concepts in a given domain' (see discussion in [55, 122]).

The source material, besides classical and modern texts on metrology, includes terminology documents related to physics, chemistry, laboratory medicine, and metrology. International, European, and a few National standards have been consulted as being the valuable outcome of consensus between various stakeholders.

There will be no attempt to adhere to a single theory of knowledge, whether under the heading of empiricism, rationalism, historicism, or pragmatism - they are all views with various valid traits [4]. The principal aim is a useful outcome. A wholesale acceptance of the proposed concepts, definitions, and terms cannot be expected, but they may serve as a stimulus for further discussion and evolution.

The necessary tools for the terminology work undertaken will be described in the following Chapter 2.

2 TERMINOLOGY

'How many a dispute could have been deflated into a single paragraph if the disputants had dared to define their terms.'

Aristotle, 384-322 B.C. [quoted in 109]

FUNDAMENTALS

2.1 The formation and description of an ontology (Ch.1-Note 5) unavoidably depends on the choice of a special language (Ch.1-Note 4) of terminology. Among the several possibilities, the current terminological inherent philosophy, principles, and vocabulary of the *ISO Technical Committee 37 Terminology (Principles and Coordination)* [71, 72, 117] have been preferentially used in the present text because they are international, updated, and generally available.

As some of the *terminological concepts* used may not be widely known to non-terminologists, such concepts are conveniently given by term and definition in an alphabetical Vocabulary (Annex A). An elevated vertical bar, '|', preceding a word in the text, usually only at first appearance in a given chapter as well as in legends to tables and figures, marks that the vocabulary has an entry starting with that word or a closely related one of the same root. Thus, among the above words, 'special language', 'vocabulary', 'terminology', 'concept', 'term', and 'definition' should have had a bar and their respective definitions can be found in Annex A. Some textual notations indicating types of terminological concept to be discussed later are given in Table 2.1.

The graphical notations used in the |concept diagrams are mostly taken from the *ISO* [72] and are given in Figure 2.1 for convenience. This set of notations is fairly primitive. Thus, there are no indications of |specific concepts under |associative relation (such as causal, sequential, and temporal relation), nor of respective roles and cardinalities of the partners in a relation. For the present purpose, however, the set suffices.

2.2 The fundamental |metalinguistic concepts

"concept" (further in Section 2.10),
"term" (also called 'definiendum'),
"definition" (also called 'definiens'), and
|"object" (also called 'referent') (further in Section 2.23)

may be considered to form a three-faced pyramidal |concept system with "concept" at the top and in associative relations with the other three at the bottom [21, 117], e.g. as in Figure 2.2, upper part.

Table 2.1 Notations for representation of some ¦terminological ¦concepts (see also Sections 2.14.2, Note 4 and 2.18, Note 2)

¦Concept (¦Definition)	Notation	Examples	
concept (S.2.10)	".."*	"erythrocyte"*	
¦superordinate concept as top concept	<..>	<blood cell>	
¦characteristic (S.2.11)	having .. or being ..	having the colour red or being red in colour	having the diameter 7.4 µm or being 7.4 in diameter
¦set of ¦coordinate characteristics (S.2.16)	{having .., having .., ...} {being .., being .., ...}	{being red, being white, ...}[a]	{being 7.3 µm, being 7.4 µm, ...}[b]
type of characteristic (S.2.14.2)	having a ..	having a colour	having a diameter
individual characteristic (S.2.18)	has .. or is ..	has the colour red or is red in colour	has the diameter 7.4 µm or is 7.4 µm in diameter
set of coordinate individual characteristics (S.2.16, 2.18)	{has .., has .., ...} {is .., is .., ...}	{is orange, is blue, ...}[c]	{is 7.3 µm, is 7.4 µm, ...}[d]
kind-of-property (S.6.19)	".."	"colour"	"diameter"
singular property (S.6.14.1)	".."	"colour = red"	"diameter = 7.4 µm"
¦instantiated property (S.5.5)	.. = ..[e]	colour = red[e]	diameter = 7.4 µm[e]
property value (S.9.15)	= ..	= red	= 7.4 µm
set of property values (S.9.15)	(= .., = .., ...)	(= orange, = blue, ...)	(= 7.3 µm, = 7.4 µm, ...)
¦term or quotation or internal reference	'... . ..'	'erythrocyte'	

* The *ISO 1087-1* uses single quotation marks [72].
a,c in colour; b,d in diameter. These phrases follow their respective parentheses.
e with spatio-temporally defined system including any relevant component

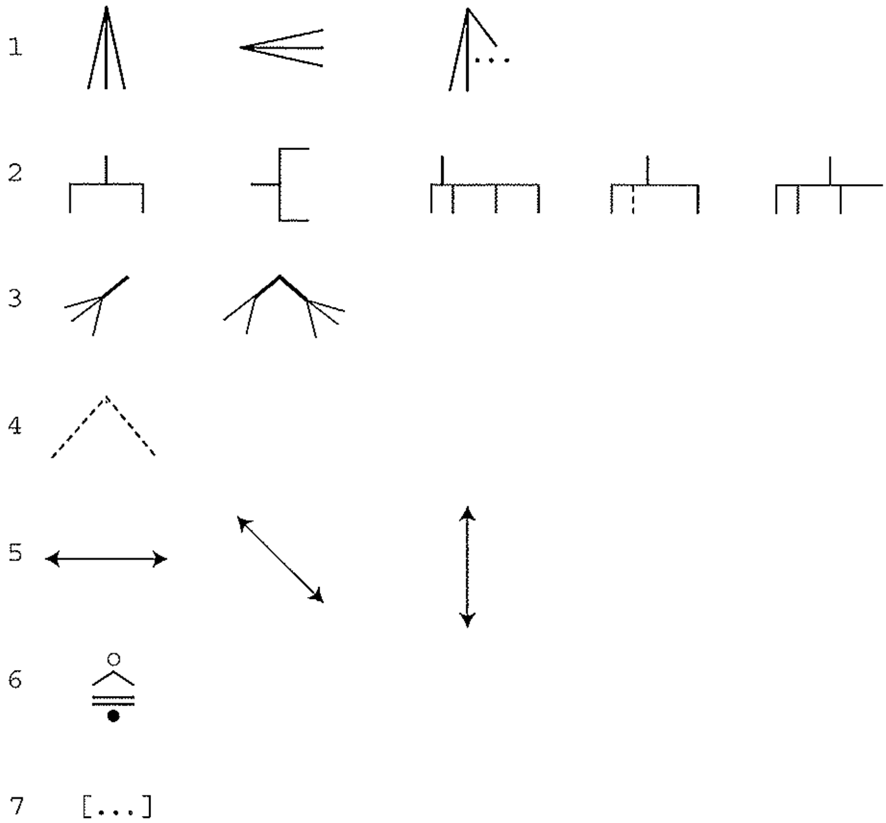


Figure 2.1 ˈTerminographical notations

ˈHierarchical structures

1 ˈGeneric relation as a tree diagram from a ˈgeneric concept to ˈspecific concepts; possible, but unspecified further specific concept(s) are shown by a short additional line and three dots.

2 ˈPartitive relation as a rake diagram from a ˈcomprehensive concept to ˈpartitive concepts where a close-set double line indicates similar partitive concepts; an uncertain such plurality is shown by one of the pair of lines being broken; possible further partitive concepts are indicated by an extended back lacking any tooth.

3 Terminological dimensions (S.2.19) (one and two)

4 Possible plurilevel ˈgeneric hierarchy

Non-hierarchical structure

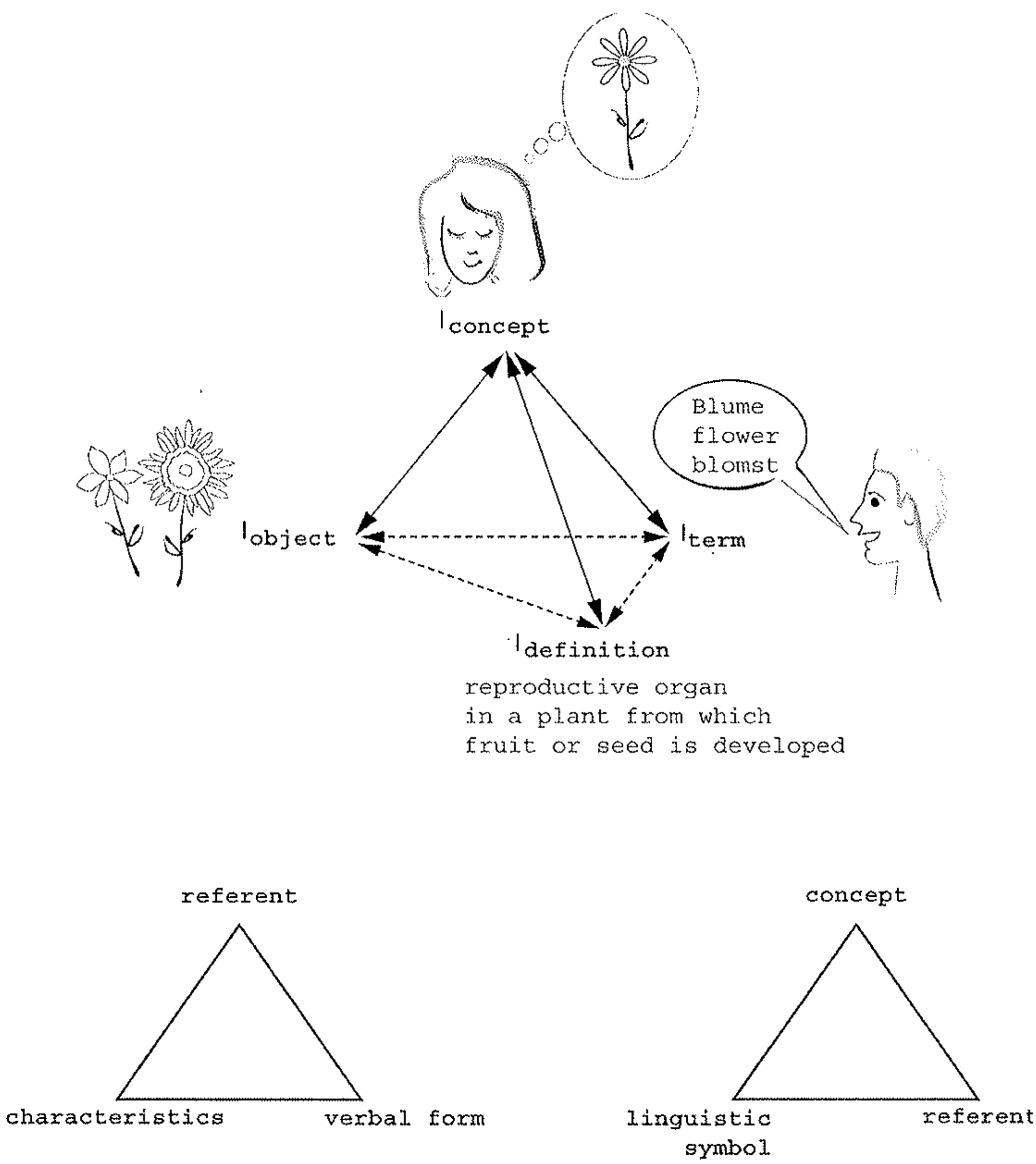
5 ˈAssociative relation as a double-headed arrow between two ˈconcepts in thematic connection

Instantiation

6 Correspondence ≙ between an ˈindividual concept ○ and its ˈinstance ●

Undefined concept

7 Concept indicated by ˈterm in a figure, but not explicitly defined. (ISO 1087-1 [72] uses parenthesis, not square brackets.)



The concept triangle, corresponding to the (rotated) base of the pyramid.

The semantic triangle (*Ogden´s* triangle), corresponding to the (left - right shifted) rear side of the pyramid.

Figure 2.2 Illustrated diagram of some fundamental ˡconcepts of the conceivable and perceivable world (after Suonuuti [117] and ENV 12264 [21]).

Double-headed full-line arrow = fundamental ˡassociative relation.
Double-headed broken-line arrow = secondary associative relation.
"Term" could be exchanged for the ˡgeneric concept "designation".
The semantic triangle [60] and the concept triangle [26] are shown for comparison.

This |onomasiological concept system, emphasizing "concept", is felt more applicable to the present task than the alternative |semasiological view of having "term" as a |comprehensive concept covering the |partitive concepts "expression" and "concept" [97]. The top of the pyramid, "concept", is in the mind. The three 'ground level' entities are claimed to be either

a) concrete or abstract phenomena, perceived or conceived (termed objects or referents), exemplifying the concept or
b) representations of the concept (such as definitions and terms) in a language used in communicating about the concept.

This arrangement should not be interpreted as if "concept" is generating all three lower entities. There is usually a |causal associative relation from object(s) to a concept that has been justified and clarified as to meaning - this process is called conceptualization [71-5.1 to 5.3] (see also Sections 6.21 to 6.25). Subsequently comes the formulation of a definition and explanation, and the selection of a term (or other verbal |designation or a non-verbal designation) for communication.

NOTE - This concept system is simplified in the sense that "term" and "definition" can be considered to be specific concepts under "representation", but the structure is sufficient in the present context.

Some triangular diagrams are closely related to the pyramidal structure (see Figure 2.2, lower part). *Dahlberg* [26] has a 'concept triangle' with "referent" at the top, "characteristics" (or "meaning") at the lower left and "verbal form" (or "term") at the lower right corner - in toto said to constitute the concept. This triangle resembles the base of the pyramid. *Iivonen* and *Kimimäki* [60] draw a 'semantic triangle' with "concept", "linguistic symbol" (or "name"), and "referent", thus resembling the rear face of the pyramid, sometimes known as '*Ogden*'s triangle'.

2.3 The terms and definitions of some |*metrological concepts* that may be unfamiliar to non-metrologists are also presented in the Vocabulary (Annex A) and signalled in the text by the elevated preceding vertical bar.

2.4 Each |terminological entry for a *proposed concept* given in the main text is framed. The |intensional definition is phrased according to the *ISO* terminological rules [71, 117] of

- being brief;
- containing information sufficient to indicate the position in a concept system;
- using the nearest |generically |superordinate concept;
- adding one or a few |delimiting characteristics; and
- putting other information in notes.

2.5 The ˡmicrostructure of such a terminological entry with suggested term(s), definition, any example(s), and note(s) is essentially according to *ISO* [63] with

- proposed ˡpreferred, usually ˡsystematic term(s) in bold type in a separate line (for each);
- ˡadmitted term(s) in lightface type in a separate line (for each);
- any symbol;
- metrological concepts used the first time in the text of the entry and defined elsewhere in the text given in bold type with parenthetic Section number '(S.Z)' or reference to the Vocabulary by an elevated vertical bar.

The proposed concepts can be found by term(s) in the alphabetic Glossary (Annex B).

2.6 *Other concepts* with terms and definitions taken from referenced sources or fashioned for discussion are indented with term in italics, colon, definition, and any relevant source in square brackets. The referenced concepts are found in Annex A, the working concepts in Annex B.

2.7 Considering the partially conflicting terms and definitions of metrological concepts found in various authoritative documents, the eventual proposals will entail choices and changes from such earlier texts. This becomes necessary if a consistent, partially systematic ˡnomenclature is to be based upon a chosen concept system and if the consequent intensional definitions are to use terms that may be substituted by the corresponding definitions [71]. It should be stressed, however, that - even within a given concept system - the definition of a concept may be phrased in several ways. As regards the choice of systematic terms, the partially conflicting principles of term formation are detailed in the *ISO 704* [71-7.3]. Important considerations have been

- transparency, i.e. inference from term to concept, and
- consistency, i.e. a coherently structured terminological system corresponding to the concept system,

whereas the advantage of

- linguistic economy,

which may conflict with

- accuracy,

is sometimes achieved by an admitted ˡabbreviated form.

2.8 Because of the multiple relations of the metrological concepts being discussed, a given concept may have to be used in text before being formally designated and defined. An internal reference to the appropriate section having the terminological entry should diminish any initial inconvenience associated with such forward references.

2.9 Unfortunately, the terminological concept systems, the definitions of seemingly similar concepts, and their terms vary between organizations and authors or even within a given text. Thus, there is no universal terminological metalanguage [e.g. 96, 97, 119]. As mentioned, however, the terminology used here is mainly that of the *ISO 1087-1* [72]. Yet, to avoid misunderstandings, it seems pertinent to discuss a few central terminological concepts and their relations for use in the present context.

"CONCEPT" AND "CHARACTERISTIC"

2.10 The basic concept "concept" is defined by the *ISO 1087-1* as follows.

> *concept*: unit of knowledge created by a unique combination of characteristics (S.2.11) [72-3.2.1]

Although there are many views on the nature of a concept [see, e.g., 4], it will here be considered to be a mental entity that generalizes a set of one or more objects. The concept corresponds to a class of such objects constituting the extension (S.2.24) of the concept.

The subject of conceptualization is taken up again in Sections 6.21 to 6.25.

2.11 A property that occurs in all the objects of such a collection is generalized as a characteristic, defined by the *ISO* as

> *characteristic*: abstraction of a property (S.5.5) of an object (S.2.23) or of a set of objects [72-3.2.4]

which together with the definition of "concept" (S.2.10) shows that concepts are considered to 'have' characteristics, whereas objects 'have' properties (see Chapter 5).

> NOTE 1 - Unfortunately, there is another definition of "characteristic" in the recent International Standard on *Quality management systems EN ISO 2000* [70-3.5.1], also quoted in the *ISO 3534-2* [75-1.1.1], namely 'distinguishing feature'. This is ambiguous because there is no indication of whether the distinction concerns a concept or an object. The latter relation is probably assumed - judging from the Notes with examples - so that the definition applies to the concept that will here be termed

'property' (S.5.5) as discussed in Section 5.1.

Note 2 - The tendency to confuse "characteristic" and "property" is not new as evidenced by the *EOQC* defining "characteristic" as 'property which helps to differentiate between items of a given population' [44-1.3.2]; the *IUPAC* giving 'property or attribute of a material that is measured, compared, or noted' [80-2.1.3]; and the *ASTM* stating 'property of items in a sample or population which, when measured, counted or otherwise observed, helps to distinguish between the items' [2].

2.12 In the *ISO* concept diagrams, the relation between "concept" and "characteristic" is shown as ¦associative [72-A.2]. This may seem strange in view of the phrase 'created by' in the definition of the former (S.2.10) and the definition of

intension: set of characteristics which make up the concept [72-3.2.9]

together with a ¦partitive relation between "characteristic" and "intension" [72-A.3]. (That this partitive relation is depicted as being 'unfinished' could be a mistake.) The difference between the definitions of "concept" and "intension" is not that obvious, as pointed out by *Nistrup Madsen* [96], and could suggest a partitive rather than an associative relation between "concept" and "characteristic". Here the latter sort of relation will be preferred in accordance with the phrases 'unique combination' in the definition of "concept" and 'set of' in the definition of "intension". The whole ('combination') is here considered to be a complex that is more than the mere accumulation of its parts ('set').

2.13 The *ISO* presents a terminologically pluridimensional (S.2.19) ¦generic tree diagram on <concept> [72-A.2] which can also be shown as a simple field diagram (Table 2.13). There is no definition for a concept entering into an associative relation with another concept; only hierarchical concepts are included.

2.14 The ¦superordinate concept <characteristic> can also be divided into a generic hierarchy, including ¦"essential characteristic" and its specific concept ¦"delimiting characteristic" [72].

2.14.1 Furthermore, the *ISO* defines "type of characteristics" (with a plural 's') as

type of characteristics: category of characteristics which serves as the criterion of subdivision when establishing concept systems [72-3.2.5]

and provides examples such as (in the *ISO* notation) <u>colour</u> embraces <u>being red</u>, <u>being blue</u>, etc.

Table 2.13 Simple field diagram on the ǀgeneric relations of ǀ<concept> (S.2.10). Fields that are separated by a horizontal double line belong to different terminological dimensions (S.2.19). ǀDefinitions are given in the ǀVocabulary.

concept	ǀgeneral concept	
	ǀindividual concept	
	ǀsuperordinate concept	ǀgeneric concept
		ǀcomprehensive concept
	ǀsubordinate concept	ǀspecific concept
		ǀpartitive concept
		ǀcoordinate concept

"Category" is not defined, but lexical synonyms are 'type', 'class', 'set', 'division', and 'group'. How a *set* of different characteristics could function as a (single) criterion of division is not quite obvious. Probably the intent is rather to consider 'type' as a divisible entity which is common to a set of characteristics.

2.14.2 For the present purposes, the term and definition and representation of examples will be modified as follows.

type of characteristic: common defining aspect of a ǀset of coordinate characteristics (S.2.16)

NOTE 1 - The set of coordinate characteristics can serve when dividing a ǀgeneral concept into ǀspecific ǀcoordinate concepts.

EXAMPLE 1 - having a physical property is ǀsuperordinate to the set of coordinate characteristics {having a colour, having a length, ...} as a physical property. Each of these coordinate characteristics subsequently become a type of characteristic for the next lower level.

EXAMPLE 2 - having a gender is superordinate to the set of coordinate individual characteristics (S.2.18) {is female, is male, ...} in gender

NOTE 2 - "Type of characteristic" gives an indication of a ǀhierarchical level where a given characteristic will be further divided into coordinate characteristics. (See further Section 2.17.)

NOTE 3 - In a plurilevel hierarchical ǀconcept system of characteristics in n levels, there may be n-2 separate types of characteristic.

NOTE 4 - In this text, the isolated |term for a characteristic in general may be underlined and begin with the present particle of a verb, e.g. '<u>having</u> ...' whereas the term for a type of characteristic undergoing division may be given a double underlining and begin with the present participle of a verb and the indefinite article, e.g. '<u>having a</u> ...'; such conventions are language dependent. See also Section 2.18 Note 3.

2.15 The |general concept "human body" might be described, e.g., by the consecutive, increasingly specific, generically related characteristics

<u>having physical property</u>
- <u>having spatial dimension</u>
  -- <u>having height</u>

Each of these characteristics can also be considered to be a type of characteristic because there would be other physical properties than <u>having spatial dimension</u>, other spatial dimensions than <u>having height</u>, and manyl heights. Thus, the first-level type of characteristic with its set of generically subordinate characteristics is

<u>having a physical property</u>	(KI)		
- <u>having spatial dimension</u>	(KIA)	)	
- <u>having mass</u>	(KIB)	)	SI
- <u>having volume</u>	(KIC)	)	
- etc.		)	

where the first three indented entries are members of the first set of delimiting coordinate characteristics (SI). The codes are used in Figure 2.15. The first of these subordinate characteristics, e.g., obviously is also a second-level type of characteristic for a second-level set of delimiting coordinate characteristics (SIA), e.g.

<u>having a spatial dimension</u>	(KIA)		
- <u>having height</u>	(KIAa)	)	
- <u>having sagittal thickness at the waist</u>	(KIAb)	)	SIA
- etc.		)	

For the concept "human body" an analogous subdivision into a second level set of further divisible coordinate characteristics would not apply in each of the characteristics <u>having mass</u> and <u>having volume</u>. They would subdivide directly into individual characteristics (S.2.18) analogously to the following.

One third-level type of characteristic and its subordinate individual characteristics (S.2.18) would be

having a height	(KIAa)		
- is 1,63 metre in height	($KIAa_1$)	)	
- is 1,64 metre in height	($KIAa_2$)	)	SIAa
- etc.		)	

where each of the two first indents (in SIAa) is a delimiting characteristic that is also an individual characteristic (S.2.18) of the individual concept of a given person. The concept system for all these characteristics is shown in Figure 2.15 by their symbols showing the plurilevel generic inheritance.

2.16 The following concept has been used already in the definition and examples of "type of characteristic" and merits a working definition.

coordinate characteristic: member of a ¦set of comparable ¦delimiting characteristics ¦subordinate to the same characteristic (S.2.11)

EXAMPLES - In Section 2.14 Examples 1 and 2; Fig. 2.15, e.g. the members of the sets {KIA, KIB, KIC} and {$KIAb_1$, $KIAb_2$}

2.17 It may be discussed whether the relation between "type of characteristic" and a given example is generic or associative (*Suonuuti* [118]). A generic relation would apply to the examples KI and KIA in Figure 2.15 because they divide generically into lower types of characteristic such as for KI into KIA, KIB, and KIC, which can inherit the traits of "type of characteristic". When the levels of KIAa, KIAb, KIB, and KIC are reached, however, the further division shown is into individual characteristics and they cannot inherit the traits to become themselves types of characteristic. For this reason, and because there is no *ISO* notation for stopping generic inheritance, the relation between "type of characteristic" and a given example is here chosen to be associative. It should be mentioned that the *ISO* shows an associative relation between "type of characteristic<u>s</u>" and "characteristic" and no superordinate concept for the former [72-A.3].

2.18 It may be useful in terminological discussions to have a concept indicating that a given characteristic relates to an individual concept and is not further subdivided in a given context. A working term and definition is the following (see also Fig. 2.15).

individual characteristic: characteristic (S.2.11) of an ¦individual concept

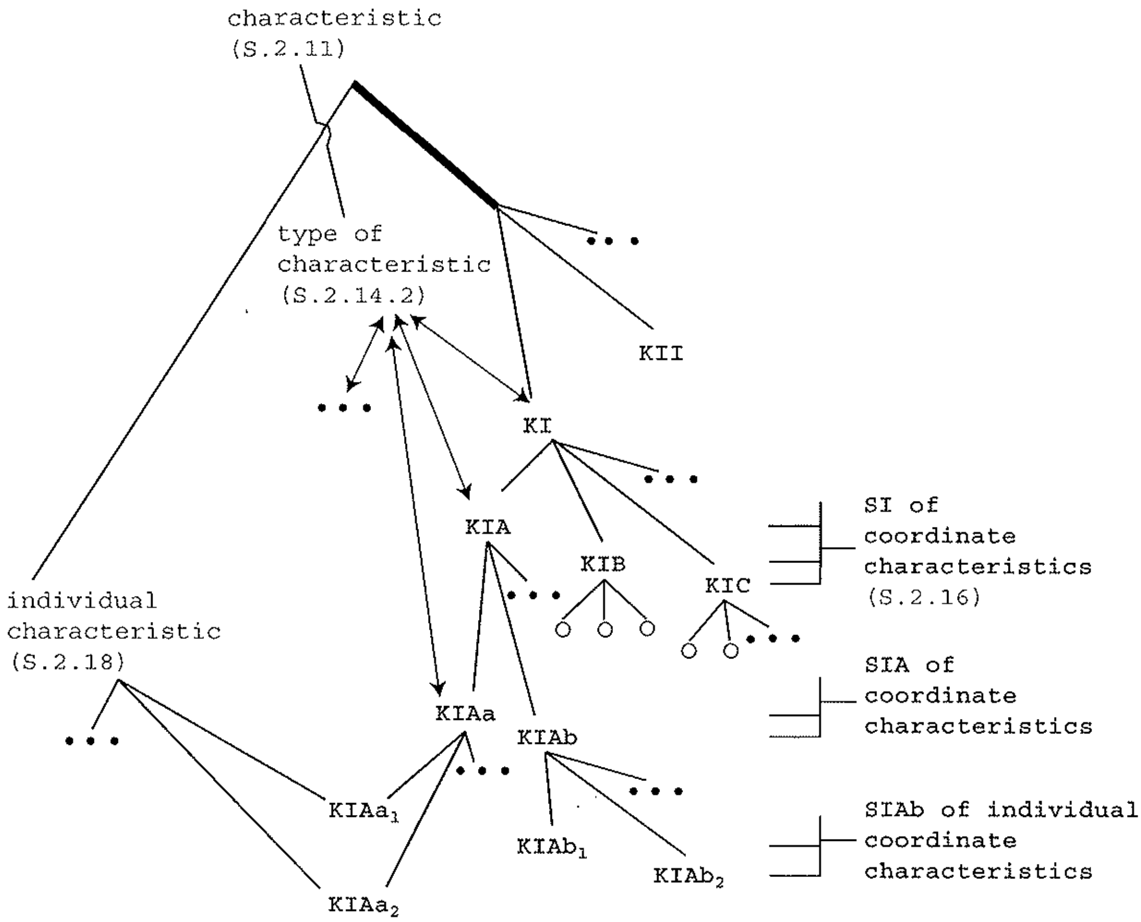


Figure 2.15 Mixed ˡgeneric, ˡpartitive, and ˡassociative ˡconcept diagram on <characteristic> (S.2.11).

The five-level generic ˡhierarchy is based on Section 2.15, starting from "characteristic" to the second level, KI, going through three lower levels (KIX, KIAx, and $KIAx_y$). KI is generically ˡsuperordinate to the members of the ˡset of coordinate characteristics (S.2.16), SI. Two of these ˡsubordinate ˡdelimiting coordinate characteristics at the third level, KIB and KIC, become ˡtypes of characteristic and are each subdivided into a set of delimiting coordinate characteristics, indicated by circles, or an unspecified branch. The third subordinate characteristic at the third level, KIA, is subdivided into an unspecified and two specified characteristics at the fourth level, KIAa and KIAb, forming a set SIA with each member having subordinate delimiting coordinate characteristics indicated by subscript Arabic numerals in $KIAa_y$ and $KIAb_y$. One set is shown as SIAb. The left hand side of the diagram shows various levels in the hierarchical concept system with type of characteristic, such as KI, KIA, or KIAa, which each covers the members of a set of coordinate characteristics. An individual characteristic (S.2.18) is an indivisible characteristic in a given context, for example the four symbolized $KIAa_y$ and $KIAb_y$.

EXAMPLES - is 2.87 metres in height (for an imagined "special human giant"); is red in colour (for "an identified erythrocyte"); the characteristics $KIAa_1$ and $KIAb_2$ in Fig. 2.15; has Danish personal social number 010198 0395 (for "a specific person")

NOTE 1 - An individual characteristic, say is red in colour, relates to an individual concept, but may occur in many individual concepts (each corresponding to one object).

NOTE 2 - In this text, the term for a characteristic taken to be individual in the context begins with a verb in the present tense, e.g. is ..., has ..., but such a convention is language dependent.

NOTE 3 - An individual characteristic in one generic hierarchy of <characteristic> may be modified into a type of characteristic in another hierarchy because of subdivision. Thus, is red in colour may disappear in favour of having a red colour with individual characteristics such as {is pink, is bordeaux, ...} in red colour.

2.19 The phrase 'terminologically pluridimensional' (S.2.13) has been used without a definition of "terminological dimension". The *ISO 1087-1* does not offer a formal entry for this important concept, but uses 'criterion of subdivision'. The *ISO 704* speaks of 'dimension criterion' without definition [71-5.4.2.2]. For the present purposes a working term and definition will be

terminological dimension: hierarchical division of a concept according to a type of characteristic (S.2.14.2)

NOTE - The concept being divided is either a ˡgeneric or a ˡcomprehensive concept. Its subordinate concepts will be distinguished by the coordinate characteristics (S.2.16) of the type of characteristic.

GENERIC INHERITANCE

2.20 An essential trait of a generic concept system is that down through the hierarchy any subordinate concept inherits all the characteristics of its previous superordinate concepts in that line. Thus, if is 1.63 metre in height is an individual characteristic (S.2.18) generically subordinate to the type of characteristic (S.2.14.2) having a height (rather than having a waist circumference), then the description of having a height also applies to is 1.63 metre in height. Going further upwards, one is consecutively informed that having a height is also subordinate to having a spatial dimension and that this, finally, is subordinate to having a physical property. Thus, strictly speaking, the full designation of the individual characteristic might be is 1.63 metre in height as a spatial physical dimension.

Usually, less will do, but the bare alphanumeric representation 'is 1.63 metre' obviously cannot ensure that the intended inherited characteristics are automatically and unambiguously conveyed and understood.

2.21 Superficially, it would seem that the characteristic is red in common parlance simply implies having a colour so that there is no need to mention the term for the type of characteristic in the term for the characteristic. Talking about wine, the assumption is valid (and so much so that 'red' is a synonym for 'claret'). If the subject of discussion is the political persuasion of a person, is red has a completely different meaning that is not related to skin, garments, or hair. Thus, as is well known, the information contained in a ꜝhomonymous ꜝdesignation depends on the context.

2.22 Entering the realm of laboratory medicine, a simple example relates to the general concept "red blood corpuscle", with the ꜝsynonym 'erythrocyte' (as used in Table 2.1). A typical human erythrocyte is shaped as a more or less circular, biconcave disk with a central thickness of about 1.2 micrometre (1.2 μm). Whereas, for the erythrocyte, is red with good reason implies having a colour, the ꜝunit of measurement, micrometre (μm), in is 1.2 micrometre by itself is not unambiguously indicating having a central thickness; the alphanumeric string is 1.2 micrometre could also apply to thickness near the rim of a cell. Even more disconcerting, having a thickness might not be meant because "erythrocyte", having a volume divided by surface area (also called 'having areic volume'), has individual characteristics expressed in the same unit, e.g., is 85 cubic micrometres divided by 140 square micrometres equal to is 0.6 micrometre. Such ꜝhomonymy becomes completely unmanageable in the many cases where the unit involved is "one", as for individual characteristics of having a relative mass density (for "erythrocyte") and having a number (e.g. of "blood group A sites on the erythrocyte surface"), both types of characteristic of "erythrocyte".

"OBJECT" AND "PROPERTY"

2.23 Turning from the world of concepts to that of objects, the *ISO 1087-1* defines the general concept covering such 'things' as follows.

object: anything perceivable or conceivable [72-3.1.1]

with a note indicating that objects may be material, immaterial (abstract), or imagined. Thus, respective examples could be a given woman's blood, her pulse rate, and a pursuing vampire from her dream. They are all ꜝinstances (or referents) of general concepts.

NOTE 1 - The form of definition, starting with 'anything' is not semantically practical for substitution. 'Thing' (as a primitive) would be proper.

NOTE 2 - It is beyond the present text to discuss the reasons for the evolution in the terms used in relation to *Aristotle*'s "substance": from the 'subject' of scholasticism to the 'object' of modern philosophy.

NOTE 3 - The *ISO* example of a conceivable object is 'a unicorn'. Whereas many representations of such a creature exist in books and on tapestries, it is highly doubtful that living examples have existed. (Any exhibited object of a metre-long straight spiral ivory horn declared to derive from a unicorn rather seems to have adorned a narwhal - and to be a tusk.) The alternative example, 'pursuing vampire from her dream' may relate to bloodsucking beasts such as a very real South American bat or an imaginary reanimated human corpse. It might be argued that both the unicorn and the dreamed vampire, instead of objects, should be considered to be individual concepts. This would make a clear separation between physical entities or objects that are perceivable, and mental entities or concepts that are conceived. In any case, metrology is concerned with the physical world, including perceivable brain processes.

2.23.1 Synonyms or quasisynonyms of 'object' are 'entity' and 'item'.

Definitions encountered are

entity; item: that which can be individually described and considered [3, 68-1.1, 105]

item; entity: anything that can be described and considered separately [75-1.2.11]

item: object or quantity [read: amount] of material on which a set of observations can be made [2]

or the more elaborate, semi-extensional

item: part, component, equipment, sub-system or system or a defined quantity [read: amount] of material or service that can be individually considered and separately examined and tested [44-1.2.1(a), ≈78-3.10]

2.23.2 The *DIN 1319-1* offers the entry

object of measurement: The object being measured in order to determine the value of the measurand [32-1.2]

which is a circular definition that does not describe "object". A remark, however, explains that physical bodies, phenomena, or physical states are included.

2.23.3 In analogy with the couple "concept" (S.2.10) - "characteristic" (S.2.11) and their respective definitions, it could be considered that properties 'combine' to form an object. The relation between "object" and "property" is not shown by the *ISO*. One might consider a partitive relation - as was discussed for "concept" and "characteristic" -but, again, the description of a biological object by a set of all its properties hardly means that a duplicate instance can be created by putting the properties together (if that were possible) and somehow shaking. So, the relation between "object" and "property" is here assumed to be associative.

NOTE 4 - The currently suggested possibility of creating living organisms from DNA and an appropriate soup of chemicals in a suitable environment would require synthesizing mechanisms different from 'amalgamating' pre-existing defined properties.

2.24 The *ISO* does not either show a relation between "concept" and "object" [72-A.2], but in spite of the definition of

extension: totality of objects to which a concept corresponds [72-3.2.8]

and a partitive relation between "extension" and "object" [72-A.3-p. 20], the verbal form 'corresponds' in this definition is well chosen. Instances of "concept" and "object" are from different worlds, and the concepts should be associatively related.

2.25 It is an obvious outcome of the above discussion to draw a four-cornered concept diagram on "concept", "characteristic", "object",and "property" with four 'sides' of associative relations (Fig. 2.25).

NOTE - A concept diagram in the *ISO 1087-1* (72-A.3-p. 20) shows an associate relation between "object" and "characteristic". This relation, although not incorrect, may be considered to be secondary, and without explanation perhaps misleading.

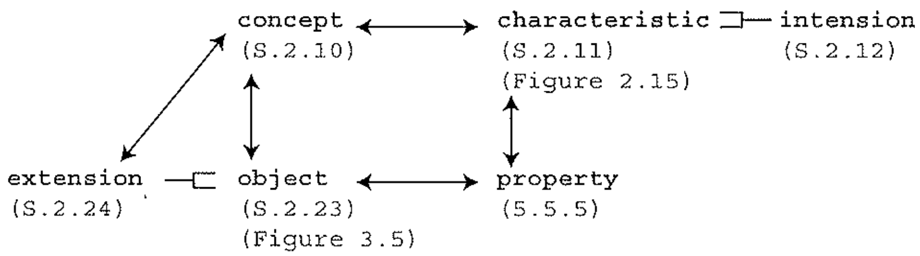


Figure 2.25 Mixed 'concept diagram on some 'terminological 'concepts around <concept> and <object>

DESIGNATION

2.26 The terminological concepts presented so far are tools in the analysis of concepts and their relations. Another task of terminology is the formulation of the designations of concepts, mainly in the form of terms and definitions. Among the 'special languages for such purposes are the 'feature-value' approach of *Gazdar* [50, 97, 119] and the 'semantic link-associated concept' procedure of *Sowa* [112] as evolved by the *CEN Technical Committee 251 'Medical informatics'* [21], but recently abandoned [21a].

2.27 The concepts used in the complex *CEN* 'metalanguage presented in the *ENV 12264* [21] were initially tried for the present concept analysis, but subsequently abandoned in favour of the *ISO* philosophy because the *CEN* approach lacked a documented internal coherent concept system.

The formation of terms according to the *CEN ENV* will be further discussed in Chapter 21.

3 "SYSTEM" and "COMPONENT"

> 'I must create a System, or be enslaved by another Man's; I will not Reason and Compare; my business is to Create.'
>
> *William Blake*, 1757-1827 (Jerusalem [quoted in 24])

"SYSTEM"

3.1 In the previous two chapters it has been assumed that properties describe objects and that the relation between the general concepts "object" (S.2.23) and "property" (S.5.5) is associative (Fig. 2.25).

3.2 In the present universe of discourse, Metrology (supplemented by properties that are not quantities), and especially in Laboratory Medicine, the delimited parts or phenomena of the world to which properties pertain will be taken to be instances of "system" under the generic concept "object". The concept "system" was originally adopted in the *R-66* to emphasize the complexity of biological objects and to accommodate any partition into components which are involved when defining most of the relevant properties, for example a mass concentration of the chemical entity "lipid" in a system "blood".

Interestingly, at the same time, *Bunge* opted for the term (concrete or material) 'system' instead of 'thing' [15]. He considered "system" to be a specific concept under "fact" (concrete object) together with "event", "process", and "phenomenon". 'System' was claimed to be more neutral than 'thing', more acceptable as a term covering immaterial systems. Furthermore, as he said, 'By calling all existents "concrete systems" we tacitly commit ourselves - in tune with a growing suspicion in all scientific quarters - that there are no simple structureless entities.' *Bunge* also made it clear 'that by adopting the convention that the protagonists of events be called concrete systems, we make an ontological hypothesis that transcends the scope of the special sciences.'

Incidentally, the concept "system" was used by the *IUPAC* around the same time in the draft definition of the SI base unit of measurement (S.18.12) for the base unitary kind-of-quantity (S.13.9) "amount of substance", which was adopted by the *14th General Conference on Weights and Measures* in 1971 as follows: 'The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kg of carbon 12: its symbol is "mol"' [6].

3.3 The proposed definition of "system" is the following.

<u>system</u>
part or phenomenon of the perceivable or conceivable world consisting of a demarcated arrangement of a ˡset of elements and a set of relationships or processes between these elements

EXAMPLES - A human being, the blood of that human being, the leukocytes of that blood, a single leukocyte among them, the DNA of that leukocyte, a given gene in that DNA; a **system of metrological units** (S.18.27)

NOTE 1 - Biological systems are essentially open, that is they allow input and output in addition to internal processes.

NOTE 2 - The ˡterminological phrase 'part or phenomenon of the perceivable or conceivable world' is a substitution for the term ˡ'object', but the extended ˡdefinition is preferred here in the context of laboratory medicine to emphasize that systems may be immaterial and are complex objects.

NOTE 3 - The term 'element' is not referring exclusively to "chemical element", such as carbon, C, but to any definable part except a relationship or a process.

NOTE 4 - The state of an ˡinstance of "system" is described by its instantiated **properties** (S.5.5).

NOTE 5 - The extent and structure of a system is essentially defined by the observer for some purpose [93].

NOTE 6 - ˡSynonyms of 'system' (or 'object') in various documents are 'entity', 'item', and 'unit' (not in the sense of ˡ"unit of measurement").

3.3.1 Slightly differently worded definitions are found in several sources [e.g. 37, 54, 86]. Recent *ISO* proposals among several - omitting some of very restricted applicability - are

system: integrated composite that consists of one or more of the processes, hardware, software, facilities and people, that provides a capability to satisfy a stated need or objective [78-3.18]

and

system: set of interrelated or interacting elements [70-3.2.1] whereas the *IUPAC's "The Gold Book"* offers

system: arbitrarily defined part of the universe, regardless of form or size [79]

3.3.2 The European Standard *EN 1614* recently adopted the definition in Section 3.1 [19-3.1].

"COMPONENT"

3.4 As mentioned, a property of a system by definition often pertains to not only the entire system, but also to one or more indicated parts of the system. Such a subsystem is here simply defined as

<u>component</u>
analyte (admitted)
part of a **system** (S.3.3)

NOTE 1 - A component - used in defining a **property** (S.5.5) - may comprise more than one element of one or more types of element and relationships or processes between them.

NOTE 2 - Besides one indicated component, a material system, in principle, consists of a complementary part, in chemistry often called 'matrix' when this is a mixture of elements.

EXAMPLE - Erythrocytes as a component in blood are suspended in blood plasma (with some leukocytes and thrombocytes). Even if this matrix is highly complex, it is considered to be an integral medium when defining, e.g., the number concentration of erythrocytes in blood.

NOTE 3 - For some properties, their definitions do not involve any individualized component; for example, the mass of a person. In such cases, for construction of appellations of properties, the system and component may be designated identically, i.e. 'Person(ID; calendar time)--Person; mass'.

NOTE 4 - A component may be anatomical (e.g. erythrocytes), physical (e.g. droplets of lipid), chemical (e.g. haemoglobin), or a process (e.g. coagulation), but such descriptions may overlap.

(cont.)

(cont.)
NOTE 5 - In chemistry, the term 'analyte' is sometimes used interchangeably with 'component' for that part of a system which is pertinent to the definition of a given property [79, 81-1.2, 121]. Unfortunately, 'analyte' is also used synonymously with 'property' [105] and will not be used here.

3.4.1 Other definitions of "component" can be found in standards [e.g. 78-3.1] and recommendations, but they suffer from being worded to apply in specific fields. Thus, the *IUPAC* has

component: constituent of a mixture the amount or concentration of which can be varied independently [79]

and it is said to be subordinate to

constituent: chemical species present in a system [79]

3.4.2 The European Standard *EN 1614* recently adopted the definition in 3.4 [19-3,2].

3.5 The general concept "system" may be considered to be a subordinate concept to "object", but not directly. A mixed concept system comprising salient concepts discussed in this main section is presented in Figure 3.5.

3.6 Before discussing the formal definition of "property" (S.5.5), the current meaning of its subordinate concept "quantity" will be presented in the next Chapter as a background.

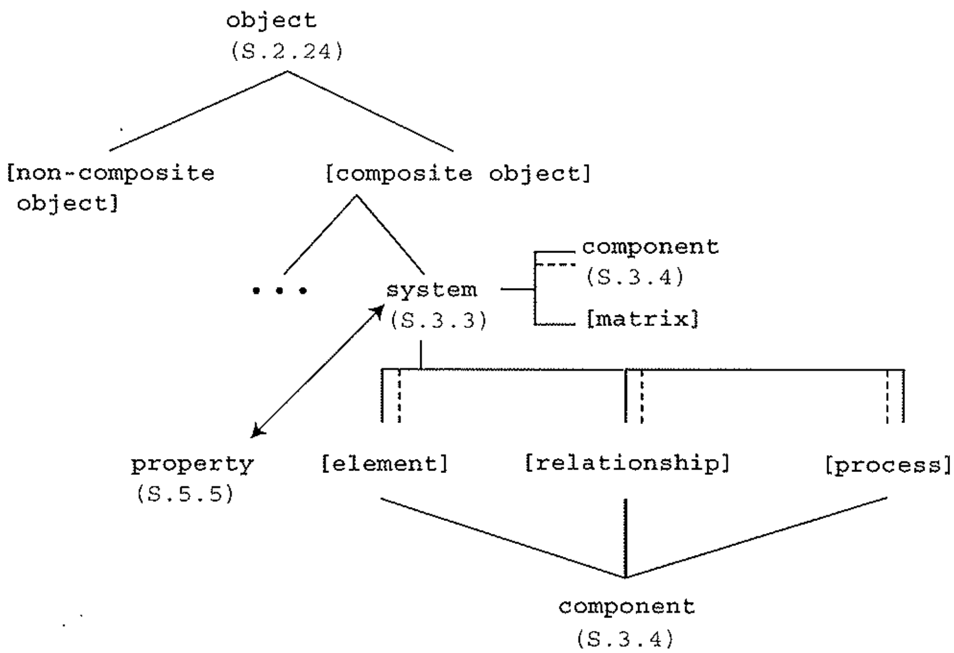


Figure 3.5 Mixed concept diagram on <object>

4 CURRENT MEANING OF 'QUANTITY'

'...science throughout the world has but one language - that of quantity, and but one argument, that of experiment.'
Ernest Henry Starling, 1866-1927 (A Century of Physiology, 1927 [113])

4.1 The central ¦metrological ¦concept ¦"quantity" was introduced into physics by *James Clerk Maxwell* around 1870 [99, 100]. It was said to be expressed by two factors, namely

- a standard of reference, called the ¦'unit' and being 'of the same kind' as the quantity itself, and
- a number, called the ¦'numerical value', indicating how many times the unit should be taken in a sum that would correspond to the magnitude of the quantity.

NOTE 1 - *Maxwell* was essentially concerned only with quantities that may be divided one by another (here later to be termed 'rational unitary quantity' (S.12.20)). The discussion in this chapter is restricted accordingly.

NOTE 2 - The word 'kind' is used here and in the following as did Maxwell in the sense that various sorts of quantity may be distinguished, and that only the values of quantities of the same kind can be compared. (The ¦complex term 'kind of quantity' will be discussed later in Chapter 6 and finally in Chapter 13.)

4.2 Consequently, metrological texts on 'physical quantities and units' - including the *ISO 31* [64] - generally present the equation

quantity = numerical value · unit

or in ¦symbolic form

$$Q = \{Q\} \cdot [Q]$$

4.3 The meaning of such an equation has been much debated, as is excellently presented by *de Boer* in a treatise on quantity calculus [30]. There is a *concrete or operational interpretation* by 'realists' where individual symbols of quantities are expressions of concrete physical objects (S.2.23) and the is-equal-to and multiplication signs are not to be considered in the algebraic sense. This is indicated by *de Boer* by parentheses, (=) and (×). There is also an *abstract or axiomatic interpretation* by 'systematists', based on the mathematization of physics, where physical quantities are 'primary concepts' that may be multiplied with each other and (if of the same rational unitary kind (S.13.3.5)) added one to the other. The two viewpoints are not always kept separate in practice.

NOTE - The use of an is-equal-to sign between quantities - a unit is also a quantity - may also be criticized. A careful presentation would preface the terms of 'quantity' and 'unit' by 'magnitude of ...'.

4.4 Taking the view that the above equations show |designations, usually |terms or |symbols of concepts, the |general concept - here designated by the |simple term 'quantity' - can be instantiated by given real-life systems and become perceivable or conceivable |instances (see also Section 5.2). Each instance of "quantity" is an aspect of a spatio-temporally specified system (S.3.2) and has a magnitude that is considered to be an instance of "value" (numerical value · unit) on the right hand side of the equation.

4.5 The unit (later to be termed 'metrological unit' in Section 18.12) on the right hand side of the equation above has the same "metrological |dimension" (cf. S.19.22) as the quantity on the left hand side, but neither dimension nor unit can tell unambiguously which is the 'kind' of that quantity (see also Section 2.22). This is because a given metrological dimension or a given term or symbol for a unit may be associated with quantities of different 'kinds'.

EXAMPLE - The term 'kilogram per cubic metre' is used in values for both quantities involving "mass density" (that is "mass" of system divided by "volume" of system) and "mass concentration" (that is "mass" of a component in system divided by "volume" of system), and both have the dimension ML^{-3}.

Quantities of fundamentally different kinds cannot be added in spite of having identical dimensions and being seemingly expressed in the same unit. It has therefore been suggested that in this situation two forms of "kilogram per cubic metre" are needed; they just 'happen' to have the same term. This view is supported by the *Italian standard on results and measurement* [43] and would also be in accordance with the principle of generic inheritance (S.2.20).

4.6 The (abstract) general concept "unit of measurement" has |specific concepts of abstract units, such as "kilogram", "millilitre", or "gram per litre". Each of these has a |definition that can be a method for 'realizing' or 'embodying' their respective physical forms, collectively conceptualized as |"measurement standard" or "etalon" [16, 116, 131], with instances such as a given one-kilogram weight (of mass), a given hundred-milliliter measure (of volume), and a given |reference material with an assigned value of seventy grams per litre (for the mass concentration of protein).

4.7 *Stille* described "physikalische Grösse" (de) ('physical quantity') in a partly negative way as being 'not a physical object, state or process in itself or to be identified with them - it only describes the natures

('Beschaffenheiten') or properties ('Eigenschaften') of such objects, states, or processes', adding that it must be measurable [116-p.8]. (That a quantity should describe a property is not compatible with the present choice of concept system and terms.)

4.8 A conventional meaning of the concept "quantity" was expressed in the *R-66* as follows.

> *quantity*: measurable real property of a specified system [39-3.1.0]

This definition uses "property" as a primitive and otherwise uses measurability and inherence as characteristics.

An ˡindividual concept is "amount-of-substance concentration of glucose in the blood of John Smith at 1995-12-03T09:00". This ˡappellation corresponds to only one instantiated quantity, mainly that which could be measured at that time in that person.

4.9 The *ISO 31-0* [64] does not explicitly define in ˡwords a concept with the simple term 'quantity'. Besides the symbolic equation in Section 4.2, however, an example is given, namely 'wavelength of one of the sodium lines being equal to $5{,}896 \times 10^{-7}$ m'. This is echoed by *Thor* [120] in saying that 'the mass of a proton is a quantity'. These two examples do not prove, however, that the *R-66* and the *ISO 31-0* have exactly the same understanding of "quantity" because the wavelength and mass quoted are not specified in time and space, but are supposed to apply to all respective instances.

4.10 The *VIM2* had the formal definition

> *(measurable) quantity*: attribute of a phenomenon, body or substance that may be distinguished qualitatively and determined quantitatively [7-1.1]

but this has been improved in the recent *VIM3* to

> *quantity*: property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference [132.1.1]

where [Note 2] 'A reference can be a measurement unit, a measurement procedure, or a reference material, or a combination of such'.

4.11 The words used in the latter definition are common language designations of concepts that are not defined elsewhere in the *VIM3*, but presumably may be 'translated' approximately as follows.

property → thing owned
phenomenon, body or substance → object or system

magnitude → size
reference → as explained in the Note quoted above

For an example given by the *VIM3* as an 'amount-of-substance concentration of ethanol in a given sample of wine', a date is understood to have applied because the sample presumably would not keep forever (for one reason or another).

4.12 The optional adjective 'measurable' in the complex term of *VIM2* 'measurable quantity' was redundant, but could have been introduced to avoid confusion with 'quantity' in another dictionary sense, "amount". Such possible misunderstanding is a side-effect of ¦terminologization, but may be circumvented by always distinguishing between 'quantity' and 'amount', ¦equivalent to French distinguishing between the respective terms 'grandeur' and 'quantité'. The term 'quantity' is now so entrenched in the English metrological ¦vocabulary that a change is unlikely. In the following, in accordance with *VIM3*, the simple term 'quantity' will be used to denote a general concept referring to real-life instantiated quantities, each of which could be measured.

4.13 Some of the problems meriting discussion stem from unsatisfactory definitions of "quantity" and related concepts. They seem often to have been defined independently, intuitively, omitting analysis of ¦characteristics or interactions within a ¦concept system.

The relevant questions to ask include the following.

- How is "quantity" related to concepts such as
  "system",
  "component",
  "value",
  "property value scale",
  "measurement",
  "measurement procedure"?
- Is there a separate concept that might be termed 'kind-of-quantity' and how would it be related to "quantity"?
- Is "quantity" subordinate to a ¦generic concept such as "property" and, if 'yes', which are one or more ¦coordinate concepts to "quantity"?

Provided that "property" as a ¦superordinate concept can be usefully defined - and this will be attempted in the next Chapter 5 - the previous questions may have to be multiplied to accommodate the respective ¦generically ¦subordinate concepts.

- How, then, should these interrelated concepts be defined?
  (For "system" and "component", see Section 3.3 and 3.4 respectively.)

At the end, the outcome of such deliberations will influence a systematic nomenclature for the subjects of examinations in laboratory medicine - quantities or otherwise.

4.14 In the following chapters, the necessary iterative interplay of concept system, definitions, and terms during the terminology work is not explicitly explained, but the suggested systems may be compared with the corresponding proposed definitions.

4.15 The discussion about quantities will only concern those that have values that are a product of a numerical value and a unit (including the unit "one") or simply a number indicating ordinal magnitude. Thus, complex quantities, vector quantities, and tensor quantities are excluded.

5 "PROPERTY", "examinand", and "measurand"

'One always measures properties of things, not the things themselves.'
Churchill Eisenhart, 1963 [42]

"PROPERTY"

5.1 As was mentioned in the Historical introduction (Ch.1), Laboratory Medicine needs to describe both bona fide quantities and other features of patients and materials. Searching for a |superordinate concept and |term, it seems pertinent that besides the *R-66* (S.4.7) the *ISO* and the *VIM* use a |concept termed 'property' in |terminological and |metrological |definitions of |general concepts that are relevant here. For example,

- "characteristic" is defined as an 'abstraction of a property of an object or of a set of objects' [72-3.2.4 = S.2.11];
- "reference material" is defined as a 'material, sufficiently homogeneous and stable with reference to specified properties, which has been established to be fit for its intended use in measurement or in examination of nominal properties' [132-5.13].

Neither source gives a definition of "property", but uses the term as a linguistic primitive in one of its ordinary English dictionary senses - as has hitherto also been the case in the present text.

5.1.1 The German Standard *DIN 55 350-12* from 1989 on concepts in the field of quality and statistics [31] offers a definition based on function.

> *Merkmal*: Eigenschaft zum Erkennen oder zum Unterscheiden von Einheiten [31-1.1]

The text translates 'Merkmal' into English 'characteristic', so

> *characteristic*: property for identification or differentiation of objects

Such a definition - besides confounding "characteristic" and "property" - includes codes for |objects and that is hardly intended. It is important, however, that the need for a concept superordinate to 'quantity' and including "Nominalmerkmal" is realized.

5.1.2 The English version of the German Standard *DIN 1313* [33] explains that "characteristic" ('Merkmahl') is superordinate to "quantity" ('Grösse') and defines *characteristic*: property which is made precise in an objective way and which assigns to any object belonging to the characteristic a value characterizing a distinctive mark of the characteristic [33-11.6]

This definition is circular, difficult to understand, and - as usual - there is overlap of 'characteristic', and 'property', whereas the *ISO* describes objects by properties and concepts by characteristics [71, 72].

5.1.3 Another attempt to promote the concept with a larger ¦extension proposed the term 'quantity' [40] - inspired by *Stevens*' paper on scales of measurement [114] - but this did not meet favour among the ¦metrologists revising the first edition of the *VIM* [9].

5.1.4 Recent documents on terminology in laboratory medicine freely use 'property' as a term for a superordinate concept left undefined [e.g. 11, 86].

Olesen proposed

property: set of data elements (system, component, kind-of-property) common to a set of particular properties [106-4.1]

which - rather than defining "property" - seems to list the ¦subordinate concepts "designation of system", "designation of component", and "designation of kind-of-property" in ¦partitive relations to a superordinate ¦comprehensive concept of "designation of dedicated kind-of-property" (see Chapter 20).

5.2 According to the *ISO* standards on ¦*Terminology work*, both the ¦*Vocabulary* [72] and the *Principles and methods* [71], a given characteristic describes a concept, both being mental constructs, whereas a given property describes a given object (S.2.23) - here in the form of a given system (S.3.3). In a ¦hierarchy of concepts the most subordinate concept is an ¦individual concept. Thus, an individual concept under "system" is ¦associatively related to one or more individual concepts under "property" (see Figure 5.2).

NOTE - The explicit distinction between an individual concept and its corresponding ¦instance of "object" is only upheld in the text when deemed helpful. Thus, an indefinite or definite acticle before the term of a concept may indicate an individual concept having a corresponding instance.

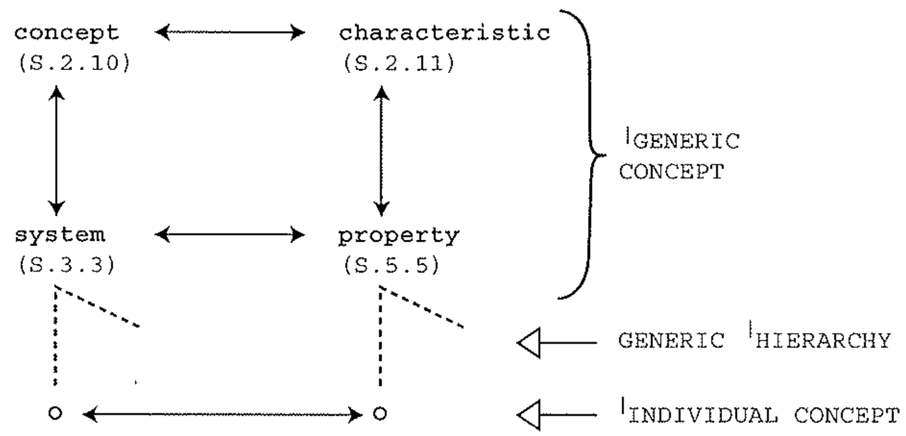


Figure 5.2 |Concept diagram on |"concept", |"characteristic", "system" (S.3.3), and "property" (S.5.5)

5.3 The usages of 'property' quoted above (S.5.1) as well as colloquial language have no requirement of measurability *sensu stricto*, that is assessment of magnitude, for the instances of the concept "property". A given sample of urine, for example, may be judged to have the property =red in colour by visual inspection - from medieval times called 'uroscopy'. It is therefore proposed that "property" be a superordinate concept to the subordinate |specific concept "quantity". (A |concept system will be detailed in Chapter 12.)

5.4 As regards a definition of "property", it is possible as mentioned to follow the *ISO* [72] implicitly considering this general concept as a primitive and rely on the explanation in an ordinary dictionary.

> NOTE - The outcome, however, may not be helpful. In the *Concise Oxford Dictionary* [1], one relevant sense of "property" just mentions "attribute", which itself leads into a ring of |synonyms with 'quality' and 'characteristic'; the *Webster* concurs [126].

In the present context, however, where specific subordinate concepts such as "quantity" have to be defined, an understanding of the meaning of "property" seems relevant.

As all systems have properties and as these are of fundamental importance to the description of our world, it is no wonder that the |characteristics of "property" have been long debated and that many often conflicting views on its nature have been advanced by eminent philosophers from *Plato* and *Aristotle* onwards. This is not the place for a discussion of these theories; reviews (and references) may be found in handbooks [e.g. 4 - especially p. 489-91 & 657-8; 18 - especially p. 65-70; 15] under various synonymous or quasi-synonymous headings such as 'attribute', 'characteristic', 'entity', 'feature', 'magnitude', 'property', 'quality', and 'trait'. In any case, properties are regarded as being somehow attached to ('possessed by', 'instantiated by', or 'exemplified by') their respective objects (here in the form of instances of "system" (S.3.3)). The two extreme viewpoints are

- properties existing independently of objects ('transcendence') and
- properties as non-spatial unique parts of their respective objects ('immanence').

Here, it will be assumed that there is an associate relation between the general concepts "system" and "property" (see Figures 3.5 and 5.2).

Applying the analytical method for devising a definition of "property", the following statements may be listed.

5.4.1 Any instance of "property" will be considered to be *inherent in or immanent in an instance of "system"* (S.3.3) *including any pertinent "components"* (S.3.4).

NOTE - The adjective 'inherent' is used here in an ordinary dictionary sense rather than in a special philosophical sense as in 'inherent value'.

<u>Being inherent</u> (in a system) seems an obvious choice as a characteristic of the concept "non-relational (internal) property", such as "number of erythrocytes (in a blood compartment)". In some cases, the property only becomes manifest by manipulation during examination (S.8.4), that is by an interaction between an instance of "system" and a given measuring device, including a human sense organ. Such is the case for instances of "catalytic activity of the enzyme alkaline phosphatase (in a blood plasma compartment)", where the catalytically induced rate of conversion of a specific substrate in a defined reaction mixture is measured. Yet, the catalytic property has to be related to the enzymatic component, and the special circumstances of 'measurement (S.15.14) are part of the definition of the property, just as could be a specified temperature at which the temperature-dependent length of a given metal rod is measured. For "relational (extrinsic) property", there is a defined interdependency with another system, such as for "degree of blood group compatibility with the blood of a given patient (for a portion of donor blood)".

NOTE - The recognition of the existence of an individual property inevitably depends on whether the property is detectable by some examining system. A bee is said to register ultraviolet radiation from a flower, but not what humans label visible light.

5.4.2 Any instance of "property" is *descriptive of the state of its 'parent' system* (S.3.3), ultimately by the distribution of its property values

(S.9.15). So, being descriptive (of a system) is another characteristic.

5.4.3 Any instance of "property", in principle, is perceivable directly by the senses or indirectly as aided by a device, or it is conceivable by a thought process. Thus, the property *may be subjected to an examination* (S.8.4) *according to an examination procedure* (S.7.3), even if such an activity may not be practicable. Thus, being examinable is a characteristic. Some kinds of property are wholly defined by their respective examination procedures, which become part of their ˡdesignations; the property involving an enzyme in Section 5.4.1 is an example.

5.4.4 Any instantiated property *has a distribution of property values* (S.9.18) permitting classification among and comparison with other properties of the same kind-of-property (S.6.19). Ergo, a further characteristic is having property values.

5.5 Of the above four characteristics, the first and second will be considered to be ˡdelimiting characteristics, and they seem sufficient for a meaningful definition. The third characteristic is ˡessential, but an instance of "property" may be assumed to exist without being examined, and not all properties are defined by their examination procedures (S.7.3). Regarding the fourth characteristic, it is considered an essential characteristic, but not a delimiting one. Consequently, the following definition is offered.

property
inherent state- or process-descriptive feature of a **system** (S.3.3) including any pertinent **components** (S.3.4)

NOTE 1 - An ˡinstance of "property" is defined on a space-time coordinated instance of "system" with one or two indicated components if relevant.

NOTE 2 - A process of a system may be internal or involve the environment.

NOTE 3 - Any instance of "property" may be subject to an **examination** (S.8.4) according to an **examination procedure** (S.7.3). Such an examination procedure may be an integral part of the ˡdefinition of a given property.

NOTE 4 - An instance of "property" has a distribution of **property values** (S.9.15) serving to describe the parent system and allowing comparison with other instances of property of the same **kind-of-property** (S.6.19).

NOTE - The *EN 1614* has adopted this definition [19-3.3], although adding 'being determined' - which is not always correct.

5.5.1 It is possible to devise a minimal definition by recalling that a relevant component is a part of a system and therefore might not need special mention, and by suggesting that if the feature is inherent it is probably also state- or process-descriptive. Thus,

property: inherent feature of a system

The more detailed formulation is preferred here for emphasis on the role of a property and the frequent involvement of a specific component.

Using the word 'feature' as a linguistic primitive in the definition of "property" allows the latter concept to be formally defined rather than itself being considered a primitive.

5.6 The insistence on "property" being an inherent and state- or process-descriptive feature of "system" distinguishes property from other possible features such as an identifying name or code, which are assigned and are not necessarily describing the state of the system. Thus, being inherent and being state- or process-descriptive are delimiting characteristics of "property". The inherence of a property is not affected by the fact that the way in which a property is defined and represented is decided by language and convention.

"EXAMINAND"

5.7 It is sometimes practical to have a specific general concept corresponding to the instances of "property" that will be or are being examined. The following concept is therefore proposed.

examinand
property (S.5.5) intended to be examined

NOTE 1 - The **property value** (S.9.15) of the examinand may be different from that of the property actually being examined due to changes of the system during the **examination** (S.8.4).

NOTE 2 - The **examined property value** (S.9.20) may be obtained indirectly through examinations of other properties giving the examined property value by calculation.

NOTE - The *Webster* has the spelling 'examinant' [126], but the *COD* explains that the suffix '-and' indicates 'a person or thing to be treated in a specified way' [1], and that is applicable here.

"MEASURAND"

5.8 The above and following definitions are fashioned differently from that of the *VIM2* concept

measurand: particular quantity subject to measurement [7-2.6]

in that the metalinguistic adjective 'particular' is omitted and that intent rather than actuality is chosen. Thus, the *VIM3* definition

measurand: quantity intended to be measured [132-2.3]

is adopted for quantities (S.12.13, 12.14).

measurand **quantity** (S.12.13, 12.14) intended to be measured NOTE - Analogously to Section 5.7 Notes 1 and 2.

The concepts defined in Sections 5.5, 5.7, and 5.8 form a ˡconcept system as diagrammed in Figure 5.8.

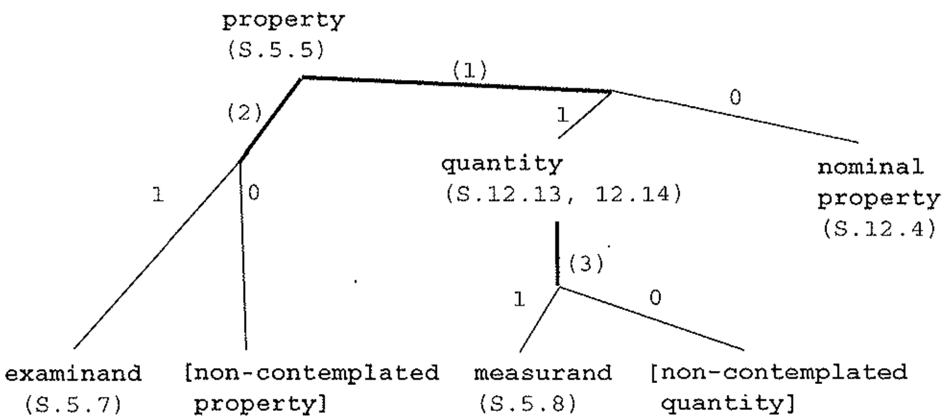


Figure 5.8 ˡTerminologically oligodimensional (S.2.19) ˡgeneric ˡconcept system on <property>

Terminological dimension
(1) having a magnitude;
(2) having intention of examination (S.8.4);
(3) having intention of measurement (S.15.14)

5.9 <Property> is a superordinate concept with characteristics as described, all occurring in the mind. Through generic division using delimiting characteristics, several hierarchical levels of specific but still generic concepts can be described, each corresponding to two or more instances of <property>. The final subdivision yields individual concepts that each corresponds to an instance that is a feature of an instance of "system" with spatio-temporal coordinates. A given individual concept, being a generic divison of <property>, has inherited all the characteristics indicated at the various levels of the unbroken chain up to and including that superordinate concept. Generic hierarchies on <property> will be discussed in Chapter 12.

5.10 In principle, a distinction can be made between three situations exemplified as follows (see also Table 2.1).

- The characteristic (in the mind) having a mass of seventy kilograms is a delimiting characteristic for a subordinate concept covering, e.g., a group of many adults under the general concept "homo sapiens sapiens".
- The individual characteristic (S.2.18) (still in the mind) has the mass of seventy kilograms, applying to the individual concept "Mr John Smith of Greenwich, global social security number 10 752 319 625, at 2009-02-14". The same characteristic undoubtedly applies to the individual concepts of many other men, but is an individual characteristic when one thinks of this Mr Smith.
- An instance (in the real world) of "property", such as mass = 70 kg, measured on the instance of "system" Mr John Smith (same spatio-temporal coordinates as above) and corresponding to the individual characteristic in the previous example.

  NOTE - That two past, present, or future instances of the human race should have had, have, or will have exactly the same mass at a given calendar time is highly unlikely - and certainly not provable - as the number of water molecules alone in a 70-kg individual is of the order of 15 $\times 10^{26}$; the numerical value '70' is truncated for practical purposes to indicate a class interval, usually [69.5; 70.4]. For many other dedicated kinds-of-property (S.20.6), such as the 'number of arms on a human being', identical values are common.

5.11 The correspondence between the second and third example, from characteristic of concept to property of instance, from mind to matter, is an expression of the dualism "idealism-materialism" that has been discussed by philosophers through the ages since *Plato*. The distinction is not always upheld in practice as evidenced by the sometime use of 'characteristic' and 'property' as synonyms.

5.12 The definition of "property" in Section 5.5 is not a description of an instance of "property" - as is occasionally claimed. The definition describes a general concept covering the common characteristics of all those individual concepts that each corresponds to an instance of "property" and where the set of instances is the |extension of the general concept.

5.13 The importance of providing a sufficiently informative |appellation for an individual characteristic was discussed in Sections 2.20 to 2.22 (Generic inheritance). It was argued that is red or is 1.63 m were not necessarily unambiguous; the next higher level in the generic hierarchy of <property> should be given also, for example colour is red and height is 1.63 m respectively. The situation is analogous for instances of "property", here the corresponding colour = red and height = 1.63 m. As will be discussed later, "colour" and "height" are short forms of, e.g., 'property having the kind-of-property colour', but the designations are also used for "kinds-of-property (S.6.19) whereas = red and = 1.63 m are customarily thought of as instances of "property value" (S.9.15).

5.14 A |generic division of <property> according to the relationship between instances of a given kind-of-property will be presented in Chapter 12.

6 "KIND-OF-PROPERTY" and conceptualization

'There must be as many units as there are different kinds of quantities to be measured, ...'
James Clerk Maxwell, 1831-79 (A treatise on electricity and magnetism 1873 [99])

"KIND-OF-PROPERTY"

6.1 Hitherto ᑊterms such as 'kind', 'kind of quantity', and 'kind-of-property' have been used (Table 2.1, S.4.1, S.4.5) without ᑊdefinitions of the corresponding ᑊconcepts, but in accordance with preponderant, long established practice. It is now necessary to explore their meanings and ᑊrelations to concepts such as "property" (S.5.5), "quantity" (S.12.13, 12.14), and "category of quantities" (S.6.10, 6.13). As the literature on the ᑊcharacteristics of "quantity" far outweighs that on "property", the principles of the former will be discussed first with a view to applying them on the latter.

6.2 Many authors, from *Maxwell* [99], *Lodge* [95], and *von Helmholtz* [123] onwards, have used phrases such as 'kinds of quantities', 'quantities of the same kind', 'Grössen der gleichen Art'(de), 'Grössenart' (de) ('kind-of-quantity') [92, 124] or 'quantities of the same nature' [56] or 'Qualität' [45]. However, these pioneers did not explicitly define the corresponding concepts.

6.3 Around 1950, *Fleischmann* [45, 46][2], and *Stille* in his fundamental treatise [116], distinguished systematically between "Grössenart" ("kind of quantity") and "Grösse" ("quantity"). The former is described as a concept of a qualitative nature, also called 'Qualität' by *Häberli* [57]; the latter in addition is said to possess a quantitative aspect, a magnitude. Examples could be "length" and the ᑊindividual concept "length of a specified thumb of Mr A. Brown at 2000-10-11" respectively. There was no ᑊterminological analysis, however, establishing a ᑊconcept system and full definitions. Thus, it is not clear how the separate concepts "quantity" and "kind of quantity" are supposed to be related to each other. Is one of them ᑊsuperordinate or are they in ᑊassociative relation or is 'kind of quantity' just a colloquial phrase meaning an unspecified 'sort of quantity'? In the following, for the sake of discussion, a concept - "kind-of-quantity" - will be taken to exist before any attempt at a definition.

6.4 When clinical chemists during the nineteen fifties realized that the

[2] *Fleischmann*'s ᑊnomenclature is less consistent in a subsequent paper 2 [47].

formation of |appellations for quantities (as |individual concepts) with corresponding |instances measured in patients preferably should have a systematic structure, the syntax and format of

'System--Component; kind of quantity'

was introduced [39]. It was stressed that the third element represented a concept different from "quantity" and therefore an independent term was necessary. (The |variant with hyphenation, 'kind-of-quantity', was lately introduced to hinder |abbreviation, thus emphasizing the indivisibility of the term [37]. This detail, however, is not essential.) Actually, this concept seems identical with the "Grössenart" above (S.6.3) although it, in some papers [47], is difficult to distinguish from "metrological |dimension" (S.19.22).

6.5 Among the proposals and formal recommendations that have appeared describing or exemplifying some concept considered to be different from "(measurable or physical) quantity" by either indicating a 'general' aspect of "quantity", also called 'quantity in a general sense', or perhaps of a set of mutually comparable |instances of "quantity", some are listed in Table 6.5.

Table 6.5 Chronological list of some published proposals - from more than the four last decades - for a |concept assumedly relating to the common aspect of a group of mutually comparable |instances of "quantity" or "property"

Entry	Term	Definition or explanation	Reference
1	Grössenart, de (= kind-of-quantity)	'Verallgemeinerung der benannten physikalischen Grössen' (generalization of instances of "quantity") Examples: length, time, energy, ...	*Fleischmann* 1951 [45]
2	physikalische Grössenart, de (= physical kind-of-quantity)	'Die Bezeichnung "Grössenart" soll nur den *qualitativen Wesensinhalt* des durch sie repräsentierten phykalischen Begriffs erfassen' (... comprises the qualitative nature of the physical concept represented) Example: length, ...	*Stille* 1961 [116]

(cont.)

(cont.)

3	kind of quantity	'nature of a property' Examples: length, area, ...	*IUPAC/IFCC* 1966 [39]
4	metrical predicate (or numerical functor, quantity, magnitude)	'designates a quantitative property ... that can be analyzed into object variable(s), numerical variable(s), and a function from the former to the latter.' Examples: length, stimulus strength, ...	*Bunge* 1967 [15]
5	physical quantity	'complete specification of the operations used to *measure* the ratio (a pure number) of two instances of the physical quantity' Examples: length, ...	*McGlashan* 1971 [101]
6	kind of quantity	'abstract concept of the property, common to a number of real phenomena (quantities)' Examples: length, area, ...	*IUPAC/IFCC* 1979 [83]
7	quantity in a general sense	Examples: 'length, time, ..., electrical resistance'	*BIPM & al.* 1984 [9]
8	property, including kind of quantity	'propositional function', 'mapping operator', 'relational operator', 'open sentence' [linking system as a set theory domain and the possible values as a range] Examples: mass (was), concentration was, colour is, is	*Zender* 1992 [130]
9	category of quantities	'Mutually comparable [physical] quantities are grouped together into subsets called categories of quantities. Quantities in such a subset are called quantities of the same kind.' [14] Example: mass	*ISO* 1992 [64] *Thor* 1993 [120]
10	quantity in a general sense	Examples: 'length, time, ..., amount-of-substance concentration'	*BIPM & al.* 1993 [7]

(cont.)

(cont.)

11	kind-of-quantity	'definition of how to obtain a value of a quantity by measuring a quantity of its system or its components or both'. Examples: length, volume, ...	*Dybkær* 1993 [37]
12	quantitative property, magnitude, measure	'function from a collection A of (actual or possible) things into a set X of numbers, such as the natural numbers or the real line. That is, $P:A \rightarrow X$.' Examples: population, age, wage	*Bunge* 1994 [17]
13	void		
14	kind-of-quantity	'abstraction [of a quantity] without indication of system and component, which is distinguished by *BIPM et al.* (1993) as quantity in a general sense and is common to a set of mutually comparable measurable quantities'. Examples: pressure, substance concentration, length	*IUPAC/IFCC* 1995 [86]
15	kind of quantity (Grössenart, de)	'collection of quantities which are considered to be qualitatively alike and for which it is meaningful to add quantity values, independent from a quantity system to which they may belong'. Examples: length, ..., volume, ... speed, ...	*DIN* 1998 [33]
16	void		
17	kind-of-quantity	'common defining aspect of mutually comparable quantities' (in analogy to 'kind-of-property') Examples: hardness, pH, mass	Dybkaer 2004 [131]

(cont.)

(cont.)

18	kind-of-quantity	'element of information common to a set of mutually comparable measurable quantities and necessary for the definition of a measurable quantity, along with a system and often a component' Examples: pressure, substance concentration, length	*CEN* 2006 [22]
19	kind-of-property	'common defining aspect of mutually comparable properties' Examples: colour, mass, amount-of-substance concentration	*CEN* 2006 [19]
20	kind of quantity	'aspect common to mutually comparable quantities' Examples: diameter, ..., heat, ...	*JCGM* 2007 [132]

The distinction between the two concepts "quantity" and "quantity in a general sense" is not always maintained in the respective texts. Although all the concepts given by the various authors to exemplify "general aspect of quantity" have the same type of term, e.g. 'length' and 'mass concentration', the definitions or explanations for that concept vary. It is therefore not always obvious that the same concept is meant.

The German Standard *DIN 1313* on quantities [33] stresses that in this updated edition of the standard the concept "kind of quantity" is distinguished from "quantity". Offhand, one could take this as an echo of the nomenclature of 50 years ago (S.6.3), but a closer look makes this conclusion uncertain because examples of "quantity" given are length, mass, etc. Furthermore, it is said that 'Kinds of quantities are collections of quantities ('Grössenarten')' and that a selected "quantity" such as "length" with wide applicability is chosen as a representative ('prototype') of a "kind of quantity" comprising quantities ('Grössen') (such as diameter, wavelength, etc.) with values that can be added. So, the text may be understood as "quantity" equivalent to either "quantity" or rather "rational unitary kind-of-quantity" (S.13.3.5) - the usual ambiguity - and "kind of quantity" to "category of quantities" (as in the *VIM2*-1.1-Note 3).

6.6 The classical concept "quantity" corresponds to only those instances having values on a rational unitary quantity-value scale (S.17.18) or possibly also a differential unitary quantity-value scale (S.17.17). That perception of "quantity" has the characteristic of being 'equal to' a ¦"numerical value" 'multiplied by' a ¦"unit of measurement" (S.4.2), and algebraic equations can be formed between different kinds-of-quantity according to the rules of quantity calculus for each sort of unitary quantity-value scale.

6.7 When ¦metrologists of a 'systematist' persuasion (see S.4.3) list ¦specific concepts under ¦"base quantity" and ¦"derived quantity" in a "system of quantities" (as discussed further in Chapter 13), such specific concepts are for use in fundamental algebraical relations between base and derived kinds-of-quantity (see Section 13.6) [e.g. 7, 9, 45, 64, 82, 116, 120, 132]. The concepts are not individual concepts with instances of "measurable (or physical) quantity" having detailed defining measurement procedures and equating values including instances of units of measurement. This was made quite clear by *Fleischmann* [45] and *Stille* [116] in the nineteen fifties, but it has sometimes been submerged in the ¦polysemous use of 'quantity'. Nevertheless, equations between ¦designations of real-life quantities are homomorphic with equations between the designations of the corresponding abstract concepts of kinds-of-quantity, but the latter equations are devoid of units and (usually) of numerical factors. For example, "mass concentration" (ρ_B) is defined quite generally by an equation as "mass" of component B divided by "volume" of system S containing that component, $\rho_B = m_B/V_S$. This is a skeletal information sufficient to place "mass concentration" in a "system of unitary kinds-of-quantity" (see Section in 13.7). The structure of such an equation may not be reflected directly in the operational measurement procedure (S.14.4.3, S.14.4.4). The latter might, for example, specify a method where mass concentration of a given component in a given system is to be measured directly from the reading of absorbance in a calibrated ¦measuring system including a light spectrometer; or the result for a pure solution could be obtained directly by mass densitometry and a conversion table.

6.8 The idea of "kind-of-quantity" as a concept that is *associatively related* to "quantity" could be an interpretation of the texts mentioned in Section 6.3 (Tab. 6.5, entries 1, 2) and of the first *IUPAC/IFCC* recommendations [39, 83] (Tab. 6.5, entries 3, 6). The functional aspect of "kind-of-quantity" was emphasized more recently [37, 130, 131] (Tab. 6.5, entry 8, 11, 17). (*Zender* [130] uses the term 'property' for the concept, including "kind-of-quantity", that is here called 'kind-of-property'.) A related proposal is that a "metrical predicate" [15] or "quantitative property" or "magnitude" is a function from a set of systems ('things') to a set of values [17] (Tab. 6.5, entries 4, 8, 12). Prior to entry 17, most of the remaining references in Table 6.5 offer little help to positioning in a concept system.

6.9 The *ISO* [64, 120 (Table 6.5, entry 9)] describes

- "(physical) quantity" for the all-comprising concept covering the ¦set of all instances of (differential and rational sorts of) "quantity";
- "category of quantities", for example "mass", covering a subset, an ¦ex-

tension of mutually comparable instances of "quantity" of that kind, among which one is chosen as a reference quantity, here "kilogram", under the concept "unit of measurement".

The phrase 'mass in a general sense' is also said to denote a category of quantities [120], so that something 'in the general sense' may also be considered to have instances from the physical world. A possible interpretation of the texts is shown as a mixed concept system in Figure 6.9.

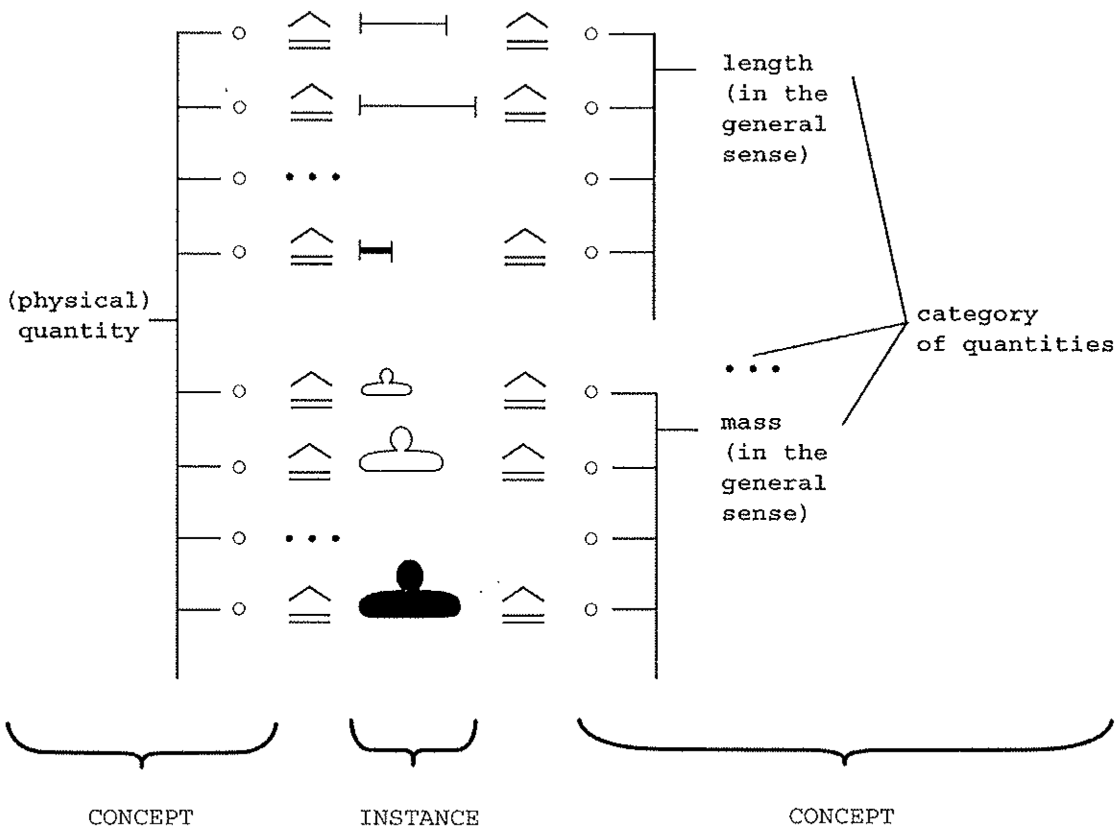


Figure 6.9 Possible mixed ꜝconcept diagram for "(physical) quantity" and "category of quantities" from texts of the ISO [64, 120]

The bold ꜝinstances represent reference quantities, in essence instances of "metrological unit".

The choice of ꜝpartitive relations rather than ꜝgeneric ones is made here because the *ISO* connects directly from each general concept to its ꜝ*set* or subset of instances.

6.10 The *VIM2* [7], had a set of concepts that was difficult to structure because ꜝpolysemy was 'officially' allowed for the term 'quantity' to mean both "quantity in a general sense" or "kind of quantity", such as 'length', and "particular quantity", such as the 'length of a given rod'. Their ꜝterminological relations to the single ꜝintensionally defined concept "(measurable) quantity" was not stated. Furthermore, a "category of quantities" was said to 'group together' quantities of the same kind, allowing them to be placed in order of magnitude. A "category of quantities" listed - 'work, heat, energy' - comprised concepts that are usually considered to be separately defined, although the values of their real-life instances may be added. This concept therefore seems to have a larger extension than that of the *ISO* under the same term - another case of polysemy. *VIM3* has abandoned these ¦metalinguistic concepts [132].

6.11 It should appear from the ¦corpus presented that the concepts, their descriptions, terms, and relations have been varying and often ambiguous. It seemed useful to revive the early clear distinction by *Fleischmann* [45] and *Stille* [116], also urged by the *IFCC/IUPAC* [39], between "quantity" whose instances possess magnitude (that may or may not be comparable and additive) and "kind-of-quantity" that identifies concepts, such as "length", each covering a number of instances with comparable values (whether additive or not).

6.12 The *ISO* term 'category of quantities' [64] could have been used as a synonym for kind-of-quantity', but the modifier 'kind-of-' is a suitable outcome of *Maxwell*'s more than a century old, phrase 'quantities of the same kind' [99]. Furthermore, 'kind-of-' has a connotation towards commonality whereas 'category' tends to indicate a set. The *VIM2* designation 'quantity in a general sense' [7-1.1-Note 1] was not terminologically acceptable as "quantity" is a ¦general concept and cannot have a further 'general sense'.

6.13 As noted in Section 6.10, 'category of quantities' was also used by the *VIM2* as a term for a group of kinds-of-quantity with separate definitions distinguished by the type of system being described, but with a fundamentally common kind-of-quantity, for example "length" for the specific concepts "circumference", "thickness", and "wavelength" [7-1.1-Note 3]. In such a case, as was mentioned in Section 6.5, the *DIN 1313* calls "length" a 'prototype' of a "Grössenart", where 'Grössenart' seems to be equivalent to 'category of quantities' [33-5.2]. Another example of a category given by the *VIM2* is the set of kinds-of-quantity "work", "heat", and "energy". Their instances have values which can be added and use the unit "joule" (= kilogram square metre per second squared). Yet, these derived quantities are defined differently by equations among kinds-of-quantity so that they are not obviously of a kind.

NOTE - "work" $W = \int F \mathrm{d}r$; "heat" $Q = T\Delta S$; "energy" $E = m\ c_0^2$

It seemed useful to reserve 'kind-of-quantity' for the concept with a definition separate from "quantity". This is now formally supported by *VIM3* [132-1.1 and 1.2]. If necessary, 'category of quantities' may be used for ¦sets comprising additive quantities with more than one separately defined kind-of-quantity. The borderline between the two concepts is not sharp and "category of quantities" will not be used here.

6.14 The *VIM2* metalinguistic term 'particular quantity' [7-1.1-Note 1] and *VIM3* 'individual quantity' [132-1.1-Note 1] presumably relate to 'instance of quantity'. Other linguistic expressions are used such as 'a real-life quantity' or 'a given quantity' or 'a special quantity' (German 'spezielle Grösse' [33]). There is generally no need to define "particular quantity", just as one would not define "particular tree". In detailed terminological discussions, however, there may be a need to distinguish between an individual concept and its corresponding instance. In connection with "quantity" (or "property") this text is using respective phrases such as 'quantity (or property) as an individual concept' or an 'individual concept of "quantity" (or "property")' corresponding to an instance. These phrases may provisionally be substituted by the following two forms respectively.

6.14.1

singular property: property (S.5.5) that corresponds to one ꜝinstance

6.14.2

singular quantity: quantity (S.12.13, 12.14) that corresponds to one ꜝinstance

6.15 Hitherto, for reasons of history and available material, the discussion has centred on "quantity" and "kind-of-quantity", and it has been argued that there is a need for both these concepts [131].

Going to the superordinate level, where magnitude is not necessarily involved, the respective concepts should be "property" and "kind-of-property".

6.16 Whereas "property" has already been defined (S.5.5), the relevant characteristics of "kind-of-property" proposed in various sources may be obtained from Table 6.5 with appropriate modification. They comprise

- qualitative nature of a property [39, 45, 116],
- predicate or propositional function [15, 17, 130],
- examination procedure [37, 101],
- abstract common feature of a set of properties [17, 19, 20, 64, 83, 86, 120, 131].

The first of these characteristics is rather vague, the second is a matter of representation, the third does not distinguish from "property". The fourth is important, and may subsume the intent of the first, but is also vague. The import of the common feature, i.e. a characteristic, is that the members of such a set belong to a defined class and are mutually comparable by their respective values (on a given property value scale (S.10.14)).

6.17 Before attempting a definition of "kind-of-property", the type of relation with "property" should be settled. For the pair "quantity" - "kind-of-quantity" the possibilities of an associative relation was hinted at in Section 6.8. It seems obvious that concepts such as "colour" and "length" are generically subordinate to "property". They both have a "kind-of-property", but their individual specific concepts cannot inherit from "kind-of-property" the characteristic of being common to a set. Inasmuch as there is analogy between characteristics generally describing concepts and properties describing systems (S.3.3), it should be considered to position "type of characteristic" (S.2.14.2) and "kind-of-property" analogously in their respective concept systems (see Figure 2.15).

6.18 Consequently, in the present context, <property> is divided in a hierarchy that may have more than one consecutive terminological dimension (S.2.19) and therefore can contain several levels with respective examples such as "physical property", "linear dimension", "height", and "height = 1.7 metre". In addition, the hierarchical level can be indicated by the concepts "kind-of-property" and "singular property" (S.6.14.1). The first one of these two concepts relates associatively to all the penultimate concepts, such as "height", "colour", and many others. The second concept indicating level, "singular property", divides generically in an infinite number of individual concepts, such as "height = 1.7 metre" and "colour = red", each of which can be instantiated and is given by representations of kind-of-property and property values. The singular properties under a given kind-of-property are coordinate concepts.

6.19 The following definition of "kind-or-property" is proposed.

<u>kind-of-property</u>
common defining aspect of mutually comparable **properties** (S.5.5)

EXAMPLES
- "blood group"; "colour"
- "Moh's hardness"
- "pH"; "base excess"
- "length"; "amount-of-substance concentration"

NOTE 1 - The defining aspect of a given kind-of-property sometimes includes an **examination procedure** (S.7.3), such as the example of Moh's hardness.

(cont.)

(cont.)
NOTE 2 - The comparability among properties, that have a given kind-of-propery as an ¦essential characteristic, is allowed between properties of different **systems** (S.3.3) and of one system, and includes comparison of corresponding **property values** (S.9.15).

NOTE 3 - Contrary to the position of "type of characteristic" (S.2.14.2) associated to a plurilevel system on <characteristic> (Fig. 2.15), a plurilevel ¦concept system on <property> cannot have more than one level of properties with specified kinds-of-property, and it will be at the level just above that of the singular properties (S.6.14.1).

NOTE 4 - The examples are short terms for, e.g., 'having a blood group'.

NOTE - The definition was adopted in the *EN 1614* [19-3.5], and (for "kind of quantity") essentially in the *VIM3*. The latter gives

> *kind of quantity;* kind: aspect common to mutually comparable quantities [132-1.2]

6.19.1 The definition requires not only comparability, but also identical fundamental definition. Thus, e.g., "work" and "heat" are here considered to be different kinds-of-property (cf. S.6.13).

6.19.2 A definition patterned on that of "type of characteristic" (S.2.14.2) would read 'common defining aspect of a set of coordinate properties', but that would constitute a metalinguistic incursion upon the common language preferably used in definitions of non-terminological concepts.

6.19.3 Any division of <property> indicated as having a certain kind-of-property, e.g. "colour" or "length", as an ¦essential characteristic is first of all a ¦specific concept under <property>, but is often simply designated by the kind-of-property short term rather than, e.g., 'property having a colour'. The ability to identify the next to last level of generic divison, that is just above singular properties, often has advantages of generalization homologous to the use of variables in mathematics and species in biological kingdoms.

6.19.4 The well-known phrase 'properties of the same kind' could also be used as a term for a concept defined as 'set of properties that are mutually comparable'. This would mean, however, defining a noun in the plural and also focussing on a set rather than on the shared traits of its members.

6.20 The concepts "property", "kind-of-property", and "singular property" are related in the concept diagram of Figure 6.20 together with examples.

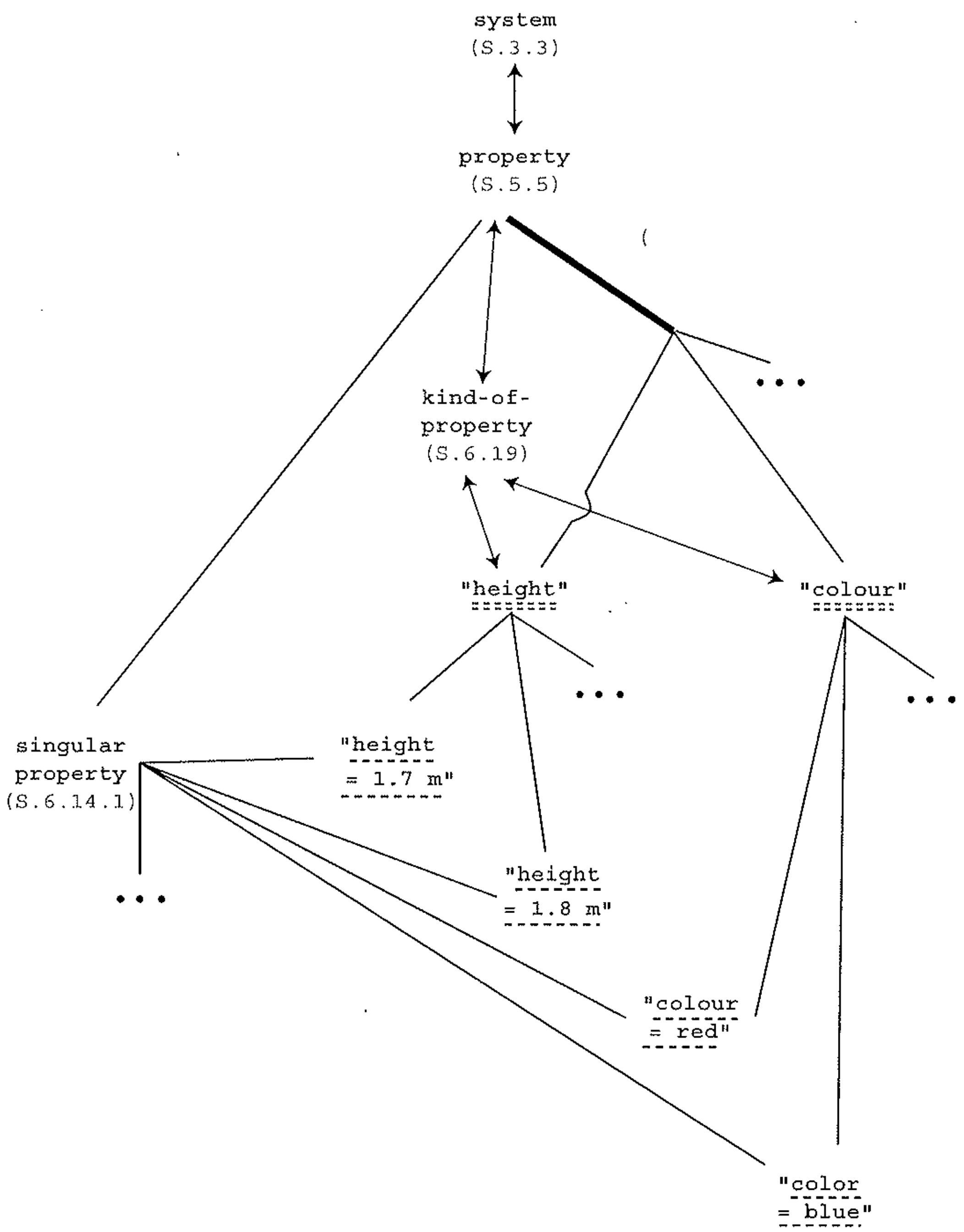


Figure 6.20 Concept diagram on "property", "kind-of-property", and "singular property" with examples

CONCEPTUALIZATION

6.21 It might be considered contradictory that a concept such as "property", residing in the mind, is defined as a feature inherent in a system, which is a part of the perceived or conceived world (S.5.5). With the concepts discussed previously in this chapter and with the terminological metalanguage of Chapter 2, it is possible to outline the process of conceptualization [71-5.1 to 5.3] with a metrological example.

6.22 The first concept defined in the systematic terminological ˡvocabulary of the *ISO* [72] is ˡ"object" (S.2.23). That is probably no accident because the formation of a concept in a person's mind usually starts with the physiological process of perceiving or conceiving an object with certain properties situated in the person's body or his environment. The object - here chosen to be an instance of "system" (S.3.3) - is abstracted by the mind for purposes of deliberating upon the phenomenon. This process produces an ˡindividual concept with individual characteristics (S.2.18).

Meeting new instances of "system" and forming new corresponding individual concepts may reveal that some of these concepts all have at least one individual characteristic which is identical. This situation allows the formation of a superordinate concept having that characteristic and corresponding to an extension with all the instances of system having a property corresponding to the characteristic.

If an individual or superordinate concept is found to have a characteristic with some aspect in common with the characteristic of another concept, the common part may be distinguished as a type of characteristic (S.2.14.2) for a general concept at the next 'synthesizing' level of abstraction. The process of generalization may be pursued level by level.

6.23 As an example, and using the notation presented in Table 2.1, a supravital preparation from a sample of an adult human's peripheral blood is perceptionally examined under a microscope according to a certain procedure (Figure 6.23). Variously shaped, sized, and coloured blood cells with spatio-temporal coordinates are seen and may be roughly distinguished into

- red blood cells, erythrocytes, E1, ..., E*n*, that are red, biconcave disks of various diameters around 8 μm;
- white blood cells, leukocytes, L1, ..., L*p* that are blue (in various shades, intensities, and irregular areas) globules of various diameters around 15 μm;
- platelets, thrombocytes, T1, ..., T*q* that are blue, biconvex disks of various diameters around 2.3 μm.

Physical world perceived by microscopist	* colour shape diameter	E1 = red = biconcave = 7.4 µm ⩶ V	E2 = red = biconcave = 7.4 µm ⩶ V	E3 = red = biconcave = 8.1 µm ⩶ V	L1 = blue = globular = 15 µm ⩶ V	T1 = blue = biconvex = 1.8 µm ⩶ V	Instance of "system" (S.3.3) with instantiated properties (S.5.5)
Mind world conceived by microscopist	has colour has shape has diameter	"E1 of red of biconcave of 7.4 µm"	"E2 of red of biconcave of 7.4 µm"	"E3 of red of biconcave of 8.1 µm"	"L1 of blue of globular of 15 µm"	"T1 of blue of biconvex of 1.8 µm"	Individual concept with individual characteristics (S.2.18)
							General concept with characteristics (S.2.11)

"E
having colour of red
having shape of biconcave
having diameter of 7.4 µm"

"E
having colour of red
having shape of biconcave
having a diameter of (6.9; 8.0)µm"

<blood cell
having a colour of (red, blue)
having a shape of (bc, gb, bx)
having a diameter of (1.5; 20)µm>

Figure 6.23 From perceived single cells of various appearances seen microscopically in a stained blood smear to the superordinate all-embracing concept <blood cell>. 'Instances and 'individual concepts are spatio-temporally specified. Notations are from Table 2.1. A broken connector indicates a multitude at the level of instances and several levels of concepts.

* In this column, each line gives the obligatory preface to each of the five examples in the same line.
E = Erythrocyte, L = Leukocyte, T = Thrombocyte, bc = biconcave, gb = globular, bx = biconvex

From individual physical systems, described by their instantiated properties in a perceiving process, the ensuing conceptual process leads through levels of increasing generalization to the superordinate concept <blood cell>. Once established, these paths form a concept system, which will usually be presented invertedly, in this case as a generic system. The hierarchy permits the classification of any single blood cell to the desired degree of specialization by examining the instantiated properties of the cell.

6.24 A given instantiated property, inherent to its instantiating parent instance of "system", cannot be detached and perceived as an isolated physical phenomenon. A recorded diameter = 7.4 µm or a colour = red is not found floating around independently in space. Each physical world property may however be conceived as corresponding to an individual concept in its own right, here called a singular property (S.6.14.1) - "diameter = 7.4 µm" or "colour = red" - with its individual concept under "system" as a specification or individual characteristic. The conceptualization and generalization process for the singular property then proceeds analogously to those described in S.6.22.

6.25 From an infinite number of singular properties the mind decides that some are identical (apart from system specifications) and furthermore that some are members of a set with a recurring aspect of all its members, say that they have the essential characteristic "length". This uniting concept is a kind-of-property (S.6.19) that delimits a specific concept under the generic concept <property>.

Continued generalization ends with the topmost concept <property>, but many such processes proceed along different paths to give different concept subsystems.

6.26 Analogously to the description for <blood cell> (S.6.23), any such system may be inverted into a generic concept system.

6.27 It is seen that terminological analysis begins with the instantiated systems and their instantiated properties, i.e. with objects. In the present context, the discussions often start with characteristics and concepts whose extensions are familiar to the particular metrological community.

6.28 The division of <kind-of-property> according to several terminological dimensions will be detailed in Chapter 13.

7 "EXAMINATION PROCEDURE", "examination method", and "examination principle"

'You know my methods, Watson.'
Sir Arthur Conan Doyle, 1859-1930 (The Memoirs of Sherlock Holmes, 'The Crooked Man' [quoted in 77])

"EXAMINATION PROCEDURE"

7.1 The proposed ¦terminological entry for "property" (S.5.5) has a Note 3 stating that 'an examination procedure may be an integral part of the ¦definition of a given property'. Indeed, many kinds-of-property (S.6.19) cannot be understood without such information as the property values (S.9.15) of their ¦instances are completely 'procedure-dependent'. The examination procedure indicates in sufficient detail how to perform an "examination" (S.8.4), usually in the form of verbal or written instructions, so that a reproducible examination result (S.16.20) with an expected examination ¦uncertainty (S.16.23) can be obtained.

7.2 The *VIM3* is concerned with ¦concepts related to "quantity" (S.12.13, 12.14), not the ¦superordinate concept "property". Consequently, as the examination of a quantity is conventionally called a 'measurement' (S.15.14.1, 15.14.2), the *VIM3* defines a series of three concepts involving increasing detail of information given about how to understand and perform the measurement.

7.2.1

measurement principle; principle of measurement: phenomenon serving as a basis of a measurement [132-2.4]

7.2.2

measurement method; method of measurement: generic description of a logical organization of operations used in a measurement [132-2.5]

7.2.3

measurement procedure: detailed description of a measurement according to one or more measurement principles and to a given measurement method, based on a measurement model and including any calculation to obtain a measurement result [132-2.6]

7.3 The Note 3 to the definition of "property" given in Section 5.5 stipulates the level as that of "procedure", and the following ¦term and definition are proposed for the concept.

<u>examination procedure</u>
detailed instructions for performing an **examination** (S.8.4)

NOTE 1 - An examination procedure is based upon a less detailed **examination method** (S.7.4), which itself is based upon one or more **examination principles** (S.7.5), each of which is designated by a word or a short ˡterminological phrase.

NOTE 2 - The examination procedure specifies the **dedicated kind-of-property** (S.20.6) involved, any sampling, examining system, and ˡreference material(s) needed, and the **property value scale** (S.10.14) used, including any ˡ**metrological unit** (S.18.12). The examination procedure is based on an examination model and specifies how many **examined property values** (S.9.20) must be obtained to calculate an **examination** ˡ**result** (S.16.20) including its expected **examination** ˡ**uncertainty** (S.16.23).

NOTE 3 - The information presented in an examination procedure is intended to be operational and should be sufficient for a trained operator to perform an examination satisfactorily.

7.3.1 The definition does not conflict with the analogous one of the *VIM3* given in Section 7.2.3, but is shorter, providing the additional information in notes.

7.3.2 The US *National Committee for Clinical Laboratory Standards* (*NCCLS*) defines.

procedure; protocol: specific sequence of actions or instructions to be followed to accomplish a task [105]

which is ambiguous because it comprises both an activity and its description.

7.3.3 The *ISO/IEC Guide 2*, 7th edition, has

test method: specified technical procedure for performing a test [77-13.2]

which uses 'method' as a ˡsynonym for 'procedure' but otherwise agrees with the proposed definition in Section 7.3. The 8th edition omitted the concept [77a}. (Concerning the term 'test', see Section 8.5.)

7.3.4 The *ISO 9000* offers a definition of

> *procedure*: specified way to carry out an activity or a process [70-3.4.5]

which covers a superordinate |generic concept for "examination procedure".

A |generic division of the superordinate concept <examination procedure> is offered in Chapter 14.

"EXAMINATION METHOD"

7.4 The more general formulation of instructions underlying a detailed examination procedure may be defined as follows.

> <u>examination method</u>
> method of examination
> structural basis of a |set of **examination procedures** (S.7.3) related to a **dedicated kind-of-property** (S.20.6)
>
> NOTE 1 - An examination method is based on one or more **examination principles** (S.7.5).
>
> NOTE 2 - The laconic description in an examination method is insufficient to allow an **examination** (S.8.4) with prescribed **examination |uncertainty** (S.16.23), but aids in devising and formulating one or more examination procedures.

Whereas the *VIM3* definition of "measurement method" (S.7.2.2) relates it directly to "measurement", the proposed definition relates to the stage betwixt the two, the operational instructions in "measurement procedure"; substitution will invoke "examination". The *VIM3* adjective 'logical' seems superfluous.

A |generic division of this concept is found in Section 14.11.

"EXAMINATION PRINCIPLE"

7.5 An examination method is based on one or more designated fundamental physical, chemical, or biological laws or types of metrological action which leads to the following concept.

<u>**examination principle**</u>
principle of examination
fundamental phenomenal elements underlying an **examination method** (S.7.4)

EXAMPLES - Gravimetry, volumetry, isotope dilution-mass spectroscopy, thin-layer chromatography, immunoprecipitation

The *VIM3* definition of "measurement principle" (S.7.2.1) relates it directly to "measurement" whereas the above definition relates to the nearest stage of "measurement method", which by sequential substitution leads to "examination".

This concept is generically divided in Section 14.12.

7.6 The three concepts defined in this chapter are associatively related as shown in Figure 11.1.

8 "EXAMINATION"

'To observations which ourselves we make/We grow more partial for th' observer's sake.'
Alexander Pope, 1688-1744 (Moral Essays I.11 [quoted in 24])

8.1 In 1946, *Stevens* reported the outcome of seven years of long and difficult discussions by a *Committee of the British Association for the Advancement of Science* [114]. They defined

measurement: assignment of numerals to things so as to represent facts and conventions about them [114]

and stressed that the essential requirement was a consistent set of rules for assigning the numerals. These studies led to descriptions of four types of scale based on respectively allowed mathematical operations with the numerical values. This view of "scale of measurement" was suggested for application in laboratory medicine (see also Chapter 10), and the concomitant use of 'measurement' as the term for the top concept was later advocated for clinical chemistry [40].

8.2 The definition of "measurement" by the *British Committee* as well as *Stevens'* later more general definition

measurement: process of mapping empirical properties or relations into a formal model [115-p.20]

are so broad that they include the assignment of values for properties using the mathematically simplest type of scale described - generally called a nominal scale (S.17.5). Representations of property values (S.9.15), such as = green and = blood type A, can alternatively be symbolized by numerals used as code numbers devoid of magnitude. Thus, it may seem illogical to restrict "measurement" to activities leading to numerical expressions of magnitude and exclude other ways of assigning numbers just because they represent synonymous phrases. In any case, to most if not all physical metrologists, *Stevens* went too far when "measurement" included 'the 'numbering' of football players for the identification of the individuals' [5, 52].

8.3 The *VIM3* reserves the term 'measurement' for activities leading to values for properties having magnitudes by defining

measurement: process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity [132-2.1]

where "quantity value" is defined as

quantity value; value of a quantity; value: number and reference together expressing magnitude of a quantity [132-1.19]

A Note 1 explains that the type of reference is either a measurement unit or a measurement procedure or a reference material. Still, most metrologists as mentioned would not favour the inclusion into "quantity" of properties with magnitudeless values, where any numerals are simply symbols of classes, such as when 'zero' and 'one' symbolizes, for example, "female" and "male" respectively.

NOTE - The *ISO 9000* has the entry

measurement process: set of operations to determine the value of a quantity [70-3.10.2]

Measurement is usually considered to be a process, however, so there is no need to choose the ¦complex term.

8.4 For the present purposes, that is a ¦superordinate concept for the activities that yield an "examined property value" (S.9.20), the proposal is to ¦designate and ¦define as follows.

> <u>**examination**</u>
> structured activity giving an **examination result** (S.16.20)
>
> NOTE 1 - The activity of examination essentially consists in comparing, by way of an examining system, the **property** (S.5.5) considered, i.e. the **examinand** (S.5.7), with a 'reference' of a like nature to obtain an **examined property value** (S.9.20) with associated **examination uncertainty** (S.16.23). Such a reference may be personal and subjective, such as a person's memory of a colour; or the reference may be objective, the best being a definition of an **SI unit** (S.18.30).
>
> NOTE 2 - The activity may be subjective or objective, even automated, and is prescribed in the **examination procedure** (S.7.3).

8.4.1 It is important that the activity should not only give a single estimating value but also its associated examimation uncertainty (S.16.23), in toto an examination result (S.16.20).

NOTE 1 - The *ISO 8402:1994* used 'examination' in defining "validation" and "verification" [68], but this standard is now replaced by *ISO 9000:2005* [70] which deleted that term.

NOTE 2 - The International Standard *ISO 15198* included the present author's suggestion to define "examination" as a superordinate concept, but chose the *VIM2* phrasing, available at that time, of

> *examination*: set of operations having the object of determining the value of a property [74-3.6]

This definition was recently augmented by *EN ISO 15189:2007* to '... value or characteristics of a property' [133-3.4], but this confuses the issue because a characteristic is not determined (S.2.11).

8.5 The term 'examination' for the superordinate concept, covering a wide spectrum of approaches to obtaining quantity values, is chosen because it has fewer unwarranted connotations and seems less associated with specific purposes or procedures than terms such as 'assessment', 'determination', 'evaluation', 'investigation', 'measurement', 'observation', and 'testing'. (Especially regarding the term 'observation', see Section 15.21.)

8.5.1 The concept "test" is defined in the *ISO 9000:2005* as

> *test*: determination of one or more characteristics according to a procedure [70-3.8.3]

which is a shorter version of previous similar definitions [such as 121] as well as a recent one giving

> *test*: <technical> technical operation that consists of the determination of one or more characteristics of a given product, process, or service according to a specified procedure [75-3.2.3]

It may be assumed that 'characteristic' is used to designate the concept here called 'property', see Section 2.11, Notes 1 and 2.

In contrast to the proposed definition of "examination", this definition uses the somewhat colloquial phrase of 'determination of one or more characteristics' rather than 'determination (or estimation) of a (property) value'. Otherwise, the meanings are similar.

8.5.2 Sometimes, it is not clear whether 'test' refers to an instruction or an act. An example is the definition by the US *National Committee for Clinical Laboratory Standards*.

> *test*: qualitative, semiqualitative, quantitative, or semiquantitative procedure for detecting the presence of, or measuring the quantity of an analyte [105]

where "procedure" is itself defined ambiguously [S.7.3.2]. Furthermore, 'quantity' seems to be a synonym for 'amount' making the concept very restricted.

8.5.3 The term 'test' is often used to indicate an activity involving stress on the item (or system) - in agreement with a dictionary sense. This is obvious in the definition by the *European Organization for Quality*

> *test*: functional trial or examination, of one or more characteristics of an item, by subjecting the item to a set of physical, chemical, environmental or operating actions and conditions [44-1.4.2]

but such strain - often to the point of destruction of the system - is certainly not always an ingredient in "examination".

'Test' is furthermore often implying a purpose of assessing whether a requirement has been met, i.e. compliance.

The term 'test', unfortunately, is also a ¦homonym for an examining system, usually of a modest size.

8.6 It is not the intent in the present study to discuss theories of measurement in detail (see, e.g. [91]), but a few words might not be amiss to show the complexity of measurement. The *classical axiomatic approach* fundamentally relates a set of empirical measurands (S.5.8), Q, one-one onto the equivalent set of numbers, M, assigned to describe them. In this idealized view there is a tendency to forget the empirical process of measurement necessary to obtain the numbers [15, 52]. The *operational approach* starts with a set of measurands, Q. Each of these interacts with a ¦measuring system (especially its sensor) and the environment to produce (a signal which may have to be further processed to give) an output signal as a member of a set of reading values, R. By ¦calibration with ¦measurement standards, a function between their assigned values and the reading values in R is established. The inverse measuring function transforms the set of reading values into a set of measurand numerical values, M. Inasmuch as the measurement is subject to sources of ¦uncertainty of measurement (S.16.24) [8], the set Q is not equivalent (one-one onto) to the set M. Each measurand is expressed by a (usually central) value with a surrounding uncertainty interval of values which can reasonably be attributed to the measurand and together constitute a ¦result of measurement (S.16.21) (see further in Section 9.22). At the present superordinate level, the respective sets involved could be termed 'examinands' (S.5.7), 'reading (including sensory) values', and 'examinand values'.

An alternative description of measurement is outlined under "property value scale" in Section 10.3

8.7 An English-language version of a German standard *DIN 1319-1* on *Basic concepts in metrology* [32] divides "measurement" into two concepts.

8.7.1

dynamic measurement: measurement during which either the measurand itself or its value changes significantly over time, or during which the measurand is a function of time-dependent quantitites, depending on the principle of measurement [32-2.1.1]

8.7.2

static measurement: measurement during which the measurand or its value does not change over time and by which the measurement is not based on other time-dependent quantities [32-2.1.2]

These definitions are confusing for two reasons.

Firstly, the phrase 'the measurand itself or its value changes' (or not) presumes that a measurand (or examinand) inherently can remain constant while its value changes (instability of measuring system aside). It seems more natural to say that a variable state-describing property indicates a changing system.

NOTE - *Heraclitus from Efesos* (c. 540-480 B.C.) already realized that 'You cannot step into the same river twice, for the second time it is not the same river'. A successor even emended this to 'You cannot step into the same river once' [quotations in 89]. In a ꜝterminological sense, it could be claimed that a given river - rather than being an ꜝindividual concept - becomes a general concept with an infinite number of time-specified ꜝinstances. The *ISO 1087-1*, however, considers "Saturn" an example of individual concept [72-3.2.2] and would label Ganges the same way. The system is not immutable but retains its identity.

In practice, however, at least some properties of a system may appear constant during its lifetime, although this is no guarantee of total stability.

Secondly, as remarked in the German standard, a given measurand which is considered constant may be measured indirectly by combining changing input quantities.

EXAMPLE - The rate of conversion of a biochemical process may be found constant during a reasonable time interval when the change of amount of substance of a reactant divided by the corresponding duration is measured repeatedly.

This latter situation appropriately may be termed 'dynamic measurement', where the modifier concerns the measurement as described in a measurement method rather than the nature of the measurand. The term 'static measurement', then, applies when, in principle, no time-dependent input-quantities are involved in the method.

The definition of "static measurement" is unfortunate in being formulated in a negative manner [19-6.4.3].

8.8 The following working definitions of the corresponding superordinate concepts may be offered.

8.8.1

static examination: examination (S.8.4) where the value of any input property value (S.9.15) is constant with time

8.8.2

dynamic examination: examination (S.8.4) where at least one input property value (S.9.15) is time-dependent

8.9 Further generic divisions of <examination> as a superordinate concept are presented in Chapter 15.

9 "PROPERTY VALUE", "true property value", and "examined property value"

'... one disciplined in the fine art of doubting never can be *absolutely* certain. Absolute certainty is a privilege of uneducated minds - and fanatics. It is, for scientific folk, an unattainable ideal.'

CJ Keyser, 1922 [88]

"PROPERTY VALUE"

9.1 The general concept "value" is discussed in philosophy with meanings such as 'virtue' or 'appropriateness', and in formal logic about correct reasoning. In the present context of "property" (S.5.5), as understood in metrology including laboratory medicine, another philosophically 'value-free' sense of "value" is involved.

9.2 As has been reiteratively stated in this text, common language is often less than exact in distinguishing between "property", "kind-of-property" (S.6.19), and "value", heavily relying on the context.

EXAMPLE 1 - The properties of a given erythrocyte may be given as 'seven micrometres and red', which is an abbreviated and therefore ambiguous version by value of the full statement seven micrometres in diameter and red in colour. The former version has contextual (and hopefully correct) assumptions about the respective kinds-of-property.

EXAMPLE 2 - 'Colour and length are properties' most likely means that they are kinds-of-property, but not "dedicated kinds-of-property" (S.20.6) or instantiated properties with values.

EXAMPLE 3 - Meeting with a king cobra, one might pause (perhaps with some trepidation) and exclaim: 'The colours and length of this fellow are impressive', mentally comparing the perceived values of its properties of these kinds to recalled modal values for such longitudinal beasts.

EXAMPLE 4 - Even a (written) standard may present ambiguous information. The *DIN 1313* [33] has the following four examples under Grössenwert [quantity value]. '15 m' and '-3.7 V' are both indubitably correct values. The next two entries are 'Lichtgeschwindigkeit im Vakuum', which is a system (S.3.3) (light in vacuum) and kind-of-quantity (speed), and 'Ruhemasse des Elektrons', which is also a system (resting electron) and kind-of-quantity (mass), and neither of these two latter examples - constituting dedicated kinds-of-property - have a quoted value, presumably because they are considered to be generally known.

9.3 The widespread practice of letting a value - and especially its metrological unit (S.18.12) if any - imply the pertinent kind-of-property can lead to mistakes because of a lack of essential information (cf. the discussion of ˡhomonymy for ˡcharacteristics in Section 2.22). Therefore, as an example, the outcome of a statistical treatment of temporarily 'severed' numerical values has to be referred back to their kind-of-property to be meaningful.

9.4 In the presently used ˡterminological notation (Table 2.1), the correspondence between individual characteristics (S.2.18) of an ˡindividual concept, say, of "erythrocyte no. 21" of the mind-world and instantiated properties of erythrocyte no. 21 of the material world is as follows (see also Section 6.22).

The "erythrocyte no. 21" is red with the type of characteristic (S.2.14) having a colour and is seven micrometres for having a diameter, alternatively expressed by is red in colour and is seven micrometres in diameter respectively.

The material red cell no. 21 is formally described by the properties colour = red and diameter = 7 μm.

Conventionally, = red and = 7 μm are called the values of their respective properties, colloquially, simply 'red' and 'seven micrometres'.

9.5 To gain further insight in the metrological conception of "value", it is both proper and useful again to quote *Maxwell* from the beginning of the *Preliminary* to his *A treatise on electricity and magnetism* [99].

> 'Every expression of a Quantity consists of two factors or components. One of these is the name of a certain known quantity of the same kind as the quantity to be expressed, which is taken as a standard of reference. The other component is the number of times the standard is taken in order to make up the required quantity. The standard quantity is technically called the Unit, and the number is called the Numerical Value of the quantity.'

As mentioned in Section 4.2, later metrological treatises routinely present this fundamental statement as the equation

quantity = numerical value · unit

and in the present text those three terms are taken to ˡdesignate mathematized general concepts.

9.6 *Maxwell* considered the right-hand side of the equation an *expression* of a given ¦quantity (S.12.13, 12.14), a standardized description by way of another quantity of the same kind, the ¦measurement unit (S.18.7, 18.12).

NOTE - It should be recalled that - irrespective of measurement uncertainty (S.16.24) - there can be more than one valid expression of a given quantity, such as a diameter of a system = 7 µm, = 0.007 mm, or = 0.00028 inch.

What the word 'expression' means is not clear. As seen from the quote above (S.9.5), one of the two 'elements' or 'factors' is said to be the 'name of a certain known quantity', that is the *name* of the unit. The text does not simply say the *unit* as one might rather expect from the equation. Probably, however, the wording of the text cannot bear strict terminological analysis, and it is unlikely that the right-hand side is thought to be a verbal designation for the concept on the left-hand side as it would not make sense to multiply a name by a number.

That the is-equal-to sign indicates a necessary 'likeness' between the two sides of the equation is supported by the generally accepted rearrangement

quantity/unit = numerical value

which shows a ratio between the mathematized general concept "quantity" and the mathematized general concept of a specific concept under "quantity", namely "unit" (cf. Fig. 18.44a). Any such pair of individual concepts under "quantity" and "unit" must be of the same kind-of-quantity.

9.7 Whereas the *ISO 1087-1* [72] does not mention "value", the *VIM3* (as already quoted in Section 8.3) ¦defines

quantity value; value of a quantity; value: number and reference together expressing magnitude of a quantity [132-1.19]

This definition implicitly echoes *Maxwell*'s words (S.9.5), including 'expression', but introduces the primitive 'magnitude'. The phrase 'magnitude of' could mean that "value" is considered to be a characteristic of "quantity".

NOTE - A definition in the *DIN 55 350-12* [31] of "Merkmalswert" (translated as 'characteristic value', but should be 'property value') has 'Der Erscheinungsform des Merkmals zugeordneter Wert'. A translation is dubious because of '-wert' and 'Wert', but could be 'expression of the value that is assigned to the property'.

9.8 The meaning of the ¦term 'quantity' in the *VIM3* is terminologically somewhat unclear because of the Note 1 which exemplifies both ¦generic concepts, ¦specific concepts, and ¦singular quantities.

9.9 The similarity between "type of characteristics" in the *ISO 1087-1* [72-3.2.5] and "type of characteristic" in the present text (S.2.14.2) on one side and "kind of quantity" in the new *VIM3* [132-1.2] and "kind-of-quantity (or -property)" in the present text (S.13.3.1, 6.19) on the other side seems to be optimal, even if the terms of the concepts and phrasing of their examples differ.

9.10 The *ISO* concept "characteristic" with the example being red is not essentially different from the presently defined "individual characteristic" (S.2.18), but this subordinate concept does not appear in the *ISO* [72]. So, it will simply be taken for granted that the usual *ISO* designation of a characteristic is an abbreviation of a full term including the term for the type of characteristic, here has the colour red.

9.11 The situation as regards the properties or quantities corresponding to characteristics is not quite so simple. The *ISO* does not elaborate on "property", but as mentioned simply lets it correspond to "characteristic". Also, the *ISO* does not list a concept related to "property" and corresponding to "type of characteristics". Here, it will be assumed that the full designation of an instantiated property should reflect inheritance like the full designation of an individual characteristic, see Section 9.4. The example of the *VIM3* concept "individual quantity" 'number concentration of erythrocytes in blood sample *i*' offers no indication of value, but it may be assumed that a value is understood as being inherent, even when it is not of known magnitude.

9.12 Before discussing the position of "property value" in a concept system, the following statements can be listed.

9.12.1 "System", "property", "kind-of-property", and "property value" are general concepts.

9.12.2 A spatio-temporally defined instance of "system" has inherent state-descriptive instantiated properties of various kinds-of-property.

9.12.3 An instantiated property inherently possesses a property value or usually a distribution of property values (see Section 9.18). (For simplicity here, the latter is generally assumed to apply even if the term 'property value' is used.)

9.12.4 Full information about an instantiated property requires data for both its kind-of-property and its property value(s) with reference to the instantiating system and its pertinent component(s). The instantiated property exists, however, and often can be perceived - either directly or aided by a device - whether its property value is known or not.

9.12.5 Instantiated properties of a given kind-of-property can be classified and compared by their respective property values.

9.12.6 According to certain rules, values of unitary quantities (S.12.17) (sometimes of ordinal quantities (S.12.16), but not of nominal properties (S.12.4)) of the same or different kinds-of-quantity may enter into appropriate algebraic property value equations formed homologously to equations between the respective kinds-of-quantity. Thus (omitting individual equation signs and single broken underlining for simplicity),

$$7 \text{ mole/litre} = \frac{3.5 \text{ mole}}{0.5 \text{ litre}}$$

is homologous to (with double quotation marks and double broken underlining omitted)

$$\text{amount-of-substance concentration} = \frac{\text{amount of substance of component}}{\text{volume of system}}$$

9.12.7 A property value of an instantiated property is a member of the set of property values of the same kind-of-property constituting an appropriately defined property value scale (S.10.14). Alternatively, one may say that a property value is a sample point in a unidimensional sample space defined for a kind-of-property.

9.12.8 The property value of an instantiated property can often be estimated by examination (S.8.4) during which a comparison is made between the examinand (S.5.7) and a reference with an assigned property value of the same kind-of-property.

9.12.9 The characteristics of inherence (S.9.12.3), comparability (S.9.12.5), and membership of a set (S.9.12.7) are ¦essential characteristics.

9.13 Based on the above information, the relation between "property" and "property value" can be explored.

9.13.1 As a property can be considered inherently to possess a property value (S.9.12.3), "property value" cannot be ¦generically subordinate to "property".

9.13.2 Forming a ¦concept system with "property" as a ¦comprehensive concept covering two ¦partitive concepts, one of which would be "property value", is not possible because a given property value is considered to be an expression of the magnitude of a property (cf. S.9.6 and 9.7) rather than a part of it.

9.13.3 The perceived inherence of a property value in a property (S.9.12.3) and the *VIM3* definition of "quantity value" (S.9.7) both suggest an associate relation between "property" and "property value". Whereas <property> is generically superordinate to, for example, "property having a diameter" and this in turn is generically superordinate to, say, the singular property "diameter of seven micrometers", this concept may be said to have is seven micrometers as the individual (S.2.18), essential, and delimiting characteristic, which corresponds to the property value = 7 μm of an instantiated diameter, diameter = 7 μm, of a given system.

9.13.4 The *VIM3* defines

> *measurement unit*; unit of measurement; unit: real scalar quantity, defined and adopted by convention, with which any other quantity of the same kind can be compared to express the ratio of the two quantities as a number [132-1.9]

and the equation in Section 9.6 also seems to require that a metrological unit is a quantity (here as its specific concept "unitary quantity" (S.12.17)). Therefore, a quantity value (S.16.7, 16.8) might also be considered to be a quantity. A diameter consisting of seven one-micrometre lengths still seems to have also a concatenated or joined length of seven micrometers. Indeed, "seven micrometers" could itself be a metrological unit - say, a "usual erythrocyte diameter unit" - just as "sixty seconds" is a metrological unit, also called 'minute'. Yet, a singular unitary quantity (cf. S.6.14.2), corresponding to an instantiated quantity of an instantiating system, is not identical with the separately defined metrological unit having a material instance used as a reference in assessing the magnitude of the instantiated quantity. Furthermore, ordinal quantities (S.12.16) are not related to metrological units. Thus, "quantity value" is associatively related to "quantity", and, by analogy, "property value" to "property".

9.13.5 Just as conceptualization eventually leads from immaterial instantiated properties inherent to instantiating systems in the physical world to "property" of the mind world (S.6.21 to 6.25 and Figure 6.23), the property value inherent to an instantiated property may be conceptualized into the general concept "property value". As a superordinate concept, <property value> may then be divided in its own concept system.

9.14 The concepts "system", "property", "kind-of-property", and "property value" may now be assumed to form a concept system as shown in Figure 9.14.

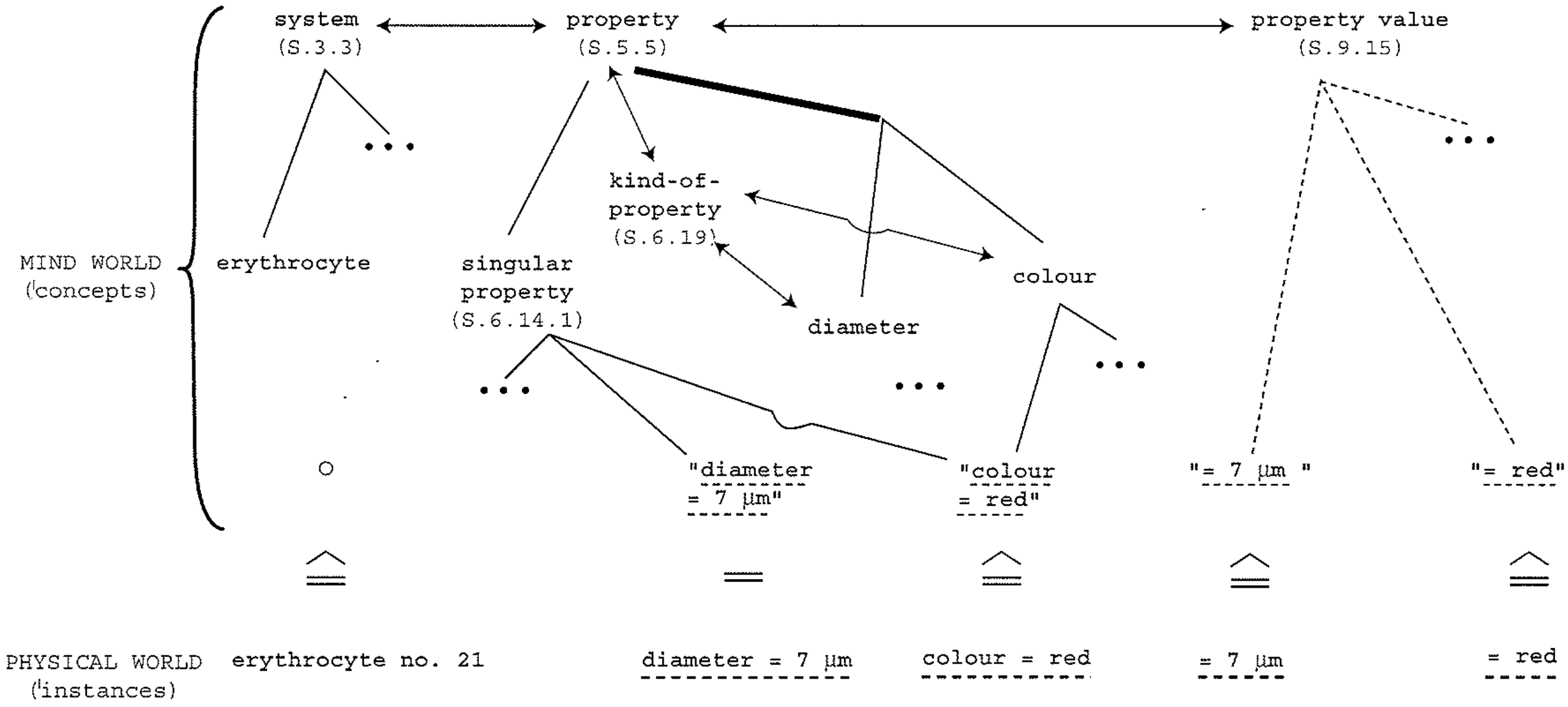


Figure 9.14 Mixed ˡconcept diagram on "system", "property", "kind-of-property", and "property value" with examples

Notations are from Table 2.1. A broken connector indicates a multitude at the level of instances and several levels of ˡconcepts.

9.15 Based on the discussion in Section 9.13, it is proposed to designate and define the general concept "property value" as follows.

<u>property value</u>
value of a property
value
inherent feature of a **property** (S.5.5) used in comparing it with other properties of the same **kind-of-property** (S.6.19)

NOTE 1 - A property value is a member of a conventionally defined set of possible values forming a **property value scale** (S.10.14).

NOTE 2 - An instance of "property value" is conveniently represented as a relational operator, such as =, ≤, or >, followed by a symbol or an alphanumeric string the form of which depends on the kind-of-property and the property value scale.

EXAMPLES
- colour, e.g. =_red (in a traffic light);
- letter, e.g. =_B (for blood group);
- word, e.g. =_yellow;
- terminological phrase, e.g. =_slightly_turbid;
- symbol, e.g. =_∞;
- alphanumerical, e.g. =_A1 as a taxon value (for an electrophoretically separated haemoglobin fraction);
- real number, e.g. =_12.7;
- some combination of such elements, e.g. >_0.7_millimole_per_litre.

NOTE 3 - Comparison between instantiated property values of the same kind-of-property serves to compare their respective properties and thereby their parent **systems** (S.3.3) or different parts of a system.

NOTE 4 - A property value may be estimated by **examination** (S.8.4).

The word pattern 'property value' has been preferred over that of the admitted term 'value of a property' for ease of further derived systematic terms.

"TRUE PROPERTY VALUE"

9.16 This definition of "property value" does not specify its 'source'. It is sometimes useful to be able to distinguish between specific subordinate concepts such as "true property value", "examined property value", "uncorrected experimentally examined property value", "corrected experimentally examined property value", and "subjectively examined property value". The first two of these specific concepts may be defined according to the type of characteristic having a source.

9.17 An instantiated property value that is conceived as inherently describing an instance of "system" without having been obtained by examination is wholly dependent on the definition of the property including its parent system. The classical term is 'true value of a quantity' and the concept is proposed to be defined as follows.

> true property value
> true value
> **property value** (S.9.15) that is consistent with the definition of a corresponding **property** (S.5.5)
>
> NOTE - A true property value is a member of a population of property values in the statistical sense, and such a property value and population remain unknown; they may, however, be estimated by **examination** (S.8.4).

This definition is analogous to the new *VIM3* definition

true quantity value; true value of a quantity; true value: quantity value consistent with the definition of a quantity [132-2.11]

9.18 It is often assumed that a single true quantity value is sufficient for the classification of an instance of "quantity". However, due to indeterminateness and - not least in laboratory medicine - uncertainty in the definition of an instance of "system" (S.3.3), with any pertinent components (S.3.4), and any defining examination procedure (S.7.3), the full 'expression' of the magnitude of the quantity generally requires a distribution of true quantity values rather than a single one. A single quantity value without conceivable variability may be sufficient for a time-specified well-delimited system where well-defined, easily recognized, and localizable items have to be counted, but such a situation will be considered to be a special case of the general principle. Analogous considerations apply for "nominal properties" (S.12.4).

"EXAMINED PROPERTY VALUE"

9.19 Even if an examinand may have a specified examination procedure (S.7.3) as part of its definition, the act of examination introduces new sources of examination uncertainty (S.16.23) stemming from the actual conditions of any sampling, equipment, calibration, procedural steps, the analyst, and the environment. Thus, the distribution of true property values is convoluted with a distribution of uncertainty effects. Consequently - even after correction for any estimated systematic effects - the population of possible property values from which actual examined property values are taken may have another location and should have a larger dispersion than those of the distribution of true property values.

9.20 An examined property value may be defined as follows.

> <u>**examined property value**</u>
> examined value
> **property value** (S.9.15) obtained by interaction between an examining system and a **system** (S.3.3) possessing the **property** (S.5.5)
>
> NOTE - The interaction constitutes an **examination** (S.8.4) performed by an examining system - consisting of a person and/or equipment - according to a given **examination procedure** (S.7.3) under specified precision conditions.

9.20.1 If nominal properties (S.12.4) are not considered, an analogous concept may be defined relating to "quantity" (S.12.14) and "measurement" (S.15.14.2).

> <u>**measured quantity value**</u>
> measured value
> **quantity value** (S.16.8) obtained by interaction between a measuring system and a **system** (S.3.3) possessing the **quantity** (S.12.14)
>
> NOTE - The interaction constitutes a **measurement** (S.15.14.2) performed by a measuring system - consisting of a person and/or equipment - according to a given **measurement procedure** (S.14.4.4) under specified precision conditions

9.20.2 The term 'observed value' is sometimes used for "examined property value", "examined quantity value" or the corresponding "result". Thus, the *American Society for Testing and Materials* has *observed value*: value obtained by carrying out the complete protocol of the test method once ... [2]

The *ISO 3534-2* gives the definition

observed value: obtained value of a quantity or characteristic [75-3.2.8]

with "observation" left undefined and a note that this term is also used as a synonym for 'observed value'. The reasons for not using 'observation' here are given in Section 15.21.

9.21 Several examined property values of an examinand or measured quantity values of a measurand, including any corrections, may be needed to obtain a final "examination result" (S.16.20) or "measurement result" (S.16.21).

This view was expressed somewhat differently by *Mergenau* [102] as follows. 'An empirically "true" value of a measured quantity does not exist. What passes for truth among the results of measurement is maximum likelihood, a concept that attains meaning if a sufficient statistical sample of differing measured values is available.'

9.22 The classical ideal approach of describing a measurement result (S.16.21) of a quantity as a true quantity value (S.9.17.2) burdened with various systematic and random errors of measurement suffers from the fact that true quantity values are essentially unknown. The modern paradigm, presented in the *Guide to the expression of uncertainty in measurement* [8], avoids the term 'true value'. Instead, an operative approach is based on a function of input quantities yielding the output quantity, the measurand. Each input quantity has an estimated quantity value obtained by measurement (S.5.14.1, S.5.14.2) or other means and corrected if necessary. These input quantity values are combined by a model or function, homologous to that between the input quantities, giving the quantity value of the measurand as the output. The measurement uncertainty (S.16.24) of this quantity value is obtained by combining the respective measurement uncertainties of the input quantity values and of any corrections. Each such input standard measurement uncertainty is evaluated from replicated measurements by classical a posteriori statistics or from other a priori sources including metrological experience. The combined standard measurement uncertainty of the output measurement result is based on an uncertainty budget and a suitable combination of the standard measurement uncertainties. The combined standard measurement uncertainty permits calculation of a coverage interval comprising the quantity values that are being attributed to the measurand with a stated level of confidence or coverage probability. The details are beyond the purpose of the present text.

9.23 A generic division of the superordinate concept <property value> is made in Section 16.

9.24 The several sorts of property value discussed so far may be connected in the concept diagram shown in Figure 9.24.

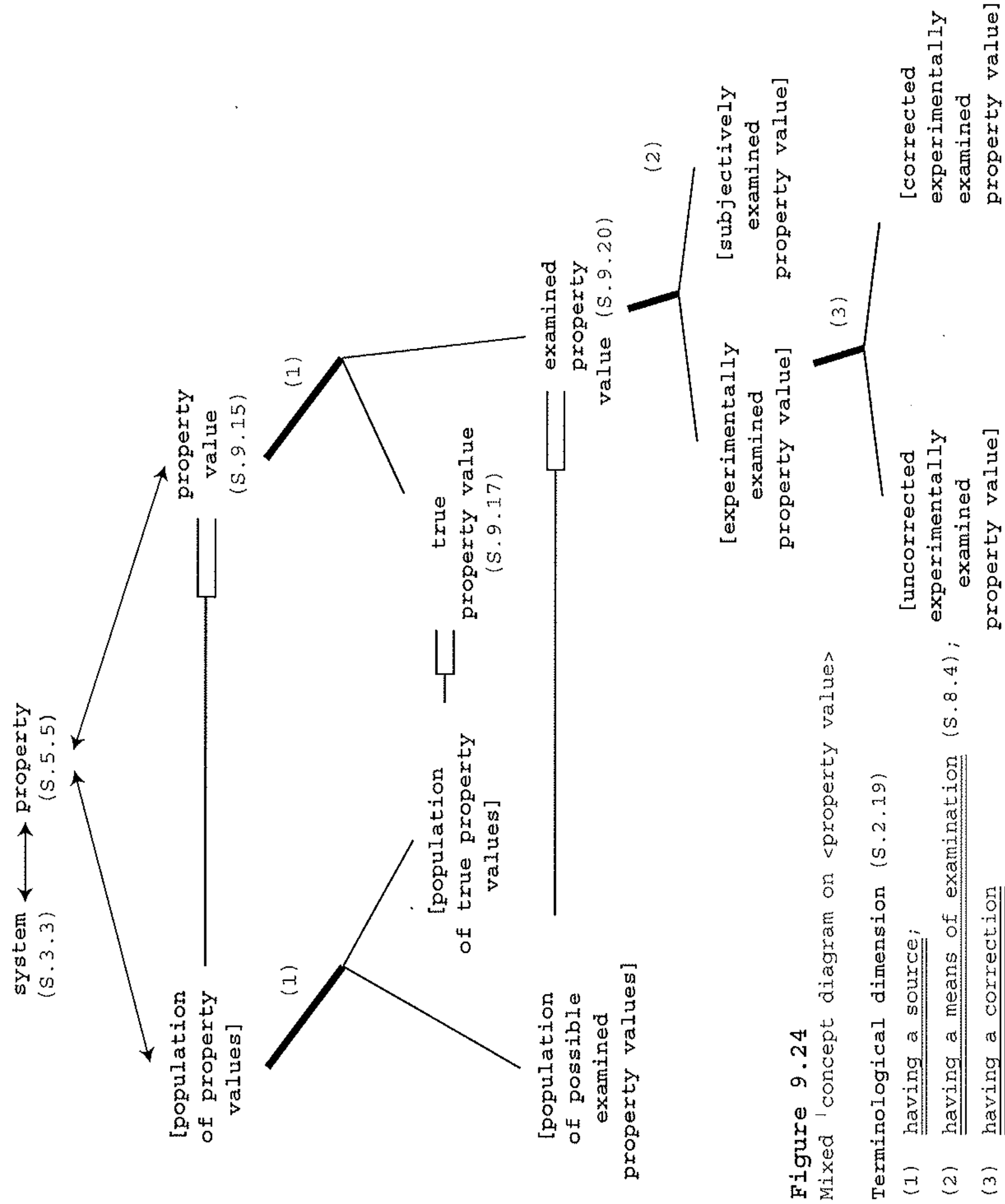


Figure 9.24
Mixed 'concept diagram on <property value>

Terminological dimension (S.2.19)
(1) having a source;
(2) having a means of examination (S.8.4);
(3) having a correction

9.25 As seen by the examples of Section 9.15, a property value can take many forms. For a unitary quantity especially, the conventional *representation* is the alphanumeric combination of the representation of a numerical unitary quantity value (S.16.16) and the representation of a metrological unit. The last two concepts are |coordinate concepts in |partitive relation to the representation of the unitary quantity value as shown in Figure 9.25.

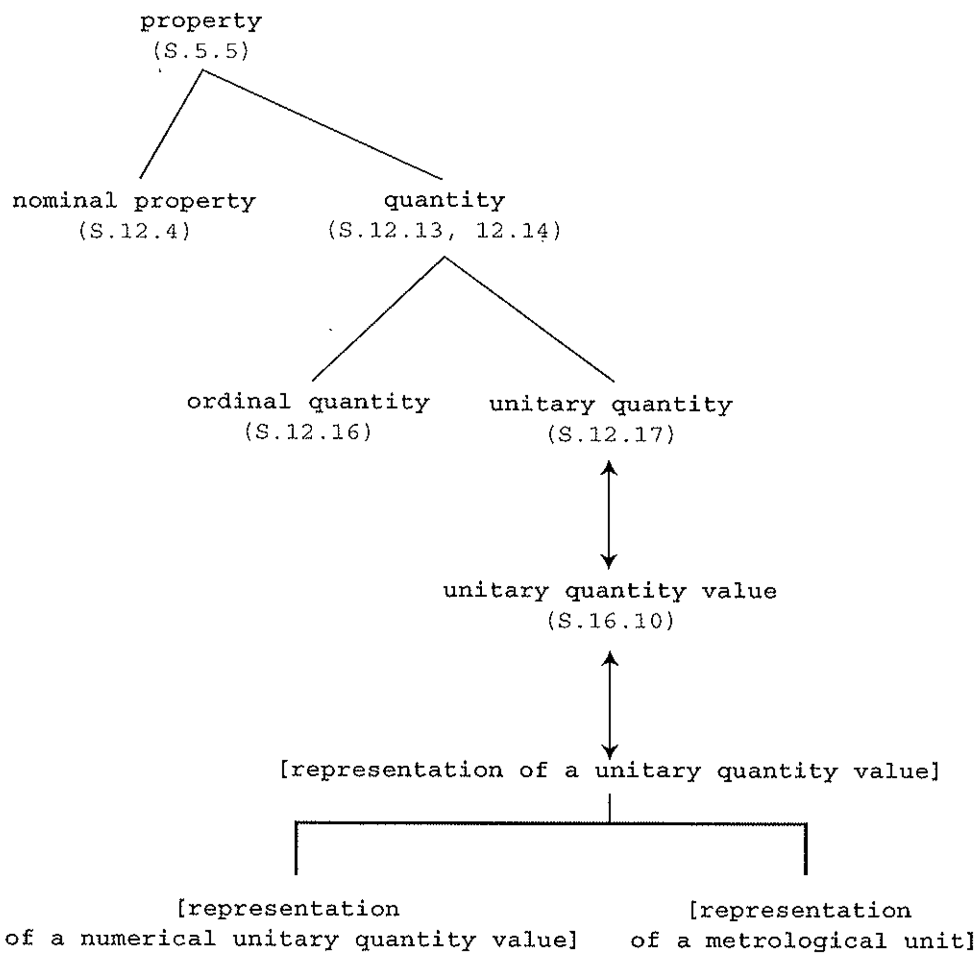


Figure 9.25 Mixed |concept diagram around "unitary quantity", "unitary quantity value", and its representational elements

10 "PROPERTY VALUE SCALE"

'For he by geometric scale/could take the size of pots of ale.'
Samuel Butler, 1612-1680 (Hudibras I.i 121 [quoted in 24])

10.1 Whereas the noun 'scale' in the *COD* [1] has three groups of meanings around "flake", "weighing device", and "graded classification system", we are here only concerned with the latter interpretation, derived from Latin 'scala' for staircase or ladder.

10.2 In his pioneering paper from 1946, *On the theory of scales of measrement*, *Stevens* gave no formal definition of "scale of measurement" [114] - covering nominal, ordinal, interval, and ratio scales (S.17). From the text, however, one may deduce an intensional definition.

scale of measurement: numeral (or numerical) series, ordered by convention, having characteristics isomorphic with certain empirical operations performed with objects, permitting use of the series as a model to represent aspects of the empirical world [114]

10.3 From *Bunge*'s momentous tome on *The search for truth* (in *Methodology and philosphy of science*) [15], the section on 'Scale and unit' permits the definition

measurement scale: interval in which the degrees of a property are represented together with the ordering and spacing of the representatives [15-p.221]

where 'degrees of a property' in the present terminology could be 'unitary quantity values (S.16.10) relating to a given unitary kind-of-quantity (S.13.3.3)' as *Bunge* excludes properties having nominal (S.16.2) or ordinal property values (S.16.3).

Furthermore, there is a division into

conceptual [measurement] scale: ordered interval on which the numerical values of a magnitude are represented [15-p.221]

where 'numerical values of a magnitude' seems to be a synonym of 'true numerical unitary quantity values of a given kind', and

material [measurement] scale: ordered set of marks, such as the numerals on an instrument, the reading of which enables us to assign numerical values to the magnitude concerned [15-p.221]

where 'numerals' are 'possible numerical unitary quantity values' and 'numerical values' are 'numerical unitary quantity values' (S.16.16).

NOTE - In the latter two definitions there is no mention of an appropriate metrological unit (S.18.12), which after all is as important as the numerical unitary quantity value.

Bunge used the dichotomy in conceptual and material scales to describe his view of the structural complexity of |measurement (S.15.14.1, 15.14.2) necessitating four relational systems (S.3.3) each requiring an ordering relation and respectively a

- factual |set of 'degrees' of a physical [kind-of-]property (S.6.19), such as weight [mass], $\overset{\bullet}{R}$;
- conceptual subset of real numbers, *R*, providing 'actual' values [true unitary quantity values];
- factual set of 'marks' on a material scale, *M**; and
- conceptual subset of rational numbers, *M*, providing measured unitary quantity values.

A mapping from $\overset{\bullet}{R}$ to *R* and partial mappings from *M** to *M* and from *M* to *R* complete the system.

From a terminological point of view, the material scales can simply be |instances of the |concept "quantity value scale". Another approach is offered in Section 10.16.

10.4 The extensive and useful review of "scale" by *Berka* [5] lists a number of |characteristics of "scale of scaling" (corresponding to "ordinal quantity value scale"), and "scale of measurement". The latter, in what *Berka* (echoing *Bunge*) calls the conceptual sense, is given at least two non-formal definitions, of which the most understandable says

scale of measurement: ordered interval of numerical values of the measured magnitude, reflecting the choice of the unit of measurement by the objective properties of this magnitude, and by its conceptual definition within some theoretical framework [5-p.12]

The meaning seems less than clear, but 'magnitude' may (again) be interpreted as 'quantities of a given kind'.

From the |context, it appears that this concept applies exclusively to properties (S.5.5) for which ratios between their values (S.9.15) have meaning, that is quantities in the narrowest sense, in French 'grandeur mesurables', in accordance with classical theory of measurement. *Berka*'s concept is one of the four scales defined by *Stevens* [114] and called 'ratio scale'. For the present purposes the concept is too narrow.

10.5 The German standard *DIN 55 350-12* from 1988 [31] on *Concepts in the field of quality and statistics; concepts relating to characteristics* (|equivalent to 'kind-of-property') embraces *Stevens'* broader concept - although referring to a German-language source. The definition given,

Skala: Zweckmässig geordneter Wertebereich eines Merkmals [31-1.1.3]

may be translated as

scale: purposefully ordered set of property values for a given kind-of-property

NOTE - Translation of the German definition is difficult. The standard gives the translation of 'Merkmal' into English 'characteristic', which in the present text is reserved for the |special language of terminology and which describes concepts, not |objects. "Merkmal" is defined through 'Eigenschaft' which could equivalate with 'property'. 'Merkmal' could alternatively equivalate with 'kind-of-property' as corroborated by the examples of Merkmal given such as "temperature". The problem seems to arise from the prevalent lack of distinction between property and kind-of-property.

10.6 A paper from 1989 on *Measurement, value, and scale* in laboratory medicine [40] suggested the application of *Stevens'* ideas. No formal definition of measurement scale was presented, but the text combines to

measurement scale: ordered set having possible values as elements [40]

where 'measurement' is a |synonym of the present text's 'examination' and a common kind-of-property is presupposed.

10.7 From the definitions discussed above, the following characteristics can be listed:

- numerals (for nominal properties (S.12.4)) or numerical quantity values,
- interval of property values or set of property values,
- ordered or purposefully ordered or conventionally ordered,
- possible property values,
- property values of a given kind-of-property,
- characteristics isomorphic with certain empirical operations on |objects,
- model of aspects of the empirical world,
- serving to order property values and thereby their respective |instances of properties.

10.8 *Stevens* restricted the values even of a nominal property value scale to 'numerals' serving as labels or type numbers [114]. This choice is consistent with his definition of "measurement" as 'assignment of numerals to objects or events according to rules'. In the present text, however, "property value" (S.9.15) may also have instances that are words or phrases, such as = slightly turbid, and combinations of numbers and metrological units (S.18.12), such as ≥ 0.7 millimole per litre.

10.9. The term 'interval' is used polysemously for the numerical values between and often including one or both of the limiting values, and for the limiting values only. The term 'set' is therefore preferred for the general concept, both because all values are defined and because there is no restriction on type of value which may include words and phrases.

10.10 Ordinary language demands that a value scale be ordered, but gives no specifics, although most numerical scales would be ordered by ascending value. For nominal property value scales (S.17.5), the order does not influence the function, but for practical, technical, or mnemotechnical reasons a constant order is often chosen, such as for blood groups A, B, AB, 0. When a set is ordered - and that requires some rule or convention - it is hardly necessary to qualify it by 'conventionally' or 'purposefully'.

10.11 An important role of a property value scale is that it presents the property values that can possibly be thought of for the singular properties (S.6.14.1) under consideration or that can be obtained by examination of instances of "property", so that these can be classified for subsequent comparison. A property value scale may be thought of as a unidimensional sample space.

10.12 The activity of classifying instances of property according to their examined property values (S.9.20) requires that the instances be of the same kind-of-property.

EXAMPLE - It makes no sense to construct a (unidimensional) examined property value scale comprising the possible examined property values (S.9.20) for the masses, lengths, intelligence quotients, and genders of children - notwithstanding that such values may have interesting relationships within one child at a given time.

10.13 *Stevens* claimed that there is 'a certain isomorphism between what we can do with the aspects of objects and the properties of the numeral series' [114]. ("Homomorphism" would have been a more appropriate, less stringent characteristic [91-p.8].) The empirical operations listed were determining equality, greater or less, equality of differences, and equality of ratios; numerals were said to yield to analogous operations. These operations will be discussed later for a generic division of <examina-

tion scale> (see Chapter 17). The general isomorphism, although considered an |essential characteristic by *Stevens*, is here not used as a |delimiting characteristic as it may not be true for all types of property. The same may be said of the allied trait that the series of numerals provides a formal mathematical system, a model for empirical properties. It is, however, important to stress that the choice of property value scale in a certain situation should be governed by the characteristics of the properties of the given kind-of-property (see Chapter 12).

10.14 As an outcome of the above considerations, the concept is termed and defined as follows.

property value scale
scale of values of properties
scale
ordered |set of possible, mutually comparable **property values** (S.9.15)

NOTE 1 - Regarding various forms of the property values, see Section 9.15, Note 2 and Examples.

NOTE 2 - A property value scale is used for ordering and comparing |instances of **property** (S.5.5) of a given **kind-of-property** (S.6.19) by their respective (distributions of) property values.

NOTE 3 - The |definition of the properties using a certain property value scale may include their respective **examination procedures** (S.7.3) as an |essential characteristic.

NOTE 4 - The statistical manipulations allowed with samples of property values from a property value scale are based on the relationships between the respective properties and characterize the property value scale (see Table 17.4).

The word pattern 'property value scale' has been preferred over that of the admitted forms 'scale of values of properties' or 'scale of property values' for ease of style and derivation.

10.15 *Berka* argued - as did *Bunge* (S.9.3) - that it is necessary to distinguish between "conceptual scale of measurement", conventionally called 'scale', and material measurement scale", which he proposed to call 'grade' [5]. The reasoning was that, for a certain kind-of-quantity, the conceptual scale includes *all* possible numerical quantity values whereas each of several material scales would comprise only a distinctive 'subinterval' of all quantity values.

It seems entirely possible that any useful, ¦generically ¦subordinate concept under <property value scale> can be defined for a given kind-of-property and selection of property values, and that material scales, whether as isolated devices or as displays on pieces of equipment, should simply be regarded as instances of such concepts.

10.16 The concept <property value scale> may be generically divided analogously to <property value> (S.9.17, 9.20) into

10.16.1

<u>true property-value scale</u> scale of true values of properties **property value scale** (S.10.14) that is consistent with the ¦definitions of corresponding **properties** (S.5.5) involved

10.16.2

<u>examined property-value scale</u> scale of examined values of properties examination scale **property value scale** (S.10.14) obtained by following an **examination procedure** (S.7.3) NOTE - The process involves firstly establishing a calibration function and secondly utilizing its inverse measuring function.

10.16.3 For a given dedicated kind-of-property (S.20.6) these two specific property value scales need not be identical. The true property-value scale, for example, might be continuous whereas the examined property-value could be discontinuous due to the nature of the examination procedure (S.7.3) and examining system; or an examination bias might change the scale limits.

10.17 A ¦concept diagram of "property value scale" and some related concepts are shown in Figure 10.17.

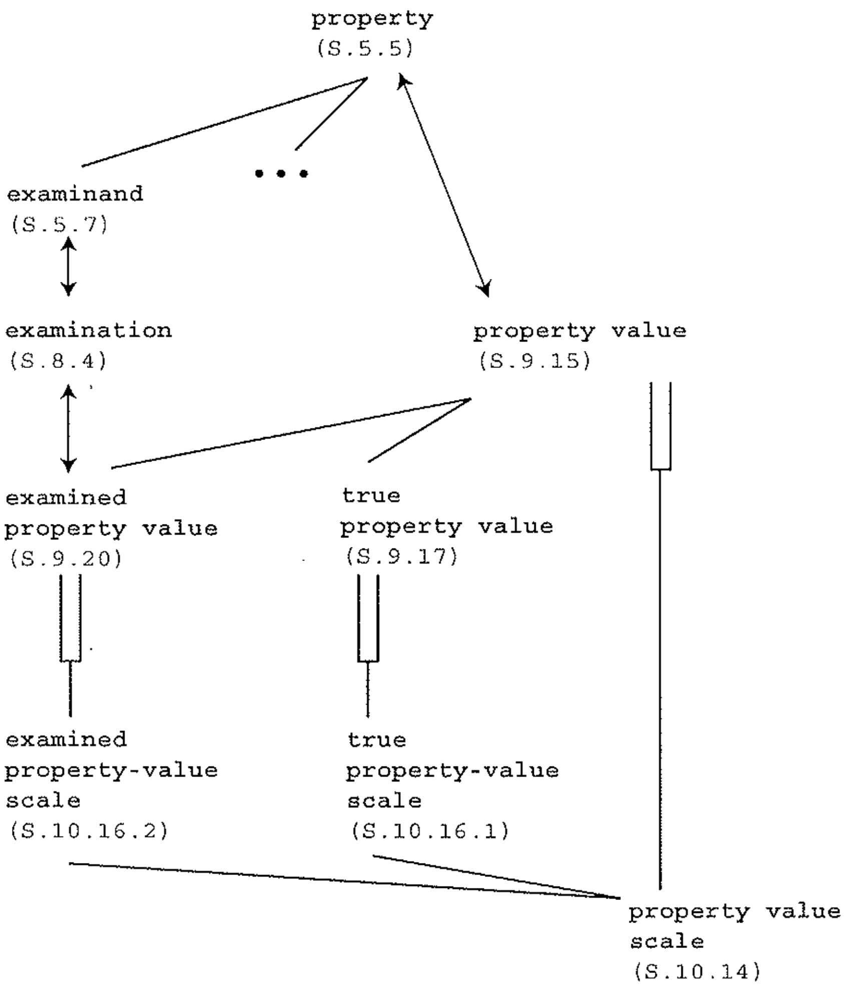


Figure 10.17 Mixed ¦concept diagram of "property value scale", "property", "examination", and "property value" with some ¦subordinate concepts

10.18 In a recent revision of the statistical vocabulary, *ISO 3534-2*, the top concept defined here in Section 10.14 is given as

scale: system of reference values for a characteristic [75-1.1.3]

where 'characteristic' unfortunately is used in the sense of 'property' and "reference value" is not defined. It seems that the proposed definition in Section 10.14 is more informative. Furthermore, "reference value" is often used for property values that are conventionally accepted as being well researched.

10.19 A generic division of "property value scale" according to relations between divisions of "property" will be described in Chapter 17.

11 GENERAL CONCEPT SYSTEM of the MAIN SUPERORDINATE CONCEPTS in CHAPTERS 3 and 5 to 10, and expanded and explicatory definitions

GENERAL CONCEPT SYSTEM

11.1 The principal ¦concepts defined in Chapters 3 and 5 to 10 may be presented as the mixed ¦concept system diagrammed in Figure 11.1. Such a presentation facilitates a review of the ¦definitions of concepts which were designed in accordance with the rules listed in Section 2.4.

11.2 Which ¦essential ¦characteristics of a concept are considered to be ¦delimiting characteristics for a definition, and which ones are put in notes, depend on

- the structure of the concept system;
- which ¦relations appear to be the most important;
- how many relations from a given concept are considered useful for explicit representation;
- the ¦terminological stress on avoiding both internal and external circularity in definitions; and
- the target audience.

As a consequence, it is unlikely that any choice will appear optimum to all users.

EXPANDED DEFINITIONS

11.3 Each of the definitions proposed so far, except for that of "system", is sufficient to indicate the position of the corresponding concept in the concept system shown in Figure 11.1. Expanded definitions of the main concepts, however, may be formulated by utilizing more of the related concepts shown.

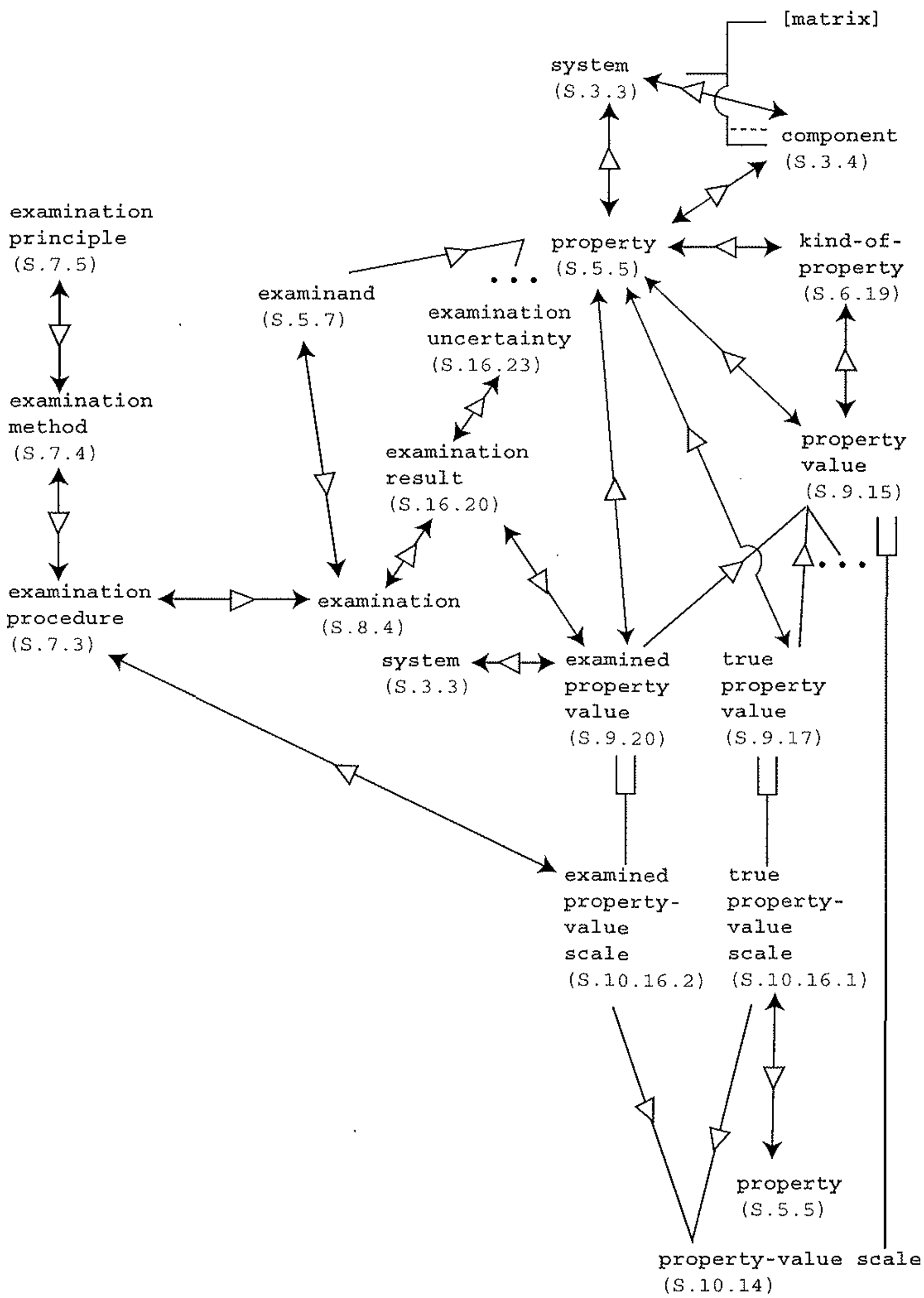


Figure 11.1 Mixed 'concept diagram on the 'metrological 'concepts given proposed 'definitions in Chapters 3 and 5 to 10 (except for "measurand").

A triangular open arrowhead points from a given concept to another concept used in the 'definiens of the first one.

11.4 The concept "property" is defined in Section 5.5 by relations to "system" (S.3.3) and "component" (S.3.4), but the definition could be greatly expanded by involving more relations as follows.

property: inherent feature of a system, including any pertinent components, that is state- or process-descriptive in the form of a distribution of true property values, which may be estimated by examined property values obtained through examination of the property as an examinand according to an examination procedure

11.5 "Examination procedure" (S.7.3) is defined by the ¦associative relation to "examination" (S.8.4), but could be further explained.

examination procedure: detailed instructions, based on an examination method utilizing one or more examination principles, for performing an examination of a property yielding one or more examined property values found on an appropriate examined property-value scale

11.6 The definition of "examination" (S.8.4) may be expanded as follows.

examination: structured activity according to an examination procedure, applied to a property, giving one or more examined property values found on an examined property-value scale

11.7 An expanded definition of "property value" (S.9.15) is possible as follows.

property value: inherent feature of a property that is found on a property-value scale of the same kind-of-property and that serves for classifying and comparing properties of that kind-of-property

11.8 The concept "property value scale" (S.10.14) is shown in Figure 11.1 with a ¦partitive relation to "property value", but the definition may be expanded.

property value scale: ordered set of possible, mutually comparable property values that may be transformed into an examined property-value scale by performing examinations on examinands according to a specified examination procedure

EXPLICATORY DEFINITIONS

11.9 Even more detailed explicatory definitions may be obtained from a given definition through substitution of defined ¦terms by their respective definitions. Table 11.9 shows "property" as an example. The outcome -

sometimes called an exploded definition - is too cumbersome for ordinary use, but serves for checking that a definition has not inadvertently become externally circular.

Table 11.9 Explicatory |definition of the |concept "property" (S.5.5): 'inherent state- or process-desciptive feature of a *system* (S.3.3) including any pertinent *components* (S.3.4)', shown after substitution of the |terms in italics. The left-hand column gives the explicatory definition, the right-hand column lists the substituted terms in brackets.

property	
inherent state- or process-descriptive	
feature of a	[system (S.3.3)]
part or phenomenon of the perceivable	
or conceivable world consisting of a	
demarcated arrangement of a |set of elements	
and a set of relationships	
or processes between these elements	
including any pertinent	[components (S.3.4)]
parts of that	[system (S.3.3)]
part or phenomenon ...	

11.10 A check can also be obtained simply through a structured listing by term of the related concepts used in the definition.

EXAMPLE - The following list appears from serial substitution in the definition of

- *examination procedure* (S.7.3)
  - examination (S.8.4)
    - examination result (S.16.20)
      - examined property value (S.9.20)
        - property value (S.9.15) ×
          - property (S.5.5) o ×
            - system (S.3.3) o ×
            - component (S.3.4) o ×
              - system (S.3.3) o ×
          - kind-of-property (S.6.19) ×
            - property (see o above) ×
        - system (S.3.3)
        - property (see o above)
      - examination uncertainty (S.16.23)
        - property value (see × above)
        - property (see o above)

12 GENERIC CONCEPT SYSTEM on <PROPERTY> and <QUANTITY>

<PROPERTY>

12.1 As has been repeatedly alluded to, the ˡconcept "property" (S.5.5) is ˡgeneric and can be divided according to either of many terminological dimensions (S.2.19) giving ˡspecific concepts with ˡcharacteristics indicated by modifiers such as

- primary (= material), secondary (= cultural);
- physical, chemical, biological, social;
- non-relational (= internal), relational (= external);
- directly perceivable, inferable (= objectifiable) [56];
- intensive, quasiextensive, extensive [56];
- subjective, instrumental;
- base, derived;
- dimensional, zero-dimensional (= having the dimension one), non-dimensional;
- non-unitary, unitary;
- qualitative, semiquantitative, quantitative;
- continuous, discrete; and
- scalar, complex, vector, tensorial (only scalar quantities are considered in this text).

A singular property (S.6.14) will be ˡsubordinate to several of the corresponding specific concepts, which are not always defined in the same way in all sources.

12.2 Here, firstly, a further important characteristic of "property" will be used for division, namely the mathematical relationships that can be defined between the property values (S.9.15) of ˡinstantiated properties of a given kind-of-property (S.6.19). *Stevens* used the respective permissible operations on property values to characterize five types of "scale of measurement", namely "nominal scale", "ordinal scale", "linear interval scale", "logarithmic interval scale", and "ratio scale" [114, 115] (see also Section 12.9). The approach was criticized by, e.g., *Berka* [5] and *Gonella* [52, 53] on the grounds that "scale" is secondary to "quantity" and "measurement". This objection can be met by instead using *Stevens'* principles describing the values that are inherent in properties. The other objection, that *Stevens* defined "quantity" and "measurement" too widely, has been met here by introducing "property" (S.5.5) and "examination" (S.8.4) as ˡsuperordinate concepts.

The choice of the ˡpreferred term for a specific concept is here sometimes a variant of current usage. The reasons are given in Sections 12.23 to 12.27.

In the proposed ˡdefinitions, concepts are ˡdesignated by full ˡsystematic terms even if the style becomes somewhat heavy.

12.3 Essentially, the division of "property" depends on which of the operators equal to (=), unequal to (≠), less than (<), greater than (>), plus (+), minus (-), multiplied by (×), and divided by (:) can be applied meaningfully between two properties of the same kind-of-property and between their property values.

12.4 The mathematically most primitive situation applies to the classification of properties, on the basis of their respective property values, between disjoint classes. The question is, Are two properties and their property values equal or different? The property values may be names, symbols, or numerals functioning as symbols without any magnitude implied, and any order is conventional. The German standard *DIN 1313* [33] defines "nominal characteristic" ('Nominalmerkmal') as 'characteristic for which no operations or relations are defined for values'. This is unfortunately a negative definition, and it could be argued that = and ≠ do represent relations.

The proposed terms and definition are as follows.

<u>nominal property</u>
nameable property
property (S.5.5), defined by an **examination procedure** (S.7.3), that can be compared for equality with another property of the same **kind-of-property** (S.6.19), but has no magnitude

EXAMPLES
of **dedicated kinds-of-property** (S.20.6)
Blood--Plasma; colour(visual examination; (milky, red, yellow))
Blood--Erythrocyte; group(visual examination; (A, B, AB, 0))
Person--; gender(visual examination; (female, male) or (0, 1))
Thermometer--; taxon(visual examination; (air, ethanol, mercury, thermoelectric))

NOTE 1 - A nominal property cannot enter into algebraic equations and is not related to a ˡ**metrological dimension** (S.19.22) or a **metrological unit** (S.18.12).

(cont.)

(cont.)
NOTE 2 - For singular nominal properties (S.6.14.1) of a given kind-of-property, classified by **property value** (S.9.15), the numbers of members in any two classes may be compared by difference and ratio.

NOTE 3 - Singular nominal properties of a given kind-of-property, classified by property value, form a number distribution (= frequency distribution), which can be described by mode and allows contingency correlation and chi-square test.

NOTE 4 - The term 'attribute' has sometimes been used to designate "nominal property", but not here. The term 'qualitative property' has also been used, but is ambiguous because "ordinal property" (S.12.5) is often included in a concept under 'qualitative characteristic' [31-1.1.5].

NOTE 5 - **Ordinal properties** (S.12.5), **differential properties** (S.12.6), and **rational properties** (S.12.7) can also be compared for equality.

NOTE 6 - See also Section 12.9.

12.4.1 It may be debated whether the characteristic involving comparability should be between the properties - as in the proposed definition - or between their property values. In the latter case the definition should read

> 'property, defined by an examination procedure (S.7.3), whose property values can be compared for equality with those of another property ...'

With the mathematization of physics (S.4.3), either choice seems allowable and the simplest approach has been preferred and applied also to the following definitions.

12.4.2 The *VIM3* now includes the definition

> *nominal property*: property of a phenomenon, body, or substance, where the property has no magnitude [132-1.30]

which is a negative definition and uses "property" as a primitive.

12.5 As soon as properties have property values in the form of ordinal numbers or words or symbols expressing degree of magnitude, many metrologists would accede that they are quantities (S.12.13, 12.14). The new type of comparison which two properties (and their property values) can enter into -besides a decision on equality - is whether one is greater or smaller than the other. Consequently, such properties can be ordered according to magnitude, but differences cannot be compared meaningfully. The following term and definition are proposed.

<u>ordinal property</u>
ordenable property
property (S.5.5), defined by an **examination procedure** (S.7.3), having a magnitude and that can be stated only to be lesser than, equal to, or greater than another property of the same **kind-of-property** (S.6.19)

EXAMPLES
of **dedicated kinds-of-property** (S.20.6)
Patient--Abdominal pain; severity(subjective judgement; (absent, slight, moderate, severe) or (0, 1, 2, 3))
Urine--Albumin; concentration(dip stix; (0, 1, 2, 3, 4))
Water--; temperature(finger feeling; (cold, tepid, hot))

NOTE 1 - An ordinal property is not related to a ˡ**metrological dimension** (S.19.22) or a **metrological unit** (S.18.12) and cannot enter into algebraic equations, only into empirical equations.

NOTE 2 - ˡSingular ordinal properties (S.6.14.1) of a given kind, classified by **property value** (S.9.15), can be ranked according to magnitude, but differences between their values in the form of ordinal numbers cannot be ranked.

NOTE 3 - Singular ordinal properties of a given kind-of-property for comparable **systems** (S.3.3), classified by magnitude of property value, form a number distribution (= frequency distribution), which can be described by mode, median and other fractiles, and which allows rank-order correlation, sign and run tests.

NOTE 4 - The modifier 'qualitative' is sometimes used instead of 'ordinal', but not here due to overlap with 'nominal'.

NOTE 5 - In the ˡdefinition, the phrase 'having a magnitude and' may be omitted as being inferable from the subsequent description of mathematical relationships.

(cont.)

(cont.)
NOTE 6 - See also Sections 12.9 and 12.16.

NOTE 7 - **Differential properties** (S.12.6) and **rational properties** (S.12.7) can also be ranked.

12.6 Properties having property values in the form of cardinal numbers enter the metrical realm. The next further meaningful operation between properties (and their property values) is subtraction and the assessment of equality of differences. The proposed term and definition are as follows.

differential property
differenceable property
property (S.5.5) having a magnitude and that can be subtracted from, but cannot be divided by, another property of the same **kind-of-property** (S.6.19)

EXAMPLES
of **dedicated kinds-of-property** (S.20.6)
Blood--Base excess(H^+-binding site); amount-of-substance concentration difference(Patient - norm; (≤ -15, -14, ..., 0, ..., 14, ≥ 15) mmol/l)
Patient--Rectum; Celsius temperature((35.1, ..., 42.0) °C)

NOTE 1 - A differential property is related to a **property value scale** (S.10.14) with a conventional arbitrary zero.

NOTE 2 - A differential property is related to a ¦**metrological dimension** (S.19.22) and a **metrological unit** (S.18.12) (including the metrological unit "one"). A ¦singular differential property (S.6.14.1) can be divided by its metrological unit.

NOTE 3 - A differential property can enter into some algebraic equations with properties of other kinds-of-property.

NOTE 4 - Differences between comparable differential properties can be divided one by another (except for division by zero); the ensuing ratio is a **rational property** (S.12.7)
(cont.)

(cont.)
NOTE 5 - Singular differential properties of a given kind-of-property for comparable systems, classified by magnitude of **property value** (S.9.15), form a number distribution (= frequency distribution), which can be described by its average, standard deviation, and average deviation, and which allows product-moment correlation, correlation ratio, *t*-test and *F*-test.

NOTE 6 - Properties with exponential values can be transformed into logarithmic properties which behave as differential properties.

NOTE 7 - *Stevens* [114] and the *DIN 1313* [33] use the modifier 'interval' rather than 'differential'. (The preference here for the latter is explained in Section 17.7, Note 6.)

NOTE 8 - Rational properties can also be subtractive.

NOTE 9 - See also Sections 12.9 and 12.19.

12.7 The full set of meaningful basic algebraic operations for properties (and their property values) is applicable when not only subtraction and addition, but also division and multiplication are allowed between properties of the same kind-of-property. The following term and definition are proposed.

rational property
ratioable property
property (S.5.5) having a magnitude and that can be divided by another property of the same **kind-of-property** (S.6.19)

EXAMPLES
of **dedicated kinds-of-property** (S.20.6)
Patient--; mass((0, ..., 30,1, ..., 207,5, ...) kg)
Plasma--Sodium ion; amount-of-substance concentration((..., 90, 91, ..., 165, ...) mmol/l)
Interstellar space--; thermodynamic temperature((0, 0,1, ...) K)

NOTE 1 - A rational property has a **property value scale** (S.10.14) with a 'natural', 'absolute' zero.

NOTE 2 - Section 12.6, Note 2 applies analogously.
(cont.)

(cont.)
NOTE 3 - A rational property can enter into algebraic equations with rational properties of the same or other kinds-of-property for a given **system** (S.3.3), but addition and subtraction within a system are restricted to properties of the same **unconditionally extensive unitary kind-of-quantity** (S.13.5.1).

NOTE 4 - ˡSingular rational properties (S.6.14.1) of a given kind-of-property for comparable systems, classified by magnitude of **property value** (S.9.15), form a number distribution (= frequency distribution), which can be described by classical statistics including coefficient of variation.

NOTE 5 - See also Sections 12.9 and 12.20.

12.8 As mentioned in Section 12.2, *Stevens* is criticized by *Gonella* [52, 53] for focusing on scales rather than on quantities and for proposing that nominal properties are measured. Instead, *Gonella* recommends the approach of the Italian standard *UNI-4546:1984* [43], restricted to the narrower field of ˡmeasurement (S.15.14.1, 15.14.2). Without claiming an exhaustive or mutually exclusive set of classes, the following classes or types of 'grandezza' (it), translated as 'entity', are described.

NOTE - The term 'grandezza' is said to cover both "kind-of-quantity" (S.6.18) and "specific quantity" - just as the *VIM2* use of "quantity" - but 'parameter' is preferred for the instantiated quantity.

12.8.1

entity: quantity, property, condition used to describe phenomena and evaluable in terms of units of measurement [53-6.1]

This definition seems to cover "differential property" (S.12.6) and "rational property" (S.12.7); however, the meaning of ˡ"unit of measurement" (S.18.12) is said to be widened so that ordinal properties (S.12.5), depending on ˡmeasurement procedure (S.14.4.3, 14.4.4) or ˡmeasuring system are included. 'The definition of "unit of measurement" must contain all the elements necessary to identify unequivocally the kind-of-entity to which the measured entity belongs', so

unit of measurement: term of reference, adopted by convention, to compare an entity with other entities of the same kind [53-6.1.2].

Consequently, the equation 'quantity/value = unit' cannot be a requirement. This widening of the extension of "unit" will not allow a system of metrological units and would probably not attract a majority of metrologists.

12.8.2

rational entity: entity whose values are expressed by rational numbers that represent the ratio between the measured entity and a specific entity of the same kind ... as the unit of measurement [is assumed to be] and for which the ratio between two entities of the same kind is meaningful [53-6.1.3.1]

This concept is identical with "rational property" (S.12.7).

12.8.3 The concept "cyclic entity" includes "angle" and "phase" and has characteristics requiring 'representation in terms of modular algebra' [52-4].

12.8.4

digital entity: entity concerning the counting of objects or events individually identified and having values expressed by positive integers [53-6.1.3.2]

The unit is said to be the individual object or event, which means that an apple is a unit for number of apples. It would appear that this quantity is simply a rational property of a discrete phenomenon where the kind-of-property is "number".

12.8.5

instrumental entity: entity whose values are expressed as a one-to-one correspondence with points on a conventional interpolable scale and for which the ratio between two entities of the same kind is meaningless whereas greater or smaller is meaningful [53-6.1.3.3]

This definition seems to be identical with that of ordinal property (S.12.5) and this interpretation is reinforced by examples such as Rockwell hardness, toughness, and rugosity. Yet, when Celsius temperature and calendar time are included - customarily classified as differential properties - the concept becomes less clearly delineated.

12.8.6

selective entity: belonging to a predefined set or interval and having as unit of measurement the definition of the selected class [52-4]

Examples given are "grading of gravel and sand by sieves"; "Mohs hardness" - which both could be labelled ordinal properties - and "category of thermometer glass by the colour of a built-in strip" - which in the present terminology would require a nominal property (S.12.4), e.g. "taxon". It seems strange that a metrological unit is claimed to be involved, especially as nominal properties are included.

12.8.7 The "complex entity", consisting of a set of entities, including vector and position in a phase space [53-6.1.3.4], is beyond the scope of this text.

12.8.8 The set of 'entities' presented from the Italian standard seems less clear as regards terms and definitions than the set described above in Sections 12.4 to 12.7.

12.9 The division of the generic top concept <property> directly into four specific 'coordinate concepts as shown in Sections 12.4 to 12.7 is traditional. The definitions do not stress, however, the 'generic aspect of the successive increase in the allowed mathematical and statistical operations on sets of property values. The respective characteristics of comparability are cumulative 'downwards' on the basis of the following operators.

nominal property	$= \neq$
ordinal property	$= \neq < >$
differential property	$= \neq < > + -$
rational property	$= \neq < > + - \times :$

It could seem possible to fashion definitions accordingly in a generic stepwise hierarchy such that

nominal property: property allowing estimation of equality

ordinal property: nominal property allowing estimation of rank of magnitude

differential property: ordinal property allowing estimation of subtractive magnitude

rational property: differential property allowing estimation of divisible magnitude

but this concept system would not take into account the 'negative' characteristics of each generic concept. For example, the characteristic of "nominal property" of <u>having no magnitude</u> cannot be inherited by "ordinal property" which demands <u>having magnitude</u>.

12.10 Among the several other ways in which <property> is being generically divided, the most common one may be shown by a simplified field diagram of a generic ꜝconcept system.

property (S.5.5)			
nominal property (S.12.4)			
quantity (S.12.13, 12.14)			
ordinal property (S.12.5)	=	ordinal quantity	(S.12.16)
differential property (S.12.6)	=	differential unitary quantity	(S.12.19)
rational property (S.12.7)	=	rational unitary quantity	(S.12.20)

where the *VIM3* definition of "quantity" (already discussed in Section 4.10) is

> *quantity*: property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference [132-1.1]

Some metrologists would prefer to use 'quantity' as a ꜝsynonym for 'rational property' (S.12.7), but admit also "differential property" (S.12.6) under "quantity". However, the *VIM3* definition invokes the characteristic having magnitude, so it does not exclude "ordinal property" (S.12.5). The French version of *VIM3* calls the latter concept 'grandeur ordinale'. The German standard *DIN 1313* [33] uses 'characteristic' ('Merkmal') as the term for the top concept, equivalent to 'property; only "ratio scaled properties" are termed 'Grösse' or 'skalare Grösse'.

12.11 The German standard *DIN 55 350-12* [31] has another interpretation of the modifier 'quantitative' applied to Merkmal (de) (= property or kind-of-property). It may be translated into the generic concept system

- property
  - qualitative property
    - nominal property
    - ordinal property
  - quantitative property.
    - differential property
    - rational property

12.12 Further ambiguity is added by various texts when the term 'semiquantitative property' is used in either of the senses

- ordinal property,
- property with only a few possible values,
- property having values with a large relative ꜝuncertainty of measurement (S.16.24).

Neither of the modifiers 'qualitative', 'semiquantitative', or 'quantitative' should be used without concomitant definition of the related concept. Here, they are avoided.

<QUANTITY>

12.13 In view of a long tradition, it will be next to impossible to abandon the concept "quantity" and only use the specific concepts in Sections 12.5 to 12.7 with terms derived from 'property'. Furthermore, many engineers would not accept that ordinal properties be excluded from being quantities. It is therefore practical to explore an alternative partial concept system and terminology based on "quantity", which it is proposed to define as follows.

> <u>quantity</u>
> **property** (S.5.5) having a magnitude
>
> EXAMPLES
> All examples given under the definitions in Sections 12.5 to 12.7 are **dedicated kinds-of-quantity** (S.20.7).
>
> NOTE 1 - All quantities have **quantity values** (S.16.7, 16.8) that can at least be stated to be lesser than, equal to, or greater than another quantity value of the same **kind-of-quantity** (S.13.3.1).
>
> NOTE 2 - The concept "quantity" comprises **ordinal quantity** (S.12.16), **differential quantity** (S.12.19), and **rational quantity** (S.12.20).
>
> NOTE 3 - The magnitude is expressed by a number and a reference that can be a **metrological unit** (S.18.12), **measurement procedure** (S.14.4.3, 14.4.4), and/or **reference material** (S.5.1).

12.14 This definition, together with Note 3, is not in conflict with that of the *VIM3* (see Section 12.10) as is obvious when 'property' is substituted by its definition in Section 5.5. Still, there might be metrologists who do not want to be involved with nominal properties (S.12.4) at all. In that case an expanded definition could be

<u>quantity</u>
inherent state- or process-descriptive feature of a **system** (S.3.3), including any pertinent **components** (S.3.4), that has a magnitude

NOTE - The Examples and Notes of Section 12.13 apply.

12.15 The recent decision clearly to include "ordinal quantity" under "quantity" is shown, e.g., by the example "Rockwell C hardness" given in the *VIM3* [132-1.1], and the inclusion of the concept "ordinal quantity" [132-1.26, S.12.16].

12.16 Assuming that "ordinal property" is a specific concept under "quantity" (S.12.13), a new term and redefinition with the new genus proximum is necessary as follows.

<u>ordinal quantity</u>
ordenable quantity
quantity (S.12.13, 12.14), defined by a **measurement procedure** (S.14.4.4), that can be stated only to be lesser than, equal to, or greater than another quantity of the same **kind-of-quantity** (S.13.3.1)

NOTE - The Examples and Notes of Section 12.5 apply analogously.

A shorter, less explicit definition could be 'quantity that is rankable by magnitude, but not substractive or divisible'.

12.16.1 The proposed definition, combined with Examples and Notes of Section 12.5, is not in conflict with that of the new *VIM3* introducing

> *ordinal quantity*: quantity, defined by a conventional measurement procedure, for which a total ordering relation can be established, according to magnitude, with other quantities of the same kind, but for which no algebraic operations among those quantities exist [132-1.26]

12.17 It is possible, also, to derive a concept from "quantity" which is coordinate and complementary to "ordinal quantity", for example

<u>unitary quantity</u>
quantity (S.12.13, 12.14) with a magnitude expressed as a reference quantity multiplied by a number

EXAMPLES
All examples given in Sections 12.6 and 12.7 are **dedicated unitary kinds-of-quantity** (S.20.7).

NOTE 1 - All unitary quantities have **quantity values** (S.16.7, 16.8) each of which can at least be subtracted from another quantity value of the same **kind-of-quantity** (S.13.3.1).

NOTE 2 - The ¦concept "unitary quantity" comprises **differential unitary quantity** (S.12.19) and **rational unitary quantity** (S.12.20).

NOTE 3 - A unitary quantity can enter into algebraic and arithmetic equations with other unitary quantities.

NOTE 4 - A unitary quantity is related to a ¦**metrological dimension** (S.19.22) if the kind-of-quantity is an element in a **system of unitary kinds-of-quantity** (S.13.7).

NOTE 5 - The "reference quantity" invoked in the ¦definition is a **metrological unit** (S.18.12), including "one", involved in a **unitary quantity value** (S.16.10).

NOTE 6 - A ¦synonym of 'unitary quantity' is 'metrical quantity', and ¦equivalents are 'quantitative Merkmal' (de), 'grandeur mesurable' (fr), but ¦definitions should be checked as the ¦concepts may have different ¦extensions.

12.18 McGlashan [101] offered the definition

> *physical quantity*: complete specification of the operations used to measure the ratio (a pure number) of two instances of the physical quantity

where the denominator is an instance of "metrological unit" that will be stipulated in the measurement procedure. Formally, this definition verges on being circular, defining the concept by (instances of) itself. Furthermore, the phrase seems to describe "rational unitary measurement procedure" (S.14.6.2) rather than "quantity" or "kind-of-quantity". *McGlashan*'s view is different from the mentioned occasional need to reference the examination procedure in a specification of a property (see Section 5.5, Note 3). The similarity with the concept "examination procedure" is seen by substituting in its proposed definition (S.7.3) the term 'examination' by its related definition (S.8.4) giving

> *examination procedure*: detailed instructions for performing a structured activity giving an examination result

12.19 Using "unitary quantity" as a genus proximum it is possible to re-define "differential property" as follows.

> <u>**differential unitary quantity**</u>
> differenceable unitary quantity
> differential quantity
> difference quantity
> **unitary quantity** (S.12.17) that can be subtracted from but cannot be divided by another quantity of the same **unitary kind-of-quantity** (S.13.3.3)
>
> NOTE - The Examples and Notes of Section 12.6 apply analogously.

This concept is not often explicitly discussed in metrological texts on quantities, although division of <property value scale> implies the necessity (see Sections 17.4 and 17.7). Yet, *Fleischmann* mentioned 'Differenzgrösse' (Grösse, de, meaning singular quantity or kind-of-quantity) and gave as examples "Überdruck" (excess pressure) and temperature with a zero point different from that of the thermodynamic temperature scale [47]. Likewise, *DIN 1313* mentions "interval scaled characteristic" ('Intervallskaliertes Merkmal') [33-11.3].

12.20 As a coordinate complementary concept, the last specific concept "rational property" can be redefined.

> <u>**rational unitary quantity**</u>
> ratioable unitary quantity
> rational quantity
> ratio quantity
> **unitary quantity** (S.12.17) that can be divided by another quantity of the same **unitary kind-of-quantity** (S.13.3.3)
>
> NOTE - The Examples and Notes of Section 12.7 apply analogously.

12.21 With the redefined series of concepts, one may build another generic ¦hierarchy on <property>.

- property (S.5.5)
  - nominal property (S.12.4)
  - quantity (S.12.13)
    - ordinal quantity (S.12.16)
    - unitary quantity (S.12.17)
      - differential unitary quantity (S.12.19)
      - rational unitary quantity (S.12.20)

The two types of generic hierarchy discussed are presented in the ¦concept diagram of Figure 12.21).

The two-level ¦concept system with four coordinate specific concepts is simple and operative. The four-level consecutively dichotomic system resembles current terminology of ¦metrology.

12.22 Some terminologists would stress succinctness more than information and it is possible to fashion much shorter definitions of the specific concepts under <property>. Thus,

12.22.1

nominal property: property (S.5.5) without magnitude

This seemingly negative definition becomes acceptable by substitution of 'property' by its definition, and the characteristic given is ¦essential and ¦delimiting.

12.22.2

ordinal property; ordinal quantity: property (S.5.5) with only rankable magnitude

12.22.3

differential property; differential quantity: property (S.5.5) with subtractive but not divisible magnitude

12.22.4

rational property; rational quantity: property (S.5.5) with divisible magnitude

12.22.5

quantity: property (S.5.5) with a magnitude

which is equivalent to the definition in Section 12.13.

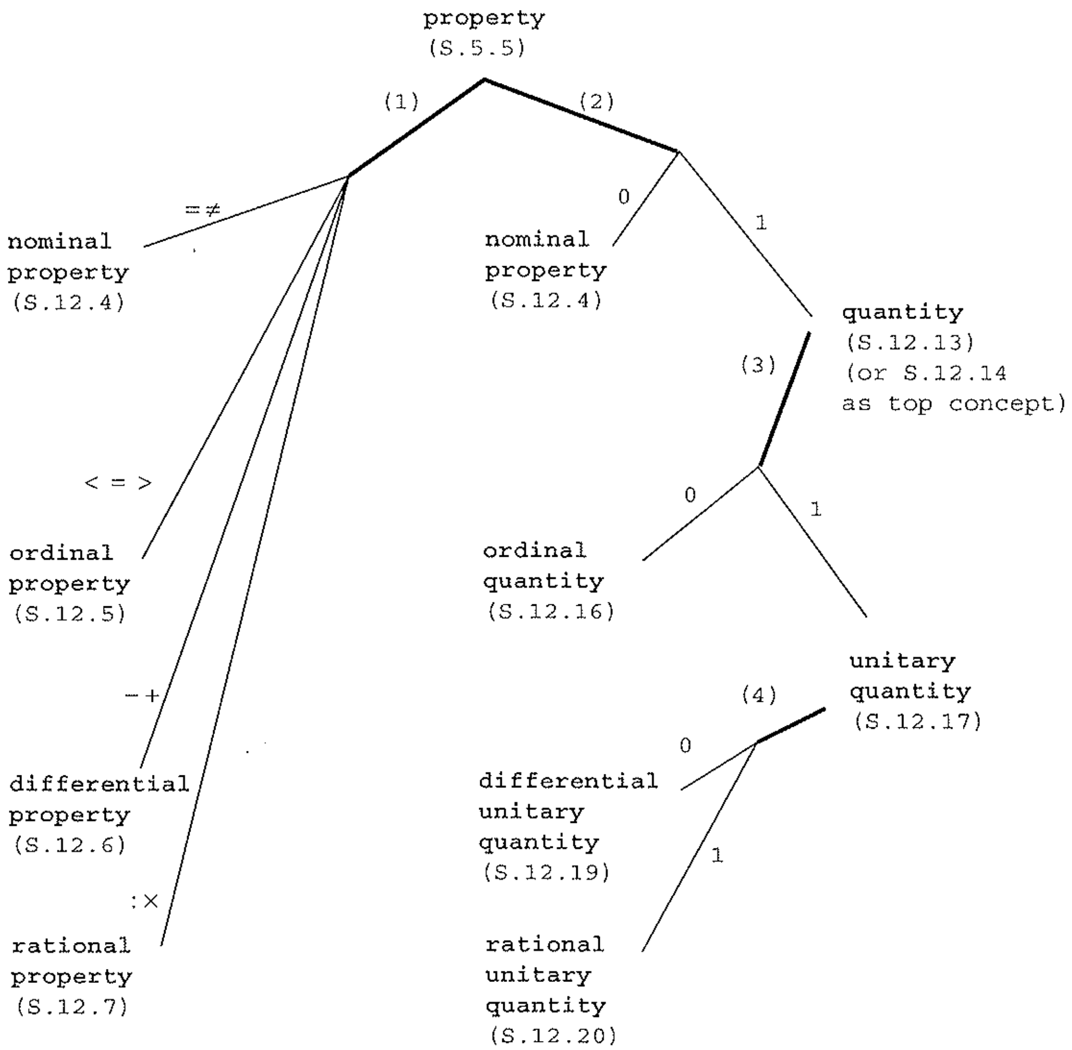


Figure 12.21 Pluridimensional 'generic 'concept diagram on <property> (S.5.5) according to two and four levels.

Terminological dimension (S.2.19)

(1) having the allowed algebraic comparisons between properties;

(2) having a magnitude; (3) having a 'metrological unit (S.18.12);

(4) allowing a ratio between quantities of the same unitary kind-of-quantity (S.13.3.3);

0 = no; 1 = yes

'Concepts paired in the same horizontal line have identical 'extensions.

12.22.6

unitary quantity: quantity (S.12.22.5) with a magnitude expressed as a reference quantity multiplied by a number

which is identical to the definition in Section 12.17.

12.22.7

differential unitary quantity: unitary quantity (S.12.22.6) with subtractive magnitude

12.22.8

rational unitary quantity: unitary quantity (S.12.22.6) with divisible magnitude

12.22.9 Such ultrashort definitions need a thorough understanding of the system of allowed mathematical operators (see Section 12.9), which can be applied algebraically or arithmetically between kinds-of-property or ᑊnumerical values of properties respectively, and when to compare within a kind-of-property and within a system bearing two properties.

12.23 Regarding the ᑊcomplex terms for the four ᑊsubordinate concepts of <property> defined in Sections 12.4 to 12.7, 12.16, and 12.22.1 to 12.22.4, the choice between adjectives and adjectival nouns as modifiers is difficult because of existing, sometimes ambiguous usage. It would be useful to have one set of modifying words for systematic terms of isologously placed, associatively related specific concepts under <property> (this chapter), <kind-of-property> (Ch. 13), <examination procedure> (Ch. 14), <examination> (Ch. 15), <property value> (Ch. 16), and <property value scale> (Ch. 17), but that is not linguistically quite simple in English.

12.24 The set of nouns 'nomination', 'ordination', 'difference', and 'ratio' used as adjectival nouns could be used with 'property value', 'property value scale', and the first two as simple terms instead of 'examination'. The set goes less well with 'examination procedure', 'property', and 'kind-of-property', which can neither designate a process nor an outcome.

12.25 The set of adjectives 'nominal', 'ordinal', 'differential' (in the *COD* [1] meaning 'of, exhibiting, or depending of a difference' rather than a requirement of infinitessimal difference), and 'rational' (ignoring philosophical connotations) comprises common language words, and the first two have been extensively used with 'scale'. Other meanings of 'nominal value', such as 'very little value' or 'supposed operating value', would have to be ignored.

12.26 Another set of adjectival forms is 'nameable', 'ordenable' (not in the *COD*), 'differenceable', and 'ratioable', where the last two ᑊneoterms have been considered for the revision of the *VIM* regarding divisions of <property>. This set is excellent and evocative for that purpose as well as with 'kind-of-property', 'property value', and 'property value scale', but will not serve with 'examination procedure' and 'examination'.

12.27 Thus, it is proposed that the set of modifiers in Section 12.25 be used for preferred derivative systematic terms. It is the simplest and linguistically least problematic as a single set for terms of specific concepts under <property>, <kind-of-property>, <examination procedure>, <examination>, <property value>, and <property value scale>.

13 GENERIC CONCEPT SYSTEM on <KIND-OF-PROPERTY> including <kind-of-quantity>

<KIND-OF-PROPERTY>

13.1 Chapter 6 discussed the ¦concept "kind-of-property" and arrived at the ¦definition

> *kind-of-property* (S.6.19): common defining aspect of mutually comparable properties

even if the ¦corpus behind this definition inevitably is mostly concerned with "kind-of-quantity", often under ¦synonyms (see Table 6.5). The proposed definitions in Chapter 12 of the ¦specific concepts under <property> (S.5.5), including those of "quantity" (S.12.13, 12.14), allow a look at a possible ¦concept system on <kind-of-property>.

13.2 One partial concept system could correspond to the ¦generic division of <property> into four specific ¦coordinate concepts as in the left-hand half of Figure 12.20. This could mean four specific coordinate concepts with ¦terms and definitions as follows.

13.2.1

> <u>nominal kind-of-property</u>
> **kind-of-property** (S.6.19) for **properties** (S.5.5) without magnitude, but with comparability for equality
>
> EXAMPLES - "taxon"; "blood group"; "colour"
>
> NOTE - A nominal kind-of-property is sometimes called an 'attribute', but not here.

13.2.2

ordinal kind-of-property **kind-of-property** (S.6.19) for **properties** (S.5.5), defined by an examination procedure (S.7.3), that are rankable by magnitude, but are neither subtractive nor divisible EXAMPLES - "hardness"; "severity"

13.2.3

differential kind-of-property **kind-of-property** (S.6.19) for **properties** (S.5.5) that are subtractive, but not divisible EXAMPLES - "base_excess"; "Celsius_temperature"

13.2.4

rational kind-of-property **kind-of-property** (S.6.19) for **properties** (S.5.5) that are divisible EXAMPLES - "mass"; "length"; "volume"; "thermodynamic_temperature"; "mass_fraction"

13.2.5 In each definition - to avoid an impression of circularity - the short description of salient characteristics of the singular properties (S.6.14.1) is stated instead of simply giving the term for the specific concept (such as 'nominal property' in Section 13.2.1).

<KIND-OF-QUANTITY>

13.3 Another generic concept system may be structured as the right-hand half of Figure 12.21, giving firstly "nominal kind-of-property" as defined in Section 13.2.1. Subsequently,

13.3.1

<u>kind-of-quantity</u>
kind-of-property (S.6.19) for **properties** (S.5.5) having a magnitude

EXAMPLES - The Examples of Sections 13.2.2 to 13.2.4 apply.

NOTE - Notes 1 to 4 of Section 6.19 apply homologously.

13.3.2

<u>ordinal kind-of-quantity</u>
kind-of-quantity (S.13.3.1) for **quantities** (S.12.13, 12.14) that are rankable by magnitude, but are neither subtractive nor divisible

EXAMPLES - The Examples of Section 13.2.2 apply.

13.3.3

<u>unitary kind-of-quantity</u>
kind-of-quantity (S.13.3.1) for **quantities** (S.12.13, 12.14) with magnitudes expressed as a reference quantity multiplied by a number

EXAMPLES - The Examples of Sections 13.2.3 and 13.2.4 apply.

NOTE - The reference quantity is a **metrological unit** (S.18.12).

13.3.4

<u>differential unitary kind-of-quantity</u>
differential kind-of-quantity
unitary kind-of-quantity (S.13.3.3) for **quantities** (S.12.13, 12.14) that are subtractive, but not divisible

EXAMPLES - The Examples of Section 13.2.3 apply.

13.3.5

> <u>rational unitary kind-of-quantity</u>
> rational kind-of-quntity
> **unitary kind-of-quantity** (S.13.3.3) for **quantities** (S.12.13, 12.14) that are divisible
>
> EXAMPLES - The Examples of Section 13.2.4 apply.

13.4 It may be argued that there is usually no need to be able to distinguish between several such specific concepts under <kind-of-property>, because the characteristics appear in the definitions of the subordinate concepts to <property>. Then the definition in Section 13.1 (= S.6.19) suffices. Sometimes, however, a specific concept may be useful, e.g. see Section 13.7.

13.4.1 If "nominal property" is excluded from the field of discussion, it will be necessary with an alternative definition to Section 13.3.1 as follows

> <u>kind-of-quantity</u>
> common defining aspect of mutually comparable **quantities** (S.12.14)
>
> NOTE - The three last lines of Examples in Section 6.19 and its Notes 1 to 4 apply homologously.

NOTE - This definition [131-13.4.1] virtually has been adapted by *VIM3* as

kind of quantity: aspect common to mutually comparable quantities {[132-1.2]

13.4.2 If this latter definition is preferred, the referenced Section number S.13.3.1 after 'kind-of-quantity' in the definitions of "ordinal kind-of-quantity" (S.13.3.2) and "unitary kind-of-quantity" (S.13.3.3) must be changed to S.13.4.1.

13.4.3 The chacteristic of "quantity" (S.12.13, 12.14) <u>having a magnitude</u> is not explicit in Section 13.4.1 but appears with substitution. An explicit formulation could be

kind-of-quantity: common defining aspect of **quantities** (S.12.14) allowing comparability by magnitude

13.5 In a separate terminological dimension (S.2.19), <kind-of-quantity> may be divided according to *physical* (and arithmetic) additivity between its instantiated properties and property values (S.9.15). The terms 'extensive quantity' and 'intensive quantity' are sometimes used somewhat loosely without distinguishing between theory and reality [82]. *Bunge* [15] gives good examples of the difference between being *arithmetically additive* as a proof of having an extensive kind-of-quantity and a *physical sum* that can be measured and compared with the individual measured values of the systems (S.3.3) or parts of a system being joined. For example, geometrical volumes are additive, so that "geometric volume" is an extensive kind-of-quantity. In contrast, a volume of ethanol dissolved in a volume of water results in a volume smaller than the arithmetic sum. Furthermore, experimental proof that a kind-of-quantity has additive instances can be difficult to obtain due to the uncertainty of measurement. *Bunge* divides kind-of-quantity (which he terms 'magnitude') into four types that may be defined as follows.

13.5.1

> <u>unconditionally extensive unitary kind-of-quantity</u>
> **unitary kind-of-quantity** (S.13.3.3) for whose **quantities** (S.12.14) a physical addition operation exists such that a **quantity value** (S.16.7) for the total of a **system** (S.3.3) equals the arithmetic sum of the quantity values for its parts
>
> NOTE - An unconditionally extensive unitary kind-of-quantity is distributive.
>
> EXAMPLES
> "distance"; "area"; "duration"; "electric charge"

13.5.2

> <u>quasiextensive unitary kind-of-quantity</u>
> **unitary kind-of-quantity** (S.13.3.3) for whose **quantities** (S.12.14) a physical addition operation exists such that a **quantity value** (S.16.7) for the total of a system (S.3.3) is approximately equal to the arithmetic sum of the quantity values for its parts
>
> EXAMPLES
> "mass" (by nuclear reactions, not in atom bombs); "energy"

13.5.3

> <u>conditionally extensive unitary kind-of-quantity</u>
> **unitary kind-of-quantity** (S.13.3.3) for whose **quantities** (S.12.14) a physical addition operation exists such that a **quantity value** (S.16.7) for the total of a **system** (S.3.3) may be different from the arithmetic sum of the quantity values for its parts due to the respective internal and environmental conditions
>
> EXAMPLES
> "length"; "volume"; "amount of substance"

13.5.4

> <u>intensive kind-of-quantity</u>
> <u>kind-of-quantity</u> (S.13.3.1 or 13.4.1) for whose **quantities** (S.12.14) a physical addition operation does not exist and where a **quantity value** (S.16.7) is invariant with the extent of a **system** (S.3.3) of constant composition
>
> EXAMPLES
> "thermodynamic temperature"; "pressure"; "mass density"; "amount-of-substance concentration"; "frequency"; "refractive index"
>
> NOTE - The definition covers both intensive **ordinal kind-of-quantity** (S.13.3.2) and intensive **unitary kind-of-quantity** (S.13.3.3)

13.6 In the description of the universe, it has proven advantageous to select by convention a reasonably small number of kinds-of-quantity as being functionally independent of each other and to define other kinds-of-quantity from such base kinds-of-quantity according to algebraic rules. The set of base and derived kinds-of-quantity is said to form a system.

13.6.1 The *VIM3* has the entry

> *system of quantities*: set of quantities together with a set of non-contradictory equations relating those quantities [132-1.3]

keeping the traditional use of 'quantity' including "kind-of-quantity".

13.6.2 The German standard *DIN 1313* defines "quantity system" ('Grössen-system') as follows.

quantity system: set of values comprising the quantity values of suitably selected kinds of quantities and the real numbers such that operations of calculation are defined in the set for which the usual laws of calculation holds [33-6.2]

This strange definition claims that a quantity system is a set of quantity values and that seems unacceptable.

13.7 For the present purposes a definition will be fashioned on the *VIM3* model, but with kind-of-quantity, without selection of prototype, and with no reference to quantity values. However, "ordinal kind-of-quantity" will have to be left out.

<u>system of unitary kinds-of-quantity</u>
set of **unitary kinds-of-quantity** (S.13.3.3) and any defining algebraic equations between them

EXAMPLES

"length", "mass", "time", and all unitary kinds-of-quantity derived from them are used with the CGS system of units;

"length", "mass", "time", "electric current", "thermodynamic temperature", "amount of substance", "luminous intensity", and all unitary kinds-of-quantity derived from them are used with the International System of Units, SI (S.18.33.2) and maintained by the *ISO Technical Committee 12* [64].

NOTE - A system of unitary kinds-of-quantity is constructed on the basis of conventionally chosen physical laws giving a coherent set of algebraic unitary kind-of-quantity equations.

The *VIM3* definition (S.13.6.1), sensu stricto, does not exclude that functionally independent kinds-of-quantity have defined (mathematical) relationships between them.

13.8 For the functionally independent kinds-of-quantity of a system, the *VIM3* defines

base quantity: quantity in a conventionally chosen subset of a given system of quantities, where no subset quantity can be expressed in terms of the others {132-1.4]

Here, the emphasis on kind-of-quantity will be preferred.

13.9 The following term and definition are proposed.

<u>base unitary kind-of-quantity</u>
unitary kind-of-quantity (S.13.3.3), in a subset of a **system of unitary kinds-of-quantity** (S.13.7), that is chosen to be algebraically independent of other unitary kinds-of-quantity in the subset

EXAMPLES
The unitary kinds-of-quantity "length", "mass", "time" in the field of mechanics are all base unitary kinds-of-quantity used with the MKS system.
The base unitary kinds-of-quantity "length", "mass", "time", "electric current", "thermodynamic temperature", "amount of substance", "luminous intensity", and their **derived unitary kinds-of-quantity** (S.13.11) are now termed the 'International System of Quantities, ISQ'.

NOTE - A base unitary kind-of-quantity has no defining unitary kinds-of-quantity (S.13.3.3), but is used in defining **derived unitary kinds-of-quantity** (S.13.11).

NOTE - The number of base unitary kinds-of-quantity in a system of unitary kinds-of-quantity is chosen according to the practical needs of a certain field of science and technology. In this connection *Guggenheim* opines that '... the number of fundamental quantities [here: base unitary kinds-of-quantity] having independent dimensions is, to some extent, a matter of choice. But, if in the same problem or set of problems two authors make a different choice, the one choosing the greater number is likely to be the more competent physicist.' [56].

13.10 Each non-base unitary kind-of-quantity in a system of unitary kinds-of-quantity is defined by the *VIM3* as

derived quantity: quantity, in a system of quantities, defined in terms of the base quantities of that system [132-1.5]

13.11 The proposed term and definition is

<u>derived unitary kind-of-quantity</u>
unitary kind-of-quantity (S.13.3.3) defined in a **system of unitary kinds-of-quantity** (S.13.7) by an algebraic equation between **base unitary kinds-of-quantity** (S.13.9)

(cont.)

(cont.)

EXAMPLE 1

From the second set of examples of Section 13.9, the derived unitary kind-of-quantity "amount-of-substance content rate" is defined as equal to "amount of substance (of component) changed" divided by "mass (of system)" and "time elapsed".

NOTE - To demonstrate physical relationships, the right-hand side of the defining equation may be expressed by including derived unitary kinds-of-quantity rather than base ones exclusively.

EXAMPLE 2

"Mass concentration rate" is defined as equal to "mass (of component)" divided by "volume (of system)" and "time".

13.12 The algebraic equation mentioned in the definition of Section 13.11 can be symbolized as a function

$$Q = f(Q_1, Q_2, \ldots, Q_n)$$

where Q is a derived unitary kind-of-quantity being defined, and Q_1, Q_2, etc. are other derived or base unitary kinds-of-quantity. Depending on the form of the function, specific concepts under <unitary kind-of-quantity> may be defined. In other words, <unitary kind-of-quantity> may be divided generically in a terminological dimension (S.2.19) according to the type of characteristic (S.2.14.2) having a defining function of .... The concepts for rational unitary kinds-of-quantity are outlined in the *DIN 1313* [33-10], but defined in a different way here.

NOTE - All the following kinds-of-quantity are derived, but it seems unnecessary to include that modifier in their systematic terms as the initial word indicates as much.

13.12.1

proportionate rational unitary kind-of-quantity

$Q = k \cdot Q_1$

rational unitary kind-of-quantity (S.13.3.5) that is equal to another rational unitary kind-of-quantity multiplied by a constant

NOTE - Q and Q_1 have instances as a pair pertaining to the same **system** (S.3.3).

(cont.)

(cont.)
EXAMPLES
"amount of substance" and "number of entities" of a defined compound with a specified elementary entity in a material; the constant is the reciprocal of the "molar number constant" (= reciprocal Avagadro constant);
"distance" travelled by a body at constant "speed" and the "duration" of the travel

13.12.2

product rational unitary kind-of-quantity

$Q = k \cdot Q_1 \cdot Q_2$

rational unitary kind-of-quantity (S.13.3.5) that is equal to a rational unitary kind-of-quantity multiplied by one or more other rational unitary kinds-of-quantity and a constant

NOTE - Q, Q_1, and Q_2 have instances as a triple pertaining to the same **system** (S.3.3).

EXAMPLE - "area" of a rectangle from "length" of each of two sides perpendicular to each other

13.12.3

quotient rational unitary kind-of-quantity

$Q = k \cdot Q_1/Q_2$

rational unitary kind-of-quantity (S.13.3.5) that is equal to a unitary kind-of-quantity divided by a different rational unitary kind-of-quantity and multiplied by a constant

NOTE 1 - Q, Q_1, and Q_2 have instances as a triple pertaining to the same **system** (S.3.3).

NOTE 2 - A quotient rational unitary kind-of-quantity is directly proportionate to the numerator rational unitary kind-of-quantity and inversely proportionate to the denominator one.

NOTE 3 - The constant is often equal to one.

EXAMPLE - "volumic mass" = "mass density" from "mass" of a system divided by its "volume"

13.12.4

<u>fractional change rational unitary kind-of-quantity</u>
$Q = (Q_{1b} - Q_{1a})/Q_{1a}$
rational unitary kind-of-quantity (S.13.3.3) that is equal to an incremental rational unitary kind-of-quantity divided by the original one

NOTE 1 - Q, Q_{1b}, and Q_{1a} have instances as a triple pertaining to the same **system** (S.3.3).

NOTE 2 - This rational unitary kind-of-quantity has the **coherent derived metrological unit** (S.18.19) "one" and the **derived metrological dimension one** (S.19.27).

EXAMPLE - "fractional length increment" from "change in length" divided by original "length"

NOTE 3 - The modifier 'relative' is often used instead of 'fractional change', but is here used for "relative rational unitary kind-of-quantity" (S.13.12.5).

13.12.5

<u>relative rational unitary kind-of-quantity</u>
$Q = Q_1/Q_{1,\mathrm{ref}}$
rational unitary kind-of-quantity (S.13.3.3) that is equal to a given rational unitary kind-of-quantity of the same **system** (S.3.3) divided by the same rational unitary kind-quantity of a reference system

NOTE 1 - Section 13.12.4, Note 2 applies.

EXAMPLE - "relative volumic mass" from "volumic mass" of a system divided by "volumic mass" of a reference system

NOTE 2 - This restrictive use of the modifier 'relative' was formulated in the *R-66* [39-4.17].

13.12.6 The set of concepts defined in Sections 13.12.1 to 13.12.5 is small. Many other useful divisions of "kind-of-quantity" can be identified, such as "compositional kind-of-quantity", "material kind-of-quantity", and a host of further specific concepts with terms from a systematic ¹terminology, where each type of mathematical definition of a unitary kind-of-quantity from other unitary kinds-of-quantity is captured by a specific modifier at the beginning or end of the term for the unitary kind-of-quantity in question [86-5.14].

EXAMPLES of modifiers are 'ratio', 'efficiency', 'decremence', 'entitic', 'lineic', 'volumic', 'concentration', 'content', 'molar', and 'rate' [86].

13.13 The concepts with proposed term and definitions given in this Chapter are related as shown in the multidimensional, mainly generic concept system of Figure 13.13. This does not show the two-level system of "kind-of-property" divided directly into the four specific concepts defined in Sections 13.2.1 to 4.

13.14 Division of <unitary kind-of-quantity> may be considered according to a further terminological dimension of whether or not a system of unitary kinds-of-quantity (S.13.7) is involved. Thus, we have

---

in-system unitary kind-of-quantity

unitary kind-of-quantity (S.13.3.3) that is a member of a **system of unitary kinds-of-quantity** (S.13.7)

EXAMPLES - "amount-of-substance", "amount-of-substance concentration", and "number fraction" in the system of unitary kinds-of-quantity, termed 'International System of Quantities', corresponding to the ¹International System of Units (SI) (S.18.33.2).

NOTE 1 - This ¹concept is usually not used explicitly, but is implied in defining the ¹specific concepts "base unitary kind-of-quantity" (S.13.9) and "derived unitary kind-of-quantity (S.13.11) by the phrase 'in a (subset of a) system of unitary kinds-of-quantity'.

NOTE 2 - An in-system unitary kind-of-quantity may utilize an **off-system metrological unit** (S.18.34.1). Thus, a length may be expressed in inches.

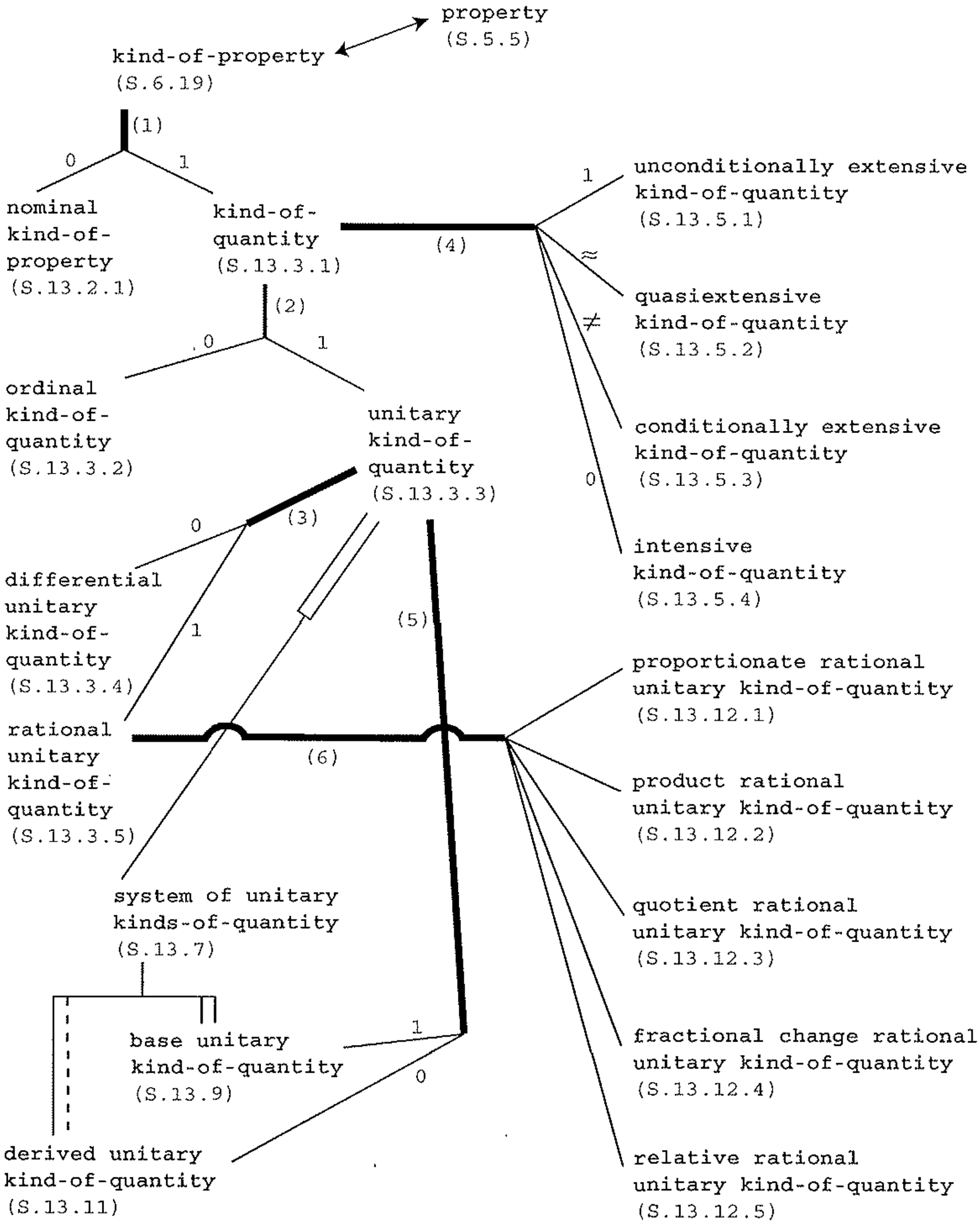


Figure 13.13 Diagram of a pluridimensional mixed ˡhierarchical ˡconcept system of the proposed ˡconcepts defined in Chapter 13 on <kind-of-property> (S.6.19).

Terminological dimension (S.2.19) having properties related to a(n) ...;

(1) magnitude; (2) ˡmetrological unit (S.18.12);

(3) ratio between quantities of the same kind-of-quantity (S.13.3.1);

(4) addition; (5) functional independence; (6) form of function;

0 = no; 1 = yes

13.15 The other specific coordinate concept is

> off-system unitary kind-of-quantity
> **unitary kind-of-quantity** (S.13.3.3) that is independent of a given **system of unitary kinds-of-quantity** (S.13.7)
>
> EXAMPLE 1 - "amount of substance" is an off-system unitary kind-of-quantity in the system of unitary kinds-of-quantity corresponding to the centimetre-gram-second system of units (CGS).
>
> EXAMPLE 2 - "antitoxicity" is independent of the International System of Quantities (ISQ) (S.13.9). A corresponding **off-system metrological unit** (S.18.34.1) is defined by a **unitary measurement procedure** (S.14.5.2).

13.16 The concepts defined in Sections 13.5 and 13.12 have characteristics which are inherited by their specific singular quantities (S.6.14.2). These may therefore be characterized by the same modifiers as their respective parent kinds-of-quantity (S.6.19). (Such subordinate concepts are not defined in Chapter 12.)

13.17 The top concept "kind-of-property" may be divided according to a further terminological dimension, namely that of scientific or technical field of use. Examples are sociology, economics, psychiatry, and biology - in which fields the kinds-of-property defined in Sections 13.2 and 13.3 occur. In physics, ten areas are presented in the *ISO Standards Handbook on quantities and units* [64], e.g. space-time, mechanics, and physical chemistry and molecular physics. Many of the listed kinds-of-quantity are used in other fields than physics.

13.18 Some of the terms given in this Chapter are formed in accordance with a systematic terminology showing generic relations. If they are found too long for a given purpose, abbreviation is possible. Thus, the terms 'kind-of-property' and 'kind-of-quantity' may be used without invoking derived terms for their respective specific concepts (cf. S.13.4). A candidate for omission is 'unitary' when the mathematical characteristics of the quantity values (S.16.7, 16.8) under discussion are well known, but then the concepts strictly speaking unintentionally include ordinal kinds-of-quantity (S. 13.3.2). The possibility of omitting 'kind-of-' in all terms is mentioned in Section 6.19.3.

14 GENERIC CONCEPT SYSTEM on <EXAMINATION PROCEDURE>, <measurement procedure>, <examination method>, and <examination principle>

<EXAMINATION PROCEDURE>

14.1 Upon reviewing the current *VIM3* ꜝconcept of "measurement procedure" (S.7.2.3) with the ꜝassociated concepts "measurement principle" (S.7.2.1) and "measurement method" (S.7.2.2), Chapter 7 arrived at a ꜝdefinition of the ꜝgeneric concept

> *examination procedure* (S.7.3): detailed instructions for performing an examination (S.8.4)

With the division of <property> in hand (Ch. 12, espec. Fig. 12.21), the necessary background for a divison of <examination procedure> seems present.

Obviously, it could be debated whether it would be more logical to start with a division of "examination" or even of "property value" (S.9.15) before discussing "examination procedure". An examination procedure requires something to describe, namely an examination, which needs a target, that is a property having a property value. Conversely, a property value cannot be detected unless by an examination, which depends on a previously existing examination procedure. The two-way situation is a reflection of the associative relations between the concepts (see Figure 11.1). The present choice of continuing with <examination procedure> is made because the definition of a property is in itself to a degree dependent upon an examination procedure (S.5.5, Note 3), and the expression of the property value inherent in a property also depends on the examination procedure.

14.2 Before continuing, it should be asked whether "examination procedure" needs to be divided. This appears to be the case because ꜝmetrology seems to require one or more ꜝspecific concepts for its restricted field.

14.3 It is entirely feasible to define a set of four ꜝcoordinate specific concepts on <examination procedure>, respectively associated to the four coordinate specific concepts on <property> shown in the left-hand side of Figure 12.21. The four concepts are defined as follows.

14.3.1

<u>nominal examination procedure</u>
nomination procedure
examination procedure (S.7.3) estimating equality

EXAMPLE - Detailed description of blood grouping

14.3.2

<u>ordinal examination procedure</u>
ordination procedure
examination procedure (S.7.3) estimating rank of magnitude

EXAMPLE - Detailed description of dip-stix **examination** (S.8.4) of concentration of urinary albumin on an **ordinal property-value scale** (S.17.6) of (1, 2, 3, 4, 5)

14.3.3

<u>differential examination procedure</u>
difference procedure
examination procedure (S.7.3) estimating a subtractive magnitude

EXAMPLE - Detailed description of how to examine rectal Celsius temperature

14.3.4

<u>rational examination procedure</u>
ratio procedure
examination procedure (S.7.3) estimating a divisible magnitude

EXAMPLE - Detailed description of how to examine the amount-of-substance concentration of lead(II) in blood

This set of coordinate specific concepts is straightforward in comprehensibility and use.

<MEASUREMENT PROCEDURE>

14.4 If the right-hand side of Figure 12.21 for division of <property> is preferred, a homologous oligolevel generic ꜝhierarchical concept system is required.

14.4.1 The first division, then, depends on whether magnitude is considered or not. The initial concept not involving magnitude is "nominal examination procedure" as defined in Section 14.3.1.

14.4.2 The complementary coordinate concept to "nominal examination procedure" as defined by the *VIM3* is not using "examination procedure" as a genus proximum.

> *measurement procedure*: detailed description of a measurement according to one or more measurement principles and to a given measurement method, based on a measurement model and including any calculation to obtain a measurement result [132-2.6]

14.4.3 In the present terminological dimension (S.2.19), however, the definition may become

> <u>measurement procedure</u>
> **examination procedure** (S.7.3) estimating magnitude
>
> EXAMPLES - The Examples of Sections 14.3.2 to 14.3.4 apply.

14.4.4 If the field of interest is metrology, excluding the necessity of the ꜝsuperordinate concepts "property" and "examination procedure", an alternative definition is

> <u>measurement procedure</u>
> detailed instructions for performing a **measurement** (S.15.14.2)
>
> EXAMPLES - The Examples of Sections 14.3.2 to 14.3.4 apply with replacement of 'examination (S.8.4)' and 'examine' by 'measurement (S.15.14.2)' and 'measure' respectively.

14.5 Dividing <measurement procedure> according to whether or not a metrological unit (S.18.12) is involved yields two new coordinate specific concepts as follows.

14.5.1

ordinal measurement procedure
ordination procedure
measurement procedure (S.14.4.4) estimating rank of magnitude

EXAMPLE - The Example of Section 14.3.2 applies although 'examination (S.8.4)' would be replaced by 'measurement (S.15.14.2)'

14.5.2

unitary measurement procedure
measurement procedure (S.14.4.4) utilizing a multiplicable reference quantity

EXAMPLES - The Examples of Sections 14.3.3 and 14.3.4 apply, although 'examine' would be exchanged by 'measure'.

14.6 The latter concept may be divided according to whether differences or ratios are involved.

14.6.1

differential unitary measurement procedure
differential measurement procedure
difference measurement procedure
unitary measurement procedure (S.14.5.2) estimating a subtractive magnitude

EXAMPLE - The Example of Section 14.3.3 applies with 'measure' for 'examine'.

14.6.2

<u>rational unitary measurement procedure</u>
rational measurement procedure
ratio measurement procedure
unitary measurement procedure (S.14.5.2) estimating a divisible magnitude

EXAMPLE - The Example of Section 14.3.4 applies with 'measure' for 'examine'.

14.7 Comparing the combined generic hierarchies on <examination procedure> presented in Figure 14.7, the right-hand side is obviously more complicated than the left-hand side, but the terms are also more informative (and two are inevitably more complex).

14.8 It is quite likely that in daily practice only "examination procedure", "nominal examination procedure", "measurement procedure", and possibly "ordinal measurement procedure" will be used. In view of the various conflicting usages, it is imperative to define "measurement procedure" in a given text.

It could be argued that terms such as 'differential examination procedure' (S.14.3.3) are ambiguous because the examination procedure may not have a difference structure. The alternative would be 'differential property examination procedure' or perhaps rather 'examination procedure of a differential property', but this term is rather unwieldy.

14.9 If a definition is thought to be too sparse, the principle of substitution will lead to more explicit information.

EXAMPLE
ordinal examination procedure (S.14.3.2)
[examination procedure (S.7.3)]
detailed instructions for performing a[n]
[examination (S.8.4)]
structured activity giving [an examination result (S.16.20)]
etc.

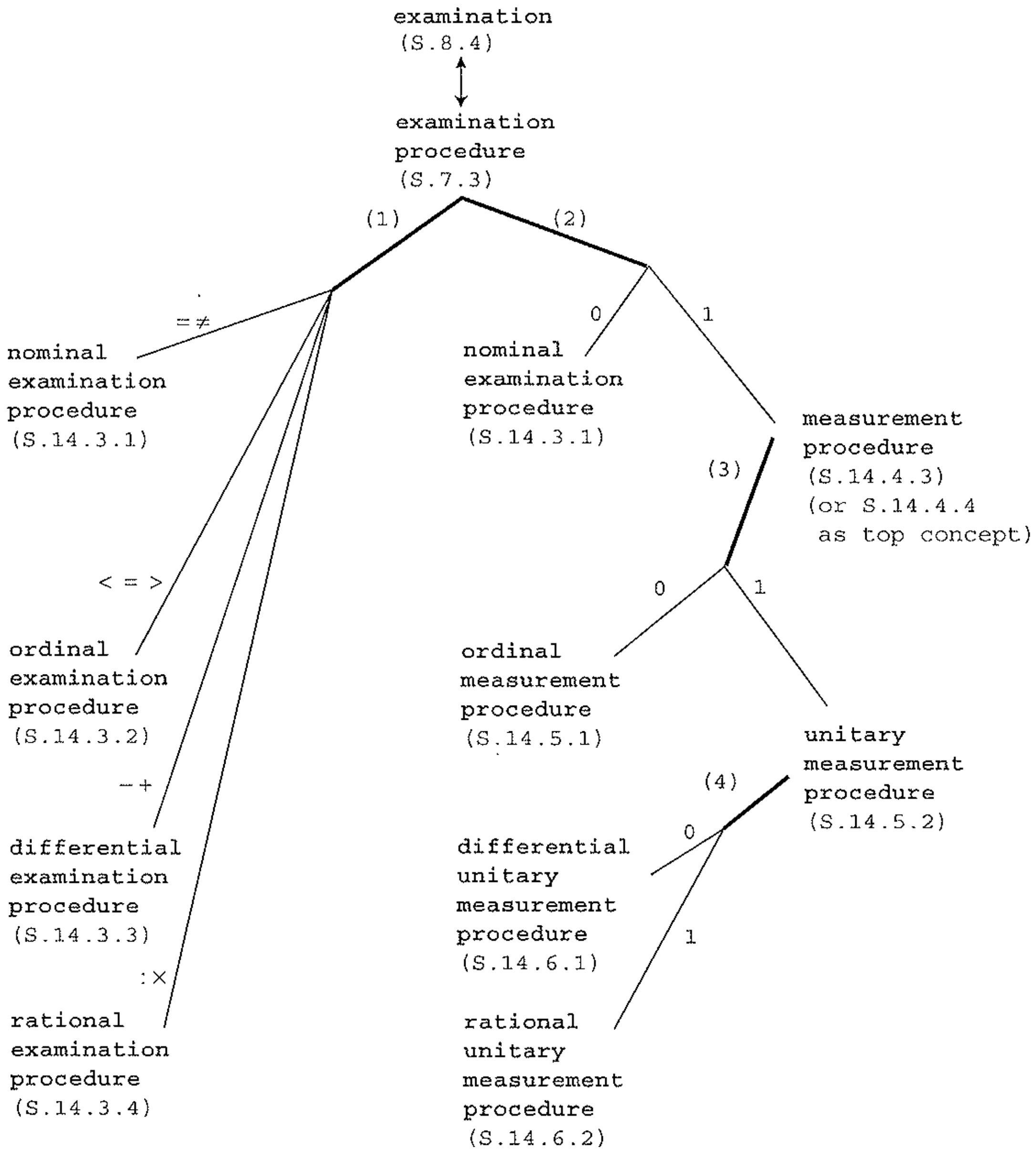


Figure 14.7 Pluridimensional 'generic 'concept diagram on <examination procedure> (S.7.3) according to two and four levels (cf. Fig. 12.21)

Terminological dimension (S.2.19)

(1) having an algebraic comparison between property values (S.9.15);

(2) having a magnitude of property values;

(3) having a metrological unit (S.18.12);

(4) having a rational magnitude of property values;

0 = no; 1 = yes
'Concepts paired on the same horizontal line have identical 'extensions.

14.10 A check for circularity can also be made.

EXAMPLE

differential unitary measurement procedure (S.14.6.1)
  unitary measurement procedure (S.14.5.2)
    measurement procedure (S.14.4.4.)
      |measurement (S.15.14.2)
        measurement result (S.16.21)
          measured quantity value (S.9.20.1)
            quantity value (S.16.8) ○
              quantity (S.12.14) × ○
                system (S.3.3) × ○
                component (S.3.4) × ○
                  system (S.3.3) × ○
            system (S.3.3 above)
            quantity (see × above)
          measurement uncertainty (S.16.24)
            quantity value (see ○ above)
            quantity (see × above)

<EXAMINATION METHOD>

14.11 Inasmuch as the salient steps of an examination procedure are given in an

examination method (S.7.4): structural basis of a set of examination procedures (S.7.3) for a **dedicated kind-of-quantity** (S.20.6)

this concept can be divided |generically, homologously to the |concept system on <examination procedure> presented in Figure 14.7. As the use of such specific concepts will probably be rather limited, only the most likely candidates are given here in accordance with Section 14.8.

14.11.1

<u>nominal examination method</u> **examination method** (S.7.4) for estimation of equality

14.11.2

<u>measurement method</u> **examination method** (S.7.4) for estimation of magnitude

14.11.3

<u>ordinal measurement method</u>
examination method (S.7.4) for estimation of rank of magnitude

14.11.4 These sparse definitions may be made more explicit by substitution of 'examination method'.

14.11.5 Within metrology *sensu stricto*, an alternative definition of "measurement method" may be preferred as follows.

measurement method
structural basis of a set of **measurement procedures** (S.14.4.4)

<EXAMINATION PRINCIPLE>

14.12 Regarding the principles behind an examination method, the concept

examination principle (S.7.5): fundamental phenomenal elements underlying an examination method (S.7.4)

can also be divided homologously to the concept system in Section 14.11.

14.12.1

<u>nominal examination principle</u>
examination principle (S.7.5) for estimation of equality

14.12.2

<u>measurement principle</u>
examination principle (S.7.5) for estimation of magnitude

14.12.3

<u>ordinal measurement principle</u>
examination principle (S.7.5) for estimating rank of magnitude

14.12.4 More explicit definitions are obtained by substitution. Furthermore, more direct definitions related to measurement may be preferred, such as

> <u>measurement principle</u>
> fundamental phenomenal elements of a generic description for a **measurement procedure** (S.14.4.4)

From this concept, as a genus proximum, specific concepts may be defined in the usual generic way, e.g. for "ordinal measurement principle", "differential measurement principle", and "rational measurement principle".

14.12.5 In practice, most metrologists would just use "measurement principle" as defined above - or in the *VIM3* (S.7.2.1)

14.12.6 The sequence of words in the terms of Sections 14.12.1 and 14.12.3 is an outcome of the generic derivation chosen. 'Principle of nominal examination', and 'principle of ordinal measurement' are other choices.

15 GENERIC CONCEPT SYSTEM on <EXAMINATION> and <measurement>; quantification

<EXAMINATION>

15.1 There is no generally agreed division of the ¦superordinate concept

examination (S.8.4): structured activity giving an examination result (S.16.20)

The simplest approach is that of *Stevens* who refrained from excluding any type of examining operation corresponding to one of the ¦specific concepts under <examination procedure> (see Figure 14.7). Only one ¦concept was offered, ¦defined by various phrases such as

15.1.1

measurement: assignment of numerals to objects or events according to rule [114-p. 677]

15.1.2

measurement: assignment of numerals to things so as to represent facts and conventions about them [114-p. 680]

15.1.3

measurement: process of mapping empirical properties or relations into a formal model [115-p. 20]

but, in any case, in *Stevens*' view, 'measurement' would be a ¦synonym of the presently proposed ¦term 'examination' for the top concept.

15.2 It was proposed to adopt this approach in clinical chemistry with the definition

measurement: set of operations by which a value is assigned to a quantity [40]

with the note that [the designation of] "value" is partitively divided into relational operator and symbols, figures, or letters, and where 'quantity' is a synonym of 'property'. Although differently worded, this definition is essentially the same as that proposed for "examination" and quoted in Section 15.1. As has been repeatedly alluded to, the comprehensive meaning of 'measurement' has been heavily criticized by several metrologists, wherefore "examination" has been introduced here instead.

15.3 Whereas metrology generally denies that "measurement" can include the activities consisting in finding values of nominal properties (S.12.4), there is some vacillation concerning ordinal properties (S.12.5), and measurement of differential properties (S.12.6) is often not formally distinguished from that of rational properties (S.12.7). However, *VIM3* now has an entry for "nominal property" (S.12.4.2).

15.4 *Bunge* shortly described the empirical operation "measurement" as 'quantitative observation' or more formally, here in paraphrase, as

> *measurement*: assignment of an individual number to a certain property of a definite object with the help of observation [15-p. 206]

As 'magnitude' was stated to be required, the property is a quantity, probably excluding an ordinal property, but the need to involve "unit of measurement" ("metrological unit" S.18.12) (including "one") is not part of this definition or those of *Stevens* above.

15.5 *McGlashan*, essentially interested in rational unitary quantities (S.12.20), insisted that measurement is counting. 'The only kind of physical quantity which we can measure [directly], that is to say count, is one that is a number, such as the number of peas in a bottle ...'. 'For any other kind of physical quantity the best we can do is to

> [*measure* (verb)]: count the number which is the ratio of two instances of the physical quantity' [101-p. 1]

Here, the denominator is a reference quantity, usually a measurement unit. This definition delineates the most restricted specific concept under "measurement".

> NOTE
> The wording is a short version of *Stille*'s
>
> > *Messung*: experimentell erfassbare[n] Äusserungen des untersuchten Vorganges oder Zustandes nach geeigneten und vorgegebenen Messverfahren mit gleichartigen und zahlenwertmässig bekannten oder definierten Äusserungen des physikalischen Geschehens zu vergleichen [116-p. 2]
>
> with the addition that the latter is the unit which is the basis of the measurement.

15.6 *Berka* after much discussion distinguished between two concepts which may be defined in paraphrase as follows.

15.6.1

scaling: examination with scales of the ordinal type [5-p. 7]

15.6.2

measurement: examination with scales of the metrical type [5-p. 7]

where metrical scale type relates to both differential and rational properties. In view of the several meanings of 'scaling' listed by *Berka*, the term is not felicitous, but "measurement" is clearly distinguished.

15.7 The German standard *DIN 1319-1* (in an English version) has

measurement: performing certain operations to determine the value of a quantity (measurand) [32-2.1]

and value of a quantity is defined in another German standard as

quantity value: value assigned to a distinctive mark of the quantity [33-3.3]

which is circular.

15.8 As was discussed in Section 8.3, the *VIM3* definition of

measurement: process of experimentally obtaining one or more qantity values that can reasonably be attributed to a quantity [132-2.1]

coupled with the definition of

quantity value; value of quantity; value: number and reference together expressing magnitude of a quantity [132-1.19]

and its Note 1 shows that an ǀinstantiated ordinal property can be measured.

15.9 The various views of division of <examination>, ǀassociatively related to division of <property>, are shown in Table 15.9.

The conclusion is that "measurement" has been ǀcharacterized so as to relate to one, two, three, or all of the series of four specific concepts under <property>, counting upwards from the mathematically most advanced, "rational property" at the bottom.

Table 15.9 Recorded ¦specific divisions of <examination> (S.8.4) ¦associatively related to ¦coordinate specific concepts under <property> (S.5.5), Figure 12.21, left-hand terminological dimension (1); see also analogous divisions under <examination procedure> (S.7.3) Figure 14.7.
e. = examination, m. = measurement, n.d. = not defined, p. = property

Division of <property>	Division of <examination> according to source							
	Stevens 1946 [114]	*Stille* 1955 [116]	*Bunge* 1967 [15]	*McGlashan* 1968 [101]	*Berka* 1983 [5]	*VIM* 2007 [132]	*DIN 1319-1* 1995 [32]	Present proposal
property	m.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	examination
nominal p.	m.	n.d	n.d.	n.d	classification	n.d.	n.d.	nominal e.
ordinal p.	m.	n.d.	n.d.	n.d.	scaling	m.	n.d.	ordinal e. or m.
differential p.	m.	n.d.	m.	n.d.	m.	m.	m.	differential e. or m.
rational p.	m.	m.	m.	m.	m.	m.	m.	rational e. or m.

15.10 On the basis of the proposed definition of "examination" (S.15.1), and starting with the most holistic, classificatory type of activity, the proposed term(s) and definition are as follows.

> <u>nominal examination</u>
> nomination
> **examination** (S.8.4) estimating equality
>
> EXAMPLES - The parenthetic procedures in the examples of Section 12.4 apply.
>
> NOTE - The outcome of a nominal examination is an examined **nominal property value** (cf. S.9.20 and S.16.2) with associated **examination uncertainty** (S.16.23).

The word 'nomination' has connotations besides the naming of individual concepts. The *Concise Oxford Dictionary* [1] has 'the act or an instance of nominating', and for 'nominate' it gives 'mention by name', which is what is intended here. The alternative 'classification' would be less accurate as other sorts of examination are also classifying property values and thereby properties.

15.11 Continuing with division of <examination> in one level, analogously to Figure 14.7 left-hand terminological dimension (S.2.19), leads to

> <u>ordinal examination</u>
> ordination
> **examination** (S.8.4) estimating rank of magnitude
>
> EXAMPLES - The parenthetic procedures in the examples of Section 12.5 apply.
>
> NOTE - The outcome of an ordinal examination is an examined **ordinal property value** (cf. S.9.20 and S.16.3) with associated **examination uncertainty** (S.16.23).

The simple term 'ordination' can have a clerical whiff, but is used here in another lexical sense of 'the arrangement of things etc. in ranks' [1].

15.12 The third coordinate specific concept is

> <u>differential examination</u>
> **examination** (S.8.4) estimating a subtractive magnitude
>
> EXAMPLE - Using a clinical thermometer
>
> NOTE - The outcome of a differential examination is an examined **differential property value** (cf. S.9.20 and S.16.4) with associated **examination uncertainty** (S.16.23).

15.13 The final coordinate concept is

> <u>rational examination</u>
> **examination** (S.8.4) estimating a divisible magnitude
>
> EXAMPLE - Using an analytical balance
>
> NOTE - The outcome of a rational examination is an examined **differential property value** (cf. S.9.20 and S.16.5) with associated **examination uncertainty** (S.16.23).

<MEASUREMENT>

15.14 It is unlikely that metrologists will forgo the concept "measurement" which excludes "nominal examination". Even with this restriction, the problem is the variation in the extension of the concept which can be derived from Table 15.9. Undoubtedly, however, the engineering disciplines would prefer to have "ordinal examination" included and this would accord with the interpretation of the *VIM3* presented in Sections 12.15 and 15.8. Consequently, one may define as follows, homologously to "measurement procedure" (S.14.4).

15.14.1

> <u>measurement</u>
> **examination** (S.8.4) estimating magnitude
>
> EXAMPLES - The examples appertaining to Sections 15.11, 15.12, and 15.13 apply.
>
> (cont.)

(cont.)
NOTE - The outcome of a measurement is an examined **quantity value** (S.16.7, 16.18) with associated **examination uncertainty** (S.16.23).

15.14.2 If the top concept "examination" is ignored, an alternative definition would be

<u>**measurement**</u>
structured activity providing a **measurement result** (S.16.21)

EXAMPLES - As for S.15.14.1.

15.15 Dividing <measurement>, as defined in Section 15.14.2, according to whether or not a metrological unit (S.18.12) is used yields two coordinate specific concepts as follows.

15.15.1

<u>**ordinal measurement**</u>
ordination
measurement (S.15.14.2) estimating rank of magnitude

EXAMPLES - The examples of Section 15.11 apply.

NOTE - The outcome of an ordinal measurement is a measured **ordinal quantity value** (cf. S.16.9 and S.16.18) with associated **measurement uncertainty** (S.16.24).

15.15.2

<u>**unitary measurement**</u>
measurement (S.15.14.2) requiring a multiplicable reference **quantity** (S.12.14)

NOTE 1 - The reference quantity is a **"metrological unit"** (S.18.12).

(cont.)

(cont.)
NOTE 2 - The outcome of a unitary measurement is a measured **unitary quantity value** (cf. S.16.10 and 16.18) with associated **measurement uncertainty** (S.16.24).

15.15.3 If the genus proximum "measurement" as defined in Section 15.14.1 is preferred, the definitions in Sections 15.15.1 and 15.15.2 should have substituted '**measurement** (S.15.14.2)' by '**examination** (S.8.4)' and the Notes should read 'examined ... **property value** (S.9.20)'. (Analogous changes could be made in the following two definitions.)

15.16 The latter concept (S.15.15.2) may be divided as follows.

15.16.1

<u>differential unitary measurement</u>
differential measurement
difference measurement
unitary measurement (S.15.15.2) estimating a subtractive magnitude
differential measurement

EXAMPLE - The example of Section 15.12 applies.

NOTE - The outcome of a differential unitary measurement is a measured **differential unitary quantity value** (cf. S.16.11 and S.16.18) with associated **measurement uncertainty** (S.16.24).

15.16.2

<u>rational unitary measurement</u>
rational measurement
ratio measurement
unitary measurement (S.15.15.2) estimating a divisible magnitude

EXAMPLE - The example of Section 15.13 applies.

NOTE - The outcome of a rational unitary measurement is a measured **rational unitary quantity value** (cf. S.16.12 and S.16.18) with associated **measurement uncertainty** (S.16.24).

15.17 The proposed concepts discussed here are depicted in the two-dimensional ꜝconcept diagram of Figure 15.17, showing the two lowest right-hand side concepts to have some more informative, but also more complex systematic terms.

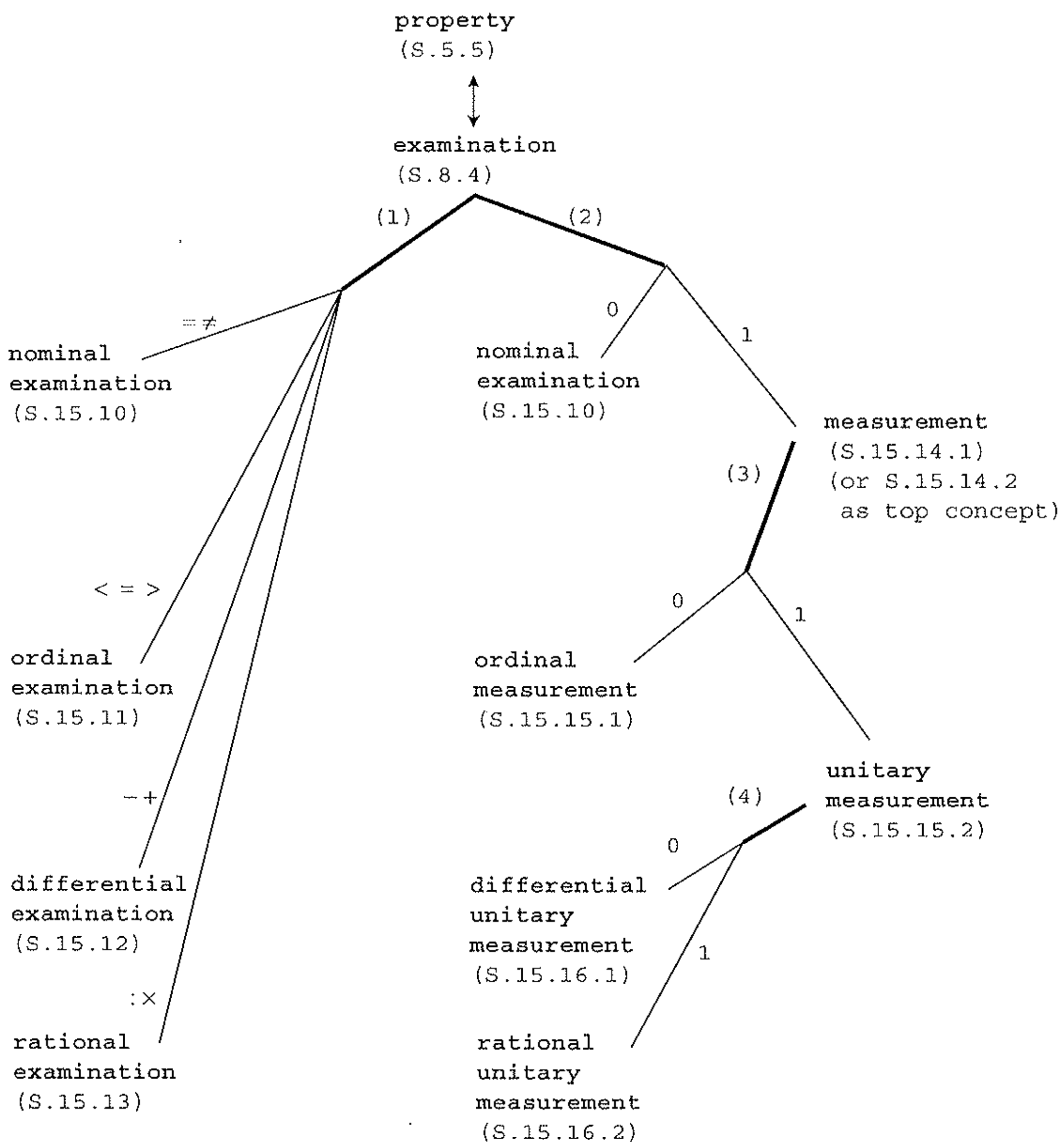


Figure 15.17 Pluridimensional ꜝgeneric ꜝconcept diagram on <examination> (S.8.4) according to two and four levels (cf. Figs 12.21 and 14.7)

Terminological dimension (S.2.19)

(1) having an algebraic comparison between property values (S.9.15);

(2) having a magnitude of property values;

(3) having a metrological unit (S.18.12);

(4) having a rational magnitude of property values;

0 = no; 1 = yes

ꜝConcepts paired on the same horizontal line have identical ꜝextensions.

15.18 For routine purposes, the concepts "examination", "nominal examination", "measurement", and possibly "ordinal measurement" may suffice. The meaning of 'measurement' in a given context should be specified.

15.19 The very succinct definitions chosen can be amplified by substitution or by explicitly using "value".

EXAMPLE
nominal examination (S.15.10): structured activity estimating a nominal property value (S.16.2) and examination uncertainty (S.13.23)

15.20 Rational unitary measurement (S.15.16.2) is classically divided in a separate terminological dimension according to whether or not additivity of the quantity values is isomorphic with the physical measuring manipulations on the systems possessing the quantities [115-p. 22]. The *direct measurement* shows additivity and is possible on quantities such as length, mass, electric resistance, and number of entities. Most quantities, however, are dealt with by *indirect measurement* based on combining quantity values from other quantities defining the target quantity, the measurand (S.5.8). The distinction is not inherent in the kinds-of-quantity, however, as for example a mass or a length can be measured by combining the values of measurements of other quantities.

15.21 A further term for activities leading to a property value is 'observation', which is being used with several meanings.

15.21.1 *Bunge* defined

observation: purposeful and enlightened perception [15-12.2]

and distinguished three stages: presentation of the object, preliminary interpretation, and description by data. Thus, examination and property (or quantity) value or examination result are both included.

15.21.2 Some current sources more or less implicitly regard "observation" as activities leading to any type of property value [2, 11, 65-1.4, 130], but the value itself is not comprised.

15.21.3 Some documents restrict "observation" to activities yielding only nominal or ordinal values [22-Annex F, 86-5.1.6].

15.21.4 Finally, "observation" can be regarded as a value obtained by measurement [8].

15.21.5 With such homonymy it seems unwise to use 'observation' in the present text.

QUANTIFICATION

15.22 Alledgedly, *Galileo Galilei* (1564-1642) urged us to 'measure the measurable and try to render measurable what is not yet' [15-p. 203]. The obvious way is to invent measurement procedures which can give numerical results for quantities not previously accessible to measurement. Mankind has become very proficient in that respect, from assessing the diameter of a given molecule to calculating the distance to a galaxy. In either case a defined instance of length is the measurand (S.5.8), and the result is given on a rational property-value scale (S.17.9).

15.23 Quite another situation is present if one wishes to attach a number to, e.g., "maleness of a given man".

The direct approach is to create a psycho-social measuring system with each member of a representative panel of five men and five women rendering a verdict on a personal scale from zero to five, and to register the mode on an ordinal quantity-value scale (S.17.15).

Another procedure, described by *Bunge* [15], is the so-called numerical quantification whereby a certain concept is associated with a relevant numerical variable. Thus, the ordinal kind-of-property (S.13.2.2) "maleness" was suggested to be equated with some hormone ratio, "fear" with adrenalinium level in blood, "hunger" with volume rate of gastric secretion. In each case, there is no measurement of the ordinal property that one wishes to have a holistic result for, but of a - quite possibly sensibly chosen - associated <rational unitary quantity (S.12.20). The term 'quantification', i.e. expressing as a rational quantity, seems to promise more than the surrogacy offers. *Krantz et al.* called the method 'a form of misplaced operationalism' [91-p.32].

15.24 It is, however, useful to remember that a given system may have properties forming an 'evolutional' series of increasingly specific information obtained by different types of examination as defined and chosen by man.

EXAMPLE
The state of a motorist having imbibed one or more types of ethanol-containing substance can be examined in the following ways.

1 On the basis of the person's general behaviour, a constable performs nominal examination and forms the opinion state = intoxicated, i.e. nominal property value.

2 Being a fair upholder of the law (and perhaps having heard of Galilei), the policeman induces the person to breathe into an ethanolo-

meter (Breathalyser®) providing means of an ordinal examination with the outcome alcohol concentration = 7, i.e. an ordinal property value, where the red zone with possible legal consequences starts, say, at = 6.

3 With no bribes offered, none taken, the person is conducted to the police station, booked, and subjected to a venepuncture by a physician. The blood sample is sent to a forensic laboratory which performs a unitary measurement and issues a report in three parts as follows.

3a The amount-of-substance concentration excess of ethanol in the motorist's blood measured by a differential unitary examination (according to a statutory measurement procedure) was = 15 mmol/l (above the legal amount-of-substance concentration limit of = 13 mmol/l), i.e. a differential unitary quantity value.

3b The amount-of-substance concentration measured by a rational unitary examination was = 28 mmol/l, i.e. a rational unitary quantity value.

3c The concentration excess in 3a is five times the expanded measurement uncertainty (corresponding to a level of confidence of 0,95) of the legal limit in 3a.

The unwise motorist was later taken to court, convicted of drunken driving, and relieved of his driving-licence for two years.

16 GENERIC CONCEPT SYSTEM on <PROPERTY VALUE>, <quantity value>, and allied concepts

<PROPERTY VALUE>

16.1 As a ˡsuperordinate ˡgeneric concept,

> *property value* (S.9.15): inherent feature of a property (S.5.5) used in comparing it with other properties of the same kind-of-property (S.6.19)

may be divided into four ˡspecific ˡcoordinate concepts in one level. Such ˡconcepts are ˡassociatively related to the corresponding divisions of <property> (S.5.5 and Fig. 12.21, left-hand side), <kind-of-property> (S.13.2), and <examination> (S.8.4 and Fig. 15.17, left-hand side), which consequently could furnish the ˡdelimiting characteristics. Here, independent characterization is preferred.

16.2 The mathematically simplest concept is

<u>**nominal property value**</u>
nameable value of a property
nominal value
property value (S.9.15) that can be compared for equality of identity, but not for magnitude, with other property values of the same **kind-of-property** (S.6.19)

EXAMPLES
= red, = yellow, = colourless for the
nominal kind-of-property (S.13.2.1) "colour" (of a urine sample)
= male, = intersexual, = female for "gender" (of a person)
= A, = B, = AB, = O for "blood group" (of a blood sample)

NOTE 1 - A nominal property value has no magnitude.

NOTE 2 - A nominal property value can take the form of a ˡterminological phrase, ˡword, or ˡsymbol, including a number, but without relation to magnitude.

(cont.)

(cont.)
NOTE 3 - A nominal property value is a member of a **nominal property-value scale** (S.17.5).

NOTE 4 - A nominal property value cannot enter into arithmetic equations.

NOTE 5 - A set of nominal property values of a given nominal kind-of-property can be distributed by value and counted in each class to form a number distribution (= frequency distribution), which can be described by mode and allows contingency correlation and chi-square test.

16.3 The next coordinate concept is

<u>ordinal property value</u>
ordenable value of a property
ordinal value
property value (S.9.15) that can be ranked as having a magnitude that is lesser than, equal to, or greater than another property value of the same **kind-of-property** (S.6.19)

EXAMPLE
=_absent, =_present or =_0, =_1 for the **ordinal kind-of-property** (S.13.2.2) "pain(subjective)"

NOTE 1 - An ordinal property value is not subtractive.

NOTE 2 - An ordinal property value can take the form of a terminological phrase or ordinal number denoting magnitude, but with no **metrological unit** (S.18.12) involved.

NOTE 3 - An ordinal property value is a member of an **ordinal property-value scale** (S.17.6).

NOTE 4 - An ordinal property value may enter some empirical equations, but differences between values have no mathematical meaning and cannot be ranked.

NOTE 5 - A set of ordinal property values of a given ordinal kind-of-property can be distributed according to magnitude forming a number distribution (= frequency distribution), which can be described by fractiles and allows rank-order correlation, sign and run tests.

16.4 The third coordinate concept is

differential property value
differenceable value of a property
difference value of a property
differential value
property value (S.9.15) that can be subtracted from but not divided by another property value of the same **kind-of-property** (S.6.19)

EXAMPLES
= -3 mmol/l, = 0 mmol/l, = 7 mmol/l for the **differential kind-of-property** (S.13.2.3) "amount-of-substance concentration difference(Patient - norm)" (of base in blood);

= -18.7 °C for "Celsius temperature" (in a deep-freeze)

NOTE 1 - A differential property value is not divisible.

NOTE 2 - A differential property value can take the form of an alphanumeric string denoting **numerical unitary quantity value** (S.16.16) and **metrological unit** (S.18.12), including "one".

NOTE 3 - A differential property value is a member of a **differential property-value scale** (S.17.7) with an arbitrary or conventional zero.

NOTE 4 - A differential property value can be subtracted from another value of the same differential kind-of-property and the difference is a **rational property value** (S.16.5).

NOTE 5 - A set of comparable differential property values of a given differential kind-of-property can be distributed according to magnitude forming a number distribution (= frequency distribution) which can be described by its average, standard deviation, and average deviation, and which allows product-moment correlation, correlation ratio, *t*-test, and *F*-test.

16.5 The final coordinate concept is

<u>rational property value</u>
ratioable value of a property
ratio value of a property
rational value
property value (S.9.15) than can be divided by another property value of the same **kind-of-property** (S.6.19)

EXAMPLES
= 72 kg for the **rational kind-of-property** (S.13.2.4) "mass" (of a person)

= 0.42 for "volume fraction" (of erythrocytes in a blood sample)

NOTE 1 - A rational property value can take the form of an alphanumeric string denoting **numerical unitary quantity value** (S.16.16) and **metrological unit** (S.18.12), including "one".

NOTE 2 - A rational property value is a member of a **rational property-value scale** (S.17.9) with a 'natural', 'absolute' zero.

NOTE 3 - A rational property value can be divided by another property value (except zero) of the same rational kind-of-property.

NOTE 4 - A set of comparable rational property values of a given rational kind-of-property can be distributed according to magnitude forming a number distribution (= frequency distribution), which can be described by its average, standard deviation, coefficient of variation, and other classical statistics.

16.6 The possibilities of types of mathematical comparison between two instances of "property value" under one of the four given specific concepts in Sections 16.2 to 16.5 increase cumulatively through the series. Thus, instead of a set of coordinate specific concepts, it is tempting to define each of the three last concepts from the previous one. Such an evolutionary approach would give, for example, the following series.

nominal property value: property value (S.9.15) allowing comparison of equality with other property values of the same kind-of-property (S.6.19)

ordinal property value: nominal property value (S.16.6.1) allowing ranking by magnitude among other property values of the same kind-of-property (S.6.19) *differential property value*: ordinal property value (S.16.6.2) allowing subtraction from other property values of the same kind-of-property (S.6.19)

rational property value: differential property value (S.16.6.3) allowing division by other property values except zero of the same kind-of-property (S.6.19)

Although this generic series seems correct according to the definitions, they ignore the 'negative' characteristics of the concepts given in the Notes 1 of the first three concepts of the corresponding coordinate set. Thus, the genus proximum in each case excludes exactly those property values having the differentia specifica. A homologous situation was found, of course, for divisions of <property> in Section 12.9.

<QUANTITY VALUE>

16.7 To define specific concepts under <property value> related to the division of <property> according to the right-hand side of Figure 12.21, the first subordinate level besides "nominal property value" (S.16.2) contains

> <u>quantity value</u>
> value of a quantity
> **property value** (S.9.15) having a magnitude represented by a number and a reference
>
> EXAMPLES - The examples of Sections 16.3, 16.4, and 16.5 all apply.
>
> NOTE - To know which statistics can be calculated on a set of quantity values, the kind-of-property and type of quantity values (S.16.3, 16.4, 16.5) have to be specified. At least the statistics mentioned for ordinal property value (S.16.3) are allowed.

The definition gives the same extension as the *VIM3* definition (S.16.8.1).

16.8 If nominal property values are not considered at all, a modified definition is necessary, such as

quantity value
value of a quantity
magnitude of a **quantity** (S.12.14) represented by a number and a reference

NOTE - The examples and Note of Section 16.7 apply.

16.8.1 This definition is esentially reflected in the new *VIM3* as

quantity value; value of a quantity; value: number and reference together expressing magnitude of a quantity [132-1.19]

16.9 The first specific concept under "quantity value" is

ordinal quantity value
ordenable value of a quantity
ordinal value
quantity value (S.16.8) that can only be ranked as having a magnitude that is lesser than, equal to, or greater than another quantity value of the same **kind-of-quantity** (S.13.3.1)

NOTE - The Examples and Notes of Section 16.3 apply analogously.

16.10 The coordinate concept, then, is

unitary quantity value
unitary value
quantity value (S.16.8) represented by a reference quantity multiplied by a number

EXAMPLES - The Examples of Sections 16.4 and 16.5 apply.

NOTE - The 'reference quantity' is a **metrological unit** (S.18.12), the 'number' is a **numerical unitary quantity value** (S.16.16).

16.11 The previous concept may be generically divided, firstly into

<u>**differential unitary quantity value**</u>
differential quantity value
differenceable unitary value of a quantity
difference unitary value of a quantity
differential value
unitary quantity value (S.16.10) that can be subtracted from but not divided by another quantity value of the same **kind-of-quantity** (S.13.3.1)

NOTE - The Examples and Notes of Section 16.4 apply.

16.12 The second coordinate concept is

<u>**rational unitary quantity value**</u>
rational quantity value
ratioable unitary value of a quantity
rational value
unitary quantity value (S.16.10) that can be divided by another quantity value of the same **kind-of-quantity** (S.13.3.1)

NOTE - The Examples and Notes of Section 16.5 apply.

16.13 The sequence of words in the various terms is here chosen so that the initial word is always 'nominal', 'ordinal', 'differential', 'rational', or 'unitary'. Another possibility would have been to start with 'value'. Thus, e.g.,

'value of a nominal property'
instead of
'nominal property value'
or
'value of a rational unitary quantity'
instead of
'rational unitary quantity value'.

In each pair, the second alternative has advantages. Firstly, the term of the genus proximum in the definition corresponds to the sequence in the new term following the modifier introduced. Secondly, the mathematical characteristic of the concept is retained in abbreviations - although not necessarily as the first word in all languages (e.g. 'valeur ordinale', fr).

16.14 It is unlikely that the complex systematic terms will be used in daily practice, however informative they may be, but they are useful for classificatory purposes.

"NUMERICAL VALUE", "RESULT", and "UNCERTAINTY"

16.15 As was mentioned in Section 9.5, *Maxwell* stated that the expression of a quantity, its value, consists of two factors or components. A standard of reference, itself a quantity called 'unit', and a number called 'numerical value of the quantity' [99]. *Guggenheim* used the term 'measure' for the latter concept [56], but that is not in current use.

Although all types of property may have property values that are or include numbers, only unitary quantities (S.12.17) have quantity values that are products of a metrological unit (S.18.12) and a numerical value. The latter concept has already been invoked in the Note 2 to "differential property value" (S.16.4), Note 1 to "rational property value" (S.16.5), and Note to "unitary quantity value" (S.16.10).

The *VIM3* definition

> *numerical quantity value*; numerical value of a quantity; numerical value: number in the expression of a quantity value, other than any number serving as the reference [132-1.20]

implicitly includes "numerical ordinal quantity value" for those ordinal quantities that are expressed by a number and a reference. Some ordinal quantities, however, have an expression containing a phrase rather than a number, e.g. see Section 16.3 Example and Note 2.

16.16 It is possible to distinguish the cases where a numerical value is always involved by the following term and definition.

<u>numerical unitary quantity value</u>
numerical value
ratio of a **unitary quantity** (S.12.17) and the **metrological unit** (S.18.12) chosen for its representation

NOTE - The unitary quantity and its metrological unit are of the same **unitary kind-of-quantity** (S.13.3.3).

EXAMPLES
diameter = 7.4 μm has the numerical unitary quantity value 7.4
number concentration = 277 × 10^9 l^{-1} has the numerical value 277 if the metrological unit is chosen to be 10^9 l^{-1}

The concept "ratio" in the definition is chosen rather than "quotient" because the two quantities are of the same unitary kind-of-quantity [86-15.14.4.2] whereas "quotient" has no such specification.

16.17 The concepts discussed so far in this Chapter are shown in the ᑊconcept diagram of Figure 16.17. Its structure is homologous to that on <property> (Fig. 12.21), <examination procedure> (Fig. 14.7), and <examination> (Fig. 15.17).

16.18 For any of the types of "property value" discussed in this Chapter, it is possible to create two coordinate specific concepts by prefacing in term and definition with the word 'true' (cf. S.9.17), or either 'examined' (cf. S.9.18) or 'measured' as appropriate.

16.19 An initially examined property value is not sufficient information about the outcome of an examination (S.8.4). According to the examination procedure (S.7.3) there may be a need to apply ᑊcorrections and/or ᑊcorrection factors and/or calculate the best estimate from several examined property values. Furthermore, there should be information about how reliable this final estimate is thought to be (cf. S.9.22).

16.19.1 The *VIM3* has the concept

measurement result; result of a measurement: set of quantity values being attributed to a measurand together with any other available relevant information [132-2.9]

with a Note about the general need of a ᑊmeasurement uncertainty.

16.19.2 The recent *ISO 3534-2* has

measurement result: value of a quantity obtained by carrying out a specified measurement procedure [75-3.4.2]

which ignores "measurement uncertainty" (S.16.24) and invokes "measurement procedure" rather than using "measurement" directly.

16.20 For the superordinate concept, the following is offered.

<u>examination result</u> result of examination concluding **examined property value** (S.9.20) with associated **examination uncertainty** (S.16.23)

This definition includes the ˡessential characteristic having an associated examination uncertainty rather than taking the *VIM3* option of a note on the subject.

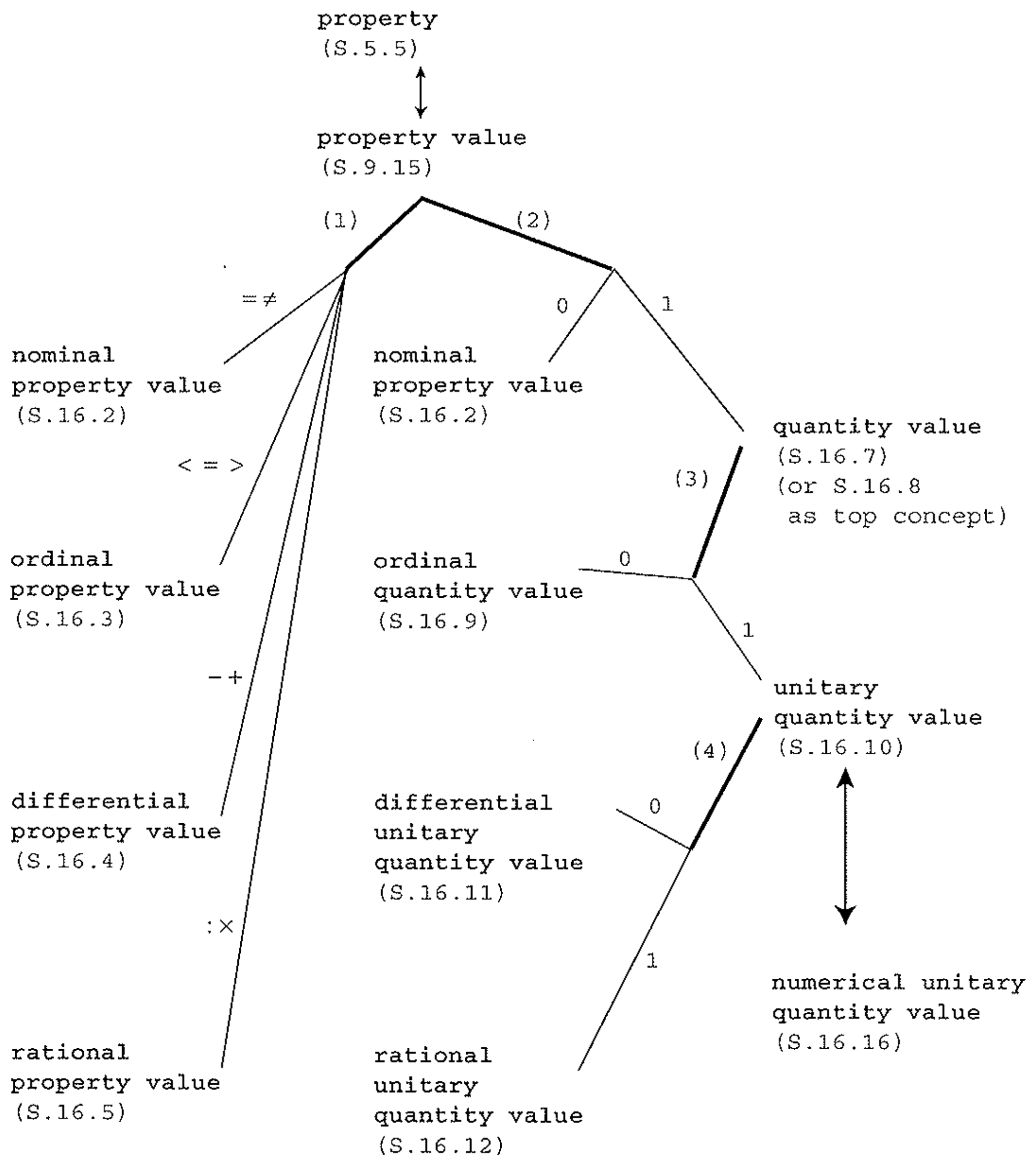


Figure 16.17 Pluridimensional ˡgeneric ˡconcept diagram on <property value> (S.9.15) according to two and four levels (cf. Figs 12.21, 14.7, and 15.17)

Terminological dimension (S.2.19)

(1) having an algebraic comparison between property values;

(2) having a magnitude;

(3) having a reference quantity;

(4) having a rational magnitude;

0 = no; 1 = yes

ˡConcepts paired on the same horizontal line have identical ˡextensions.

NOTE - In some documents preferring the term 'test' for 'examination' and 'characteristic' for 'property', the obvious term is 'test result', and the definition is

test result: value of a characteristic obtained by carrying out a specified test method [2, 44-1.3.9, 75-3.4.1]

analogous to that of "measurement result" (S.16.19.2).

16.21 Homologously, for the final outcome of a measurement,

<u>measurement result</u> result of measurement concluding **measured quantity value** (S.9.20.1) with associated **measurement uncertainty** (S.16.24)

16.22 The definition of measurement uncertainty given by the *VIM3* is

measurement uncertainty; uncertainty of measurement; uncertainty: non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information available [132-2.26]

16.23 As a result of a nominal examination (S.15.10) also has an uncertainty, the following definition may be used

<u>examination uncertainty</u> uncertainty of examination description of the dispersion of the set of **property values** (S.9.15) being attributed to a **property** (S.5.5)

16.24 For the outcome of measurement, the homologous term and definition are

<u>measurement uncertainty</u> uncertainty of measurement non-negative parameter that describes the dispersion of **quantity values** (S.16.7, 16.8) being attributed to a **quantity** (S.12.14)

that are virtually identical to the *VIM3* entry, except for omitting the last phrase '..., based on the information available' which seems redundant.

17 GENERIC CONCEPT SYSTEM on <PROPERTY VALUE SCALE> and <QUANTITY VALUE SCALE>

<PROPERTY VALUE SCALE>

17.1 Having ¦defined and ¦generically divided "property" (S.5.5 and Ch.12) and its dependent "property value" (S.9.15 and Ch.16), the background is available for a generic division of the further dependent "property value scale" (S.10.14).

17.2 The number of possible ways to divide <property value scale> is large as shown by *Berka* in his comprehensive although allegedly not exhaustive discussion [5]. Here, some of the ¦coordinate ¦sets need only to be mentioned without definitions, including those touched upon in Chapter 10.

17.2.1

conceptual scale = *mathematical scale*
material scale = *empirical scale*

or ¦concept versus ¦instance (S.10.3)

17.2.2

true value scale (S.10.16.1)
examined value scale (S.10.16.2)

17.2.3 Generic division according to

kind-of-property

is inevitable in conjunction with examination procedures (S.7.3) giving, e.g. "scale of length", "scale of taxon".

17.2.4 There are numerous ¦characteristics for the distribution of the scale values, such as

unidimensional, bidimensional, pluridimensional;
complete, partial;
regular, irregular;
uniform, logarithmic;

discrete (= denumerable), *continuous* (= non-denumerable);
2-valued, 3-valued, ..., multivalued.

17.2.5 Division according to whether a kind-of-quantity is extensive (S.13.5.1, 13.5.2, 13.5.3) or intensive (S.13.5.4) leads to

extensive quantity scale
intensive quantity scale

17.2.6 Incidental to the present purposes is division into

subjective scale
physical scale

and division according to the

inventor

of the scale, such as the Beaufort scale of windforce and the Réaumur temperature scale.

17.3 The essential and controversial problem in dividing

property value scale (S.10.14): ordered set of possible, mutually comparable property values (S.9.15)

is to define specific concepts that are conveniently related to the generic divisions of <property value> and <property>, and that have evocative terms.

17.4 However much *Stevens* has been criticized [5, 53] for extending the concept "measurement" to include "nominal examination" (S.15.10) and "ordinal examination" (S.15.11), there can be no doubt that his description of the specific concepts under an all encompassing concept <scale of measurement>, based on the mathematical characteristics of each scale, is a major contribution [114, 115]. Further strictly mathematical representations may be found in the monograph by *Krantz & al.* [91-p. 10-11 and elsewhere]. The salient traits are summarized in Table 17.4. It should be noted that the lines of characteristic 'Basic physical determination', 'Algebraic comparison', and 'Permissible statistics' are cumulative to the right, whereas the other lines are cumulative in the opposite direction. There are, however, some constraints as discussed by *Stevens* [115].

17.4.1 The sets of 'permissible statistics' may have to be modified depending on the definition of the measurands and the questions asked of the data [135].

Table 17.4 Mathematical ᴵcharacteristics of *Stevens'* ᴵspecific concepts [114, 115] under the present ᴵsuperordinate concept <property value scale> (S.10.14)

ᴵAbbeviations: g. = group; s. = property value scale; tp. = temperature

→ this ᴵstatistic also applies in the last two columns

Characteristic	**Term** (according to *Stevens*)				
	nominal s.	ordinal s.	linear interval s.	logarithmic interval s.	ratio s.
Basic physical determination	equality of class	greater or less	equality of differences	equality of log differences	equality of **ratios**
Type of value	class symbol	ordinal number	cardinal number →		
Mathematical structure	permutation g.	isotonic g.	linear g.	power g.	similarity g.
Function for replacing x by x'	$x' = f(x)$	$x' = f(x)$	$x' = \alpha x + \beta$ ($\alpha > 0$)	$x' = kx^n$ (k and x are real numbers)	$x' = \alpha x$ ($\alpha > 0$)
Invariance under transformation	one-to-one substitution	increasing monotonic	positive linear	positive exponential	similarity
Algebraic comparison	$a \overset{=}{\neq} b$	$a \overset{<}{\underset{>}{=}} b$	$\lvert a - b \rvert \overset{=}{\neq} \lvert c - d \rvert$		$a \overset{=}{\neq} nb$
Permissible statistics	mode number of values contingency correlation chi-square	fractiles sign test	average → variance → rank-order correlation → product-moment correlation → t-test, *F*-test →		geometric mean coefficient of variation
Examples	blood group type of thermometer	intelligence subjective tp.	rectal Celsius tp.	blood plasma pH logarithmic tp.	body mass thermodynamic tp.

17.4.2 If the specific concepts under <property value scale> are considered to be ¦coordinate, the following terms and definitions can be made.

17.5 The mathematically most primitive, but also most holistic scale is

<u>**nominal property-value scale**</u>
nominal scale of values of properties
nominal scale
property value scale (S.10.14) on which only comparison of equality equality of identities applies

EXAMPLES
(=_milky, =_red, =_yellow) for "colour"

(=_A, =_B, =_AB, =_O) for "blood_group"

(=_female, =_intersexual, =_male) for "gender"

NOTE 1 - The ¦characteristics of **nominal property value** are given in Section 16.2.

NOTE 2 - The mathematical characteristics of a nominal property value-scale are listed in Table 17.4.

NOTE 3 - The order of nominal property values on a nominal property-value scale is arbitrarily or conventionally chosen according to practical considerations or nature of the related systems or phenomena.

NOTE 4 - The position on the scale of any two nominal property values may be interchanged at will.

NOTE 5 - ¦Synonyms are 'categorical scale', 'nomination scale', and 'naming scale'.

17.5.1 This definition focusses on mathematical characteristics. In the new *ISO 3534-2* is given

nominal scale: scale with unordered labelled categories or ordered by convention [75-1.1.6]

17.5.2 *Berka* [5] rejected the idea of including "nominal scale" under <scale of measurement>, arguing that 'Scale values cannot be linguistic expressions - numerals - but always are extralinguistic entities, that is numbers'. This postulate is somewhat weak inasmuch as the number "7" can be expressed linguistically. In the present text, however, the widespread feeling among metrologists that "nominal scale" is not a specific concept under "scale of measurement" is dealt with by defining the ˡsuperordinate generic <property value scale>.

17.6 As soon as magnitude of a property is involved, the next concept may become relevant.

<u>**ordinal property-value scale**</u>
ordinal scale of values of properties
ordinal scale
property value scale (S.10.14) on which only comparison of equality of magnitudes applies

EXAMPLES
(= absent, = slight, = moderate, = severe) or
(= 0, = 1, = 2, = 3) for "subjective pain"

(= 0, = 1, = 2, = 3, = 4) for "arbitrary concentration" of urinary albumin according to specified examination procedure

NOTE 1 - The ˡcharacteristics of **ordinal property value** are given in Section 16.3.

NOTE 2 - The mathematical characteristics of an ordinal property-value scale are listed in Table 17.4.

NOTE 3 - The ordinal property-value scale is conventionally arranged in ascending (or descending) order of magnitude.

NOTE 4- An ordinal property-value scale can still serve its purpose after all property values have been multiplied by a constant, squared, or cubed.

NOTE 5 - ˡSynonyms are 'scale of scaling', 'scale of ranking', 'ordination scale'.

17.6.1 The *ISO 3534-2* has

ordinal scale: scale with ordered labelled categories [75-1.1.7]

with no definition of "labelled" and "category", and a Note mentioning that a nominal scale may be ordered by convention. Thus, there is no clear distinction from "nominal scale" and "magnitude" is not mentioned.

17.7 The third type of property value scale is relevant when metrological unit (S.18.12) and difference of magnitude apply.

> **differential property-value scale**
> differential scale of values of properties
> difference value scale
> differential scale
> **property value scale** (S.10.14) on which comparison by subtraction but not division applies
>
> EXAMPLES
> (≤ -15, = -14, ..., = 0, ..., = 14, ..., ≥ 15) mmol/l for "amount-of-substance concentration difference(actual - norm)"
>
> (= 35,1, = 35,2, ..., = 42,3) °C for "Celsius temperature"
>
> NOTE 1 - The characteristics of **differential property value** are given in Section 16.4.
>
> NOTE 2 - The mathematical characteristics of a differential property-value scale are listed in Table 17.4 under "linear interval scale".
>
> NOTE 3 - A differential property-value scale has an arbitrarily, possibly conventionally chosen zero value.
>
> NOTE 4 - Section 17.6, Note 3 applies.
>
> NOTE 5 - A differential property-value scale may still serve its purpose after all **numerical unitary property values** (S.16.16) have been multiplied by a constant and/or have had a constant added, i.e. a change of zero point.
>
> NOTE 6 - The synonym 'interval scale' [31, 114] is not used here because "interval" is taken to be a set of **unitary quantity values** (S.16.10) between and possibly including two limits. Thus, the closed interval [1; 5] is different from [6; 10] even if both have a width of 4. Other synonyms are 'difference scale' and 'incremental scale'.

17.7.1 The *ISO 3534-2* defines

interval scale: continuous scale or discrete scale with equal sized scale values and arbitrary zero [75-1.1.8]

The zero value of the definition is given in the proposed Note 3. How scale values can be 'equal sized' is not clear.

17.8 *Stevens'* subordinate concepts of <scale> initially numbered four, but in a subsequent paper [115] the "interval scale" was divided into "linear interval scale" and "logarithmic interval scale" (see Table 17.4). Here, it is preferred to make the logarithmic transformation at the kind-of-property stage. Thus, an originally exponential property value becomes a differential property value which is found on a (linear) differential scale.

EXAMPLE - The differential kind-of-quantity "pH" is defined as the negative decadic logarithm of the relative molal activity of hydrogen ion [86-8.13.5].

17.9 The final coordinate concept further requires that ratio of magnitude applies.

rational property-value scale
rational scale of values of properties
ratio value scale
rational scale
property value scale (S.10.14) on which comparison by division applies

EXAMPLES
(= 0, ..., = 30, ..., = 70, ...) kg for body "mass"
(= 0, ..., = 230, ..., = 400) K for "thermodynamic temperature" of a system

NOTE 1 - The characteristics of **rational property value** are given in Section 16.5.

NOTE 2 - The mathematical characteristics of a rational property-value scale are listed in Table 17.4.

NOTE 3 - A rational property-value scale is often said to have a 'natural' or 'absolute' zero value [75-1.1.9].

NOTE 4 - Section 17.6, Note 3 applies.

(cont.)

(cont.)
NOTE 5 - A rational property-value scale may still serve its purpose after all **numerical unitary property values** (S.16.16) have been multiplied by a constant.

NOTE 6 - A ˡsynonym is 'ratio scale'.

17.9.1 The *ISO 3534-2* offers

ratio scale; proportional scale: continuous scale with equal sized scale values and an absolute or natural zero point [75-1.1.9]

which does not capture the ˡessential characteristic of divisibility. Furthermore, the phrases 'absolute zero' and 'natural zero' seem to be ˡsynonyms, but the former is usually related to "thermodynamic temperature" and the latter is ambiguous because the numerical value zero for "amount-of-substance concentration difference" of base excess in blood plasma is quite natural although an element of a differential property-value scale. The problematic 'equal sized scale values' remains from Section 17.7.1.

17.10 The four subordinate concepts in Sections 17.5-6-7-9 have characteristics that are cumulative in that sequence for 'Basic physical determination', 'Algebraic comparison', and 'Permissible statistics' whereas they are cumulative in the opposite direction for 'Mathematical structure', 'Function for replacing *x* by *x*'', and 'Invariance under transformation' (cf. Tab. 17.4). Therefore, a stepwise generic subordination from <scale> is not possible. This is homologous to the finding for <property> (cf. S.12.9) and <property value> (cf. S.16.6).

17.11 Several other divisions of <scale> have been proposed with or without reference to *Stevens*' system and having none, one, or two of his specific concepts excluded. Table 17.11 is a summary presentation of such proposals. It is seen that neither 'topological scale' nor 'measurement scale' or 'metrical scale' are unambiguous terms.

Table 17.11 Various proposals for ¦specific concepts under <property value scale> (S.9.14).
¦Abbreviations: meas. = measurement; n.c. = no ¦concept ¦defined;
s. = scale (of values of properties/quantities)

Source	Term			
Stevens [114]	nominal s.	ordinal s.	interval s.	ratio s.
Bunge [15]	n.c.	ordinal s. topological s.	metrical s. meas. s.	metrical s. meas. s.
Berka [5]	n.c.	ordinal s. s. of scaling	n.c.	metrical s. s. of meas.
DIN 55350-12[a] [31]	topological s. nominal s.	topological s. ordinal s.	cardinal s. metrical s. interval s.	cardinal s. metrical s. ratio s.
ISO 3534-2 [75]	nominal s.	ordinal s.	interval s.	ratio s. propor-tional s.
Present text	nominal s.	ordinal s.	differential s.	rational s.
Allowed relational operators	= ≠	= ≠ < >	= ≠ < > + -	= ≠ < > + - × :

[a]Translated from German

<QUANTITY VALUE SCALE>

17.12 The ¦concept system alternative to the coordinate set of Sections 17.5-6-7-9 will be homologous to those of the right-hand side of Figure 12.21 for <property> and Figure 16.15 for <property value>. Thus, the first division concerns the relevance or not of magnitude, giving "nominal property-value scale", as defined in Section 17.5, and a complementary specific concept related to "quantity" (S.12.13 or 12.14). A linguistically obvious term for this latter concept is 'quantitative scale', but it is not preferred here because "ordinal scale" is sometimes called 'qualitative scale' or 'semiquantitative scale'. In fact, the following three overlapping concepts are found in the literature with various combinations of the listed characteristics.

qualitative scale
- nominal scale
- ordinal scale
- any two- or few-value scale

semiquantitative scale
- ordinal scale

- few-value ordinal, differential, or rational scale

- ordinal, differential, or rational scale with a large relative uncertainty

quantitative scale
- ordinal scale
- differential scale
- rational scale
- multivalued ordinal, differential, or rational scale with a low relative uncertainty

The other candidate is 'measurement scale' relating to "measurement" (S.15.14.1, 15.14.2), but as noted the term has been used in a more restricted sense and the scales in question are not necessarily used in measurement. This latter noun, however, may function as a modifier when it is thought useful to emphasize that a scale is employed during a measuring activity.

17.13 Consequently, the concept involving magnitude is termed and defined.

> <u>quantity value scale</u>
> scale of values of quantities
> **property value scale** (S.9.14) on which comparison of magnitudes applies
>
> EXAMPLES - The Examples of Sections 17.6, 17.7, and 17.9 all apply.
>
> NOTE - The statistics allowed depend on the characteristics of the **kind-of-quantity** (S.13.3.1) involved.

17.14 If nominal properties are not a part of the field of interest, a modified definition is

> <u>quantity value scale</u>
> scale of values of quantities
> ordered set of possible, mutually comparable **quantity values** (S.16.8)
>
> NOTE - The Examples and Note of Section 17.13 apply.

17.14.1 The *VIM3* has introduced

quantity-value scale; measurement scale: ordered set of quantity values of quantities of a given kind of quantity used in ranking, according to magnitude, quantities of that kind [132-1.27]

which is more explicit but not in conflict with the proposed short definitions.

17.15 The first specific concept under "quantity value scale" corresponds to "ordinal property-value scale" (S.17.6), i.e.

> <u>**ordinal quantity-value scale**</u>
> ordinal scale of values of quantities
> ordinal scale
> **quantity value scale** (S.17.13 or 17.14) on which comparison of equality of magnitudes applies.
>
> NOTE - The Examples and Notes of Section 17.6 apply.

17.15.1 The *VIM3* now has

ordinal quantity-value scale; ordinal value scale: quantity-value scale for ordinal quantities [132-1,28]

which definition is not very informative compared to the term.

17.16 The coordinate concept is

> <u>**unitary quantity-value scale**</u>
> unitary scale of values of quantities
> unitary scale
> **quantity value scale** (S.17.13 or 17.14) on which a multiplicable reference quantity is used
>
> EXAMPLES - The Examples of Sections 17.7 and 17.9 apply.
>
> NOTE - The reference quantity is a **metrological unit** (S.18.12).

17.17 Depending on whether division between values is allowed or not, the first specific concept is

<u>**differential unitary quantity-value scale**</u>
differential quantity-value scale
differential unitary scale of values of quantities
differential scale
unitary quantity-value scale (S.17.16) on which comparison by subtraction applies

NOTE - The Examples and Notes of Section 17.7 apply.

17.18 The coordinate concept is

<u>**rational unitary quantity-value scale**</u>
rational quantity-value scale
rational unitary scale of values of quantities
rational scale
unitary quantity-value scale (S.17.16) on which comparison by division applies

NOTE - The Examples and Notes of Section 17.9 apply.

17.19 In practice, it is likely that the ¦abbreviated terms will be preferred to the ¦systematic terms despite the more informative nature of the latter.

17.20 The concepts defined in this Chapter are shown as a ¦concept diagram in Figure 17.20 which is homologous to those for <property> (Fig. 12.21), <examination procedures> (Fig. 14.7), <examination> (Fig. 15.17), and <property value> (Fig. 16.15).

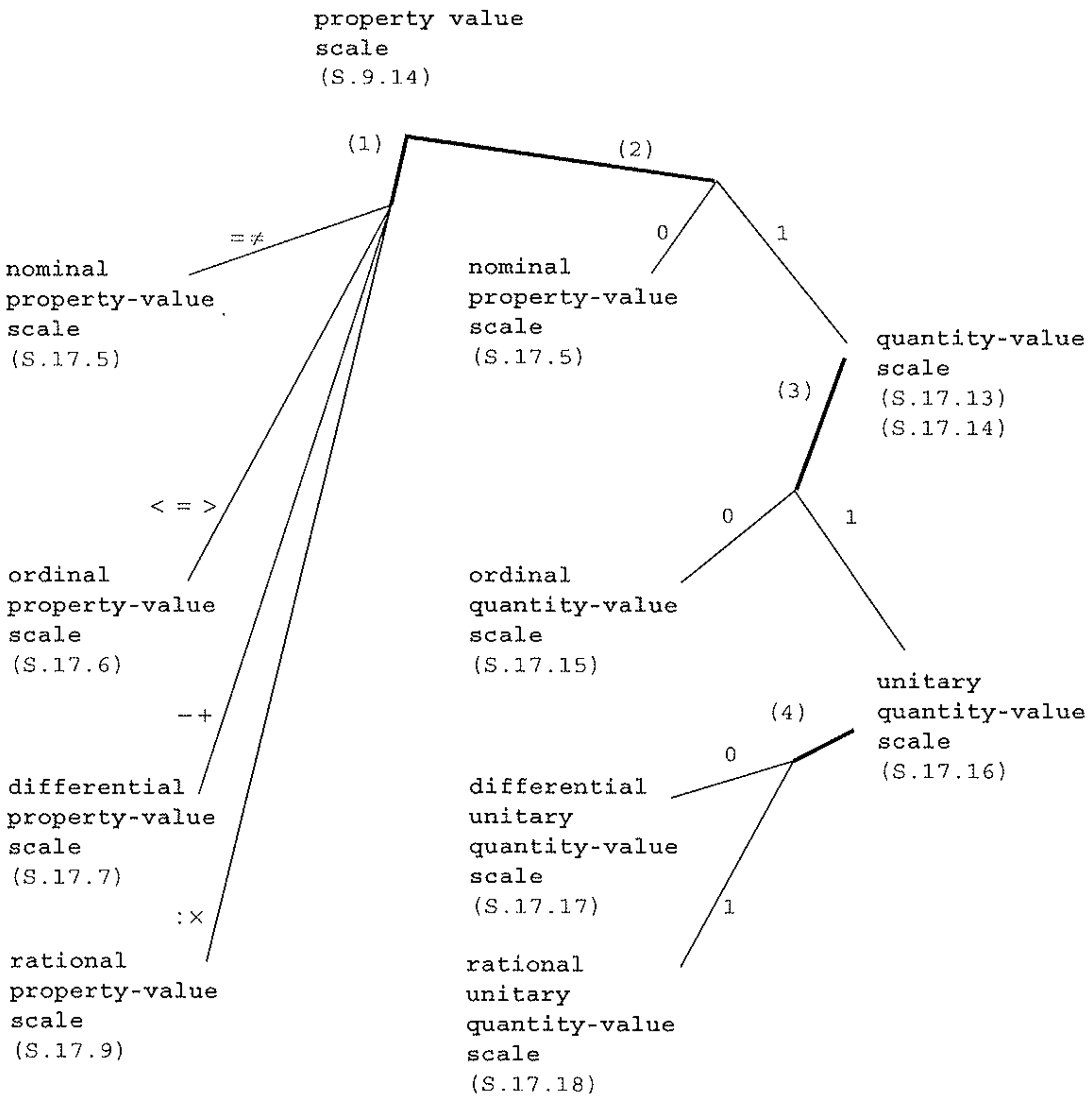


Figure 17.20 Pluridimensional ˡgeneric ˡconcept diagram on <property value scale> (S.10.14) according to two and four levels (cf. Figs 12.21, 14.7, 15.17, and 16.15).

Terminological dimension (S.2.19)
(1) having an algebraic comparison between property values (S.9.15) (cf. Tabs 17.4, 17.11);
(2) having a magnitude of property value (S.9.15);
(3) having a "metrological unit" (S.18.12);
(4) having a rational magnitude of property values;

0 = no; 1 = yes
ˡConcepts paired on the same horizontal line have identical ˡextensions.

17.21 The *VIM3* defines the concept

conventional reference scale: quantity-value scale defined by formal agreement [132-1.29]

which can be a further characterization of any of the concepts mentioned from Sections 17.6 to 17.9.1 and 17.13 to 17.18.

17.22 The concepts termed and defined in this Chapter have no requirements as to source of values and their arrangement on the scale. In relation to "examination procedure" (S.7.3) and "examination" (S.8.4), including "measurement procedure" (S.14.4.3 or 14.4.4) and "measurement" (S.15.14.1 or 15.14.2) respectively, as well as their generic divisions, it may be useful to specify the scale accordingly.

By prefacing with the modifier 'true' or 'examined' in terms of the coordinate specific concepts in Sections 17.5-6-7-9, a pair of specific concepts based on "true property-value scale" (S.10.16.1) and "examined property-value scale" is formed from each of the four. The same applies to "quantity value scale" defined in Section 17.13 and 17.14, the latter with its generically subordinate four concepts (S.17.15-16-17-18). The term 'examined property-value scale' is generally shortened to 'measurement scale' or 'scale of measurement', but one should beware of homonymy (cf. S.17.11).

18 MIXED CONCEPT SYSTEM on <METROLOGICAL UNIT> and <system of metrological units>; the metrological unit "one" and SI units revisited

'Für die Entscheidung über die jeweils für Grösse oder Einheit zu wählende Definition ist nicht die Fragestellung "richtig oder falsch", sondern die Alternative "zweckmässig oder unzweckmässig" bestimmend: Grösseneinführung und Einheitenfestlegung unterliegen weitgehend der Konvention.'

Ulrich Stille, 1961 [116]

<METROLOGICAL UNIT>

18.1 As was mentioned in the Historical introduction (Ch.1), the unequivocal recording, communication, and comparison of examination results (S.16.20) need at least one conventionally accepted reference for each kind-of-property (S.6.19). The reference can be, e.g., a series of pictures for taxonomic classification of blood cells, i.e. a nominal examination (S.15.10) with a nominal property-value scale (S.17.5); or a standardized examination procedure (S.7.3) giving colour change of a dip-stix for magnitude of urinary albumin concentration, i.e. an ordinal examination (S.15.11) with an ordinal property-value scale (S.17.6 or 17.15) in the form of numbers corresponding to increasing amount-of-substance concentrations.

18.2 The important jump in the understanding and use of magnitude occurred, however, when so-called units of measurement were introduced in communities to aid commerce, agriculture, and building, such as in Mesopotamia millenia ago. Then, measurement results (S.16.21) could be expressed on a differential property-value scale (S.17.7 or 17.17) or a rational property-value scale (S.17.9 or 17.18), each with a series of possible unitary quantity values (S.16.10) in the form of multipla of one given metrological unit (S.18.12).

18.3 The further evolution consisted in defining a system comprising a convenient set of base unitary kinds-of-quantity (S.13.9) with corresponding base metrological units (S.18.15) and algebraically derived kinds-of-quantity (S.13.3.1) with corresponding coherent derived metrological units (S.18.19) [6-pp.103-110, 29-pp.19]. The immense number of possible structures [e.g. see 34] is illustrated here by four important sets of base metrological units, all related to "length" - "mass" - "time", namely

"foot" - "pound" - "second"	(FPS system)
"centimetre" - "gram" - "second"	(CGS system)
"metre" - "tonne" - "seconde"	(MTS system)
"metre" - "kilogram" - "second"	(MKS system)

which have all been used in mechanics and where the latter set is subsumed under the current winner, the *International System of Units, SI* (for Système international d'unités (fr)) [6, 29-pp.21-41].

18.4 The embryonic version of the SI was defined 1875 and consisted of the following two SI base units for the corresponding base kinds-of-quantity.

"length"	"metre"
"mass"	"kilogram"

Subsequent additions have led to the present set of seven pairs [6].

"length"	"metre"
"mass"	"kilogram"
"time"	"second"
"electric_current"	"ampere"
"thermodynamic_temperature"	"kelvin"
"amount_of_substance"	"mole"
"luminous_intensity"	"candela"

18.5 A formal definition of "unit" was hardly considered by the early authors; the ˡconcept and ˡterm were just used naturally. However, *James Clerk Maxwell* in *A treatise on electricity and magnetism* from 1873 [99] said that one of the two factors or components comprised in every *expression of a quantity* is 'the name of a certain known quantity of the same kind as the quantity to be expressed, which is taken as a standard of reference. The other component is the number of times the standard is to be taken in order to make up the required quantity. The standard is technically called the Unit, and the number is called the Numerical Value of the quantity.' From these quotes one may fashion the following term and definition of a ˡgeneral concept.

unit: quantity that is taken as a standard of reference for other quantities of the same kind-of-quantity [paraphrase on 99]

18.6 Many authors writing about units appear to assume that "unit" is a primitive [e.g. 5, 34, 45[3] ½, 56, 57, 124] or they just state that a unit is a (reference) quantity (S.12.13, 12.14) [40, 92].

18.6.1 *Stille* gave the textual description of "Einheit" as '...gleichartig[en] und zahlenwertmässig bekannten oder definierten Äusserungen des phy-

[3] In a footnote of this paper from 1951, *Fleischmann* incorrectly quotes a correct, rather free German translation of *Maxwell*'s treatise (see Section 18.5) by saying that a unit is a 'Qualität' (quality) - rather than calling it a 'Quantität'.

sikalischen Geschehens ...' [116-1.2], that is a

> *unit*: manifestation of the physical phenomenon that is numerically known or defined and of the same kind-of-quantity [as that of the perceived manifestation to be compared] [translated from 116-1.2].

18.6.2 *Fleischmann* said that a unit is 'ein aussgewählter Grössenwert, der für alle Grössen gleicher Dimension verbindlich ist (also auch für alle Sachgrössen!)' [47-3] that is

> *unit*: selected value of a quantity that is bound to all kinds-of-quantity of the same dimension (and consequently also to all instantiated quantities!) [translated from 47-3]

18.6.3 This view of "unit" is still reflected in the *DIN 1313:1998* by the ultrashort definition of

> *unit of measurement*: positive quantity value selected by convention [33-4.1]

This definition and that of *Fleischmann* seem to claim that a unit is a value of a quantity (S.16.7, 16.8) rather than a special quantity, and that is not generally accepted. (In the present text, "value" and "quantity" are in associative relation (Fig. 9.25)).

18.6.4 *Bunge* did not define "unit" formally, but distinguished between the *concept* of unit for the so-called conceptual scale and a *material* unit for the material scale [15-p.224], i.e. general concept and instance. In a later paper on *A mathematical theory of the dimensions and units of physical quantities* [16-2.1], he averred (in his usual sweeping style) that 'The concept of a unit is one of those scientific notions that has remained obscure for want of a theory and excess of a coarse philosophy' - a reason being confusion between "unit", "metrological dimension", and "measurement standard". *Bunge* required that the concept be 'theoretical' - presumably meaning 'mathematical' - and should be 'embedded in definite algebraic structures sanctioning the usual operations among units and among units and numbers'. He rightly pointed out that units are conventional, freely chosen, but need to be in accordance with some basic theory and theoretical formulas between kinds-of-quantity as well as to be practical in a certain field. The concept "unit" was explained in terms of mathematical axioms and definitions, not explicitly, but it was said that 'every physical system, whether simple or complex, is characterized by properties representable as real functions, and the values of those functions depend not only on the system itself but also on the units that have been adopted conventionally' [16-2.2].

18.6.5 In the excellent review by *de Boer, On the history of quantity* *calculus and the International System*, he stated that 'in quantity calculus the concept "unit", through its definition [by *Maxwell*] as a special reference quantity, has all the properties [read 'characteristics'] of the concept "quantity" itself' [30-2.1.2]. Like *Bunge*, he distinguished between the symbolic expression for the unit called 'unit', $[Q]$, used by theoreticians in quantity calculus based on mathematical models, and a 'unit standard', Q°, used by the pragmatists for a unit realized by a physical system for which the numerical value $\{Q\} = 1$. The theoretical expression is

$$Q = \{Q\} \cdot [Q]$$

whereas the outcome of a measurement of a concrete quantity, Q^{*}, is generalized as

$$Q^{*} \ (=) \ \{Q\} \ (\times) \ Q^{\circ}$$

where the round brackets, (), indicate doubt about the use of the operators in the designation of real situations. Although the meaning of "unit" was amply discussed with quotations from *Maxwell*, *de Boer* gave no explicit definition.

18.7 An explicit definition, however, is given by the *VIM3* as follows.

> *measurement unit*; unit of measurement; unit: real scalar quantity, defined and adopted by convention, with which any other quantity of the same kind can be compared to express the ratio of the two quantities as a number [132-1.9]

The concept is meant to be a general one, having many realizations in its extension.

18.7.1 The US National Committee for Clinical Laboratory Standards (*NCCLS*) (now Clinical and Laboratory Standards Institute, CLSI)), besides quoting the *VIM2* definition, also offers

> *unit*: chosen reference quantity, which may be used for comparison of quantities of the same dimension [105]

This wording is different from that of *VIM3* (S.18.7) where it is not enough that the two quantities be of the same metrological dimension; identical kinds-of-quantity are also necessary. (See, however, Section 18.8.8.)

18.8 From the above definitions and descriptions, the following characteristics of "unit" may be derived.

18.8.1 The concept is a general one with numerous specific concepts distributed over all historical periods and kinds-of-quantity as isolated concepts or members of a system of metrological units (S.18.27).

18.8.2 "Unit" is a specific concept under "property" (S.5.5), more particularly under "quantity" (S.12.13 or 12.14), and finally under "unitary quantity" (S.12.17).

18.8.3 "Unit" is not related to "ordinal quantity" (S.12.16) ('ordinal property') - except in the view presented in Section 12.8.1 - only to "unitary quantity" (S.12.17) and thus also by inheritance to "differential unitary quantity" (S.12.19) and "rational unitary quantity" (S.12.20) (with synonyms 'differential property' and 'rational property' respectively).

18.8.4 A unit has a standard magnitude, generally with an associated uncertainty of definition, which is often neglected.

18.8.5 The magnitude of a given unit is chosen by convention, usually so that its (representative) ¦numerical unitary quantity value (S.16.16) is =one in a given system of units or under defined circumstances of measurement (S.15.14.1).

18.8.6 A given unit is a specific concept under its appropriate unitary kind-of-quantity (S.13.3.3).

18.8.7 A unit, being a unitary quantity, may have a ¦metrological dimension (S.19.22), but only if the unit is a member of a system of units.

18.8.8 A unit and its parent unitary kind-of-quantity naturally have the same metrological dimension, if they are members of corresponding systems of unitary kinds-of-quantiy and of units. A given metrological dimension, however, may characterize more than one unitary kind-of-quantity [95] and it may be claimed that their corresponding units (of the same magnitude) are different, but happen to have the same designation. This viewpoint seems to be in accordance with Note 2 to the *VIM3* entry of "measurement unit" as follows. 'Measurement units of quantities of the same quantity dimension may be designated by the same name and symbol even when the quantities are not of the same kind [132-1.9].' This is a ¦polysemous practice, which can be ambiguous if the unitary kind-of-quantity is not mentioned in the ¦appellation of a measurand (S.5.8). It should be added that the *BIPM* is not in agreement, saying that 'in some cases the same SI unit can be used to express the values of several different quantities' [6-p.106 with reference to p.119]. *Bunge* also stated that 'Magnitudes with the same dimension shall be reckoned and measured with the same basic unit' [15-p.224].

EXAMPLES 1

1 "amount-of-substance content" = "amount of substance of component" divided by "mass of system", n_B/m_{Sy}, and "molality" = "amount of substance of solute" divided by "mass of solvent", n_B/m_{So}. Both have the unit "mole per kilogram", but are different rational unitary kinds-of-quantity (S.13.3.5) which cannot be added.

2 A large number of various unitary kinds-of-quantity of metrological dimension 1 all use the unit "one".

3 Further examples are found in the *IUPAC/IFCC's The Silver Book* [86], distributed by metrological dimension.

Such 'different' units of the same metrological dimension should not be distinguished by specifications to term and symbol. Sometimes, however, special terms are created to separate the equidimensional units or the various uses of the same unit.

EXAMPLES 2

1 Metrological dimension Θ

"thermodynamic temperature", "kelvin" (but = "degree Celsius")
"Celsius temperature", "degree Celsius" (but = "kelvin")

2 Metrological dimension $T^{-1}N$

"amount-of-substance rate", "mole per second"
"catalytic activity" (which expresses an amount of catalyst), "katal" = "mole per second"

3 Metrological dimension L^2MT^{-2}

"energy", "joule"
"work", "watt second"
Both units are equal to "kilogram square metre per second squared".

4 Metrological dimension 1

"plane angle", "radian"
"mass fraction", "kilogram per kilogram"
"logarithmic ratio quantity", "neper"
These three units are equal to "one".

All the terms for metrological units mentioned in these examples are accepted by the *General Conference on Weights and Measures (CGPM)*.

This widespread practice of associating a special term for a unit with a certain unitary kind-of-quantity should not be coupled with omission of the term for the latter in the appellation of a measurand. Sadly to say, the sage admonition by the *BIPM* that 'It is therefore important not to use the unit alone to specify the quantity.' [6-p.119] is often not followed.

18.9 The reason for defining a metrological unit obviously is to be able to express and consequently compare the magnitudes of instances of unitary quantities of the same kind-of-quantity and to perform arithmetical calculations between their numerical unitary quantity values (S.16.16).

18.10 There can be no doubt from the above set of characteristics that "unit" has all the characteristics of "unitary quantity" which should be the genus proximum. The magnitude chosen by convention is an ꜝessential characteristic (S.18.8.4, 18.8.5). Not all units have metrological dimensions (S.18.8.7), so that is a non-essential characteristic. The use of units (S.18.9) is an essential characteristic.

18.11 The ꜝword 'unit' has several dictionary meanings [e.g. 1, 126] although they generally concern an entity regarded as an individual thing. Even if the ꜝsingle term 'unit' has been used extensively and for a long time in documents of a metrological nature, for example by *Maxwell* [99], *Guggenheim* [56], *Stille* [116], *Bunge* [16], and the *BIPM* [6], as well as in common language, there is sometimes felt a need to specify the restricted metrological meaning. To this end the *VIM3* uses 'measurement unit', but here the derivation from 'metrology' is preferred.

18.12 As an outcome of this discussion it is possible to devise the following term and definition.

<u>metrological unit</u>
measurement unit
unit
unitary quantity (S.12.17) of a conventional magnitude that is used as a multiplicable reference in expressing the magnitudes of other unitary quantities of the same **unitary kind-of-quantity** (s.13.3.3)

NOTE 1 - A metrological unit and its unitary kind-of-quantity have the same ꜝmetrological dimension if they are members of a corresponding **system of metrological units** (S.18.27) and **system of unitary kinds-of-quantity** (S.13.7) respectively.

NOTE 2 - The ꜝterm of a given metrological unit does not unequivocally indicate a corresponding unitary kind-of-quantity.

NOTE 3 - The modifier 'metrological' in the term is generally omitted when this is permitted by the context.

NOTE 4 - Metrological units are usually given conventionally assigned symbols, such as 'mol' for "mole" and 'Pa' for "pascal" ($= 1\ m^{-1} \cdot kg \cdot s^{-2}$).

18.13 As mentioned in Sections 13.6 and 18.2, the description of properties of The Universe is greatly aided by forming corresponding systems of unitary kinds-of-quantity (S.13.7) and of metrological units allowing kind-of-quantity calculus [30] and homologous numerical unitary quantity value equations. In such a corresponding pair of systems, a few unitary kinds-of-quantity are conventionally considered to be metrological-dimensionally independent of each other whereas the rest are derived from them. The first group are here called 'base unitary kinds-of-quantity' (S.13.9), the second 'derived unitary kinds-of-quantity' (S.13.11).

18.14 The former *VIM2* had an ambiguous definition of "base unit (of measurement)", unintentionally allowing several base units for a given base unitary kind-of-quantity. The *VIM3* has the entry

> *base unit*: measurement unit that is adopted by convention for a base quantity [132-1.10]

which formally speaking still does not exclude conventionally choosing more than one base unit in a given system, although this is explicitly excluded in a Note 1, but only for a coherent system of units (S.18.29).

18.15 In the present context, therefore, the following term and more specific definition are proposed.

> <u>base metrological unit</u>
> base unit
> unique and conventionally chosen **metrological unit** (S.18.12) for a **base unitary kind-of-quantity** (S.13.9)
>
> EXAMPLES 1 - The base metrological unit of "length" is "metre" in the ¦International System of Units (SI) (S.18.33.2) and "centimetre" in the CGS system of units (in spite of the factor "centi" in the ¦term of the latter).
>
> NOTE 1 - Some derived unitary kinds-of-quantity (S.13.11), however, have a **coherent derived metrological unit** (S.18.19) with the same ¦term and **metrological dimension** (S.19.22) as those of the base metrological unit.
>
> EXAMPLES 2 - In the SI, the coherent derived metrological unit of "areic volume" is "cubic metre" divided by "square metre", equal to "metre", which ¦term is indistinguishable from that of the base metrological unit of "length".
>
> (cont.)

(cont.)
NOTE 2 - The term of the *SI* base metrological unit for "mass", "kilogram", contains the prefix 'kilo' = 10^3 for historical reasons. Terms for multiples or submultiples of kilogram are constructed, however, by adding **SI prefixes** (S.18.31) to the term 'gram'. Thus, = one millionth kilogram should be expressed as = 1 milligram, not = 1 microkilogram.

18.15.1 Both this definition and that of *VIM3* (S.18.14) invoke a system of quantities by inheritance; in the proposed definition substitution of the phrase 'base unitary kind-of-quantity' by its definition (S.13.9) gives

base metrological unit: unique and conventionally chosen metrological unit for a unitary kind-of-quantity, in a system of unitary kinds-of-quantity, that is conventionally chosen to be algebraically independent of all others

18.15.2 In a given system of unitary kinds-of-quantity, the base unitary kinds-of-quantity by convention are metrological-dimensionally independent of each other. The same applies to their corresponding base metrological units. By contrast, the *definition* of a given base metrological unit may require other such units.

EXAMPLE - In the SI, '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 these conductors a force equal to 2×10^{-7} newton per metre of length.' [*CIPM* 1946, Resolution 2, ratified by the 9th *CGPM* 1948, ref.6-p.96].

18.16 A coordinate specific concept to "base metrological unit", comprising non-base units, is given by the *VIM3* as

derived unit: measurement unit for a derived quantity [132-1.11]

18.16.1 This definition includes non-coherent units for derived quantities. So, the *VIM3* defines "coherent derived unit" separately (S.18.18).

18.17 Here, the term and definition are proposed as follows.

derived metrological unit
derived unit
metrological unit (S.18.12) for a **derived unitary kind-of-quantity** (S.13.11) that is expressed as a product of powers of **base metrological units** (S.18.15) and a proportionality factor

EXAMPLES 1 - "kilometer"; "mole per second"; "millimole per cubic metre"; "one per thousand"

NOTE 1 - This definition includes such a derived metrological unit as "millimetre" for "rainfall", reduced from, e.g., "one thousandth cubic metre per square metre, 10^{-3} m^3/m^2, for "volume per area".

NOTE 2 - Some derived metrological units have special terms conventionally related exclusively to respective **unitary kinds-of-quantity** (S.13.3.3).

EXAMPLES 2
"kilogram square metre per second squared": 'joule', J, for "energy" in the SI

"reciprocal second": 'hertz', Hz, for "frequency of a regular periodic phenomenon"

"reciprocal second": 'bequerel', Bq, for "radioactivity of a nuclide"

"mole per second": 'katal', kat, for "catalytic activity"

"one": 'radian', rad, for "plane angle"

18.18 A subset of derived metrological units comprises those that are products of powers of base metrological units only, defined by the *VIM3* as

> *coherent derived unit*: derived unit that, for a given system of quantities and for a chosen set of base units, is a product of powers of base units with no other proportionality factor than one [132-1.12]

The *BIPM* text states that the modifier 'coherent', describing a set of units, 'is used here in the following sense: when coherent units are used, equations between the numerical values of quantities take exactly the same form as the equations between the quantities themselves' [6-1.4].

18.19 In the present context the term and definition become

<u>**coherent derived metrological unit**</u>
coherent derived unit
derived metrological unit (S.18.17) that has a proportionality factor of one

EXAMPLES 1 - "one"; "kilogram per mole" (even if the term 'kilogram' contains an **SI prefix** (S.18.31)); both in the International System of Units (S.18.33.2)

NOTE 1 - Coherency is defined on the **base metrological units** (S.18.15) of a given **system of metrological units** (S.18.27).

EXAMPLES 2 - "kilogram per cubic metre" is a coherent derived metrological unit in the SI, but not in the CGS system, whereas the coherent derived metrologial unit "centimetre per second" in the CGS is not coherent in the SI.

NOTE 2 - Equations between **numerical unitary quantity values** (S.16.16), expressed in coherent derived metrological units, and equations between the corresponding **unitary kinds-of-quantity** (S.13.3.3) have the same form, including numerical factors.

NOTE 3 - This definition includes such a coherent derived metrological unit as "metre" for "<u>rainfall</u>", see also Section 18.17, Note 1.

NOTE 4 - Within the "International System of Units, SI" (S.18.33.2) the term 'coherent derived unit' is used with the same meaning as here, but the "set of coherent SI units" is said to comprise both 'base and coherent derived units of the SI' (6-1.4).

The *VIM3*'s mention of 'product of powers of base units' (S.18.18) is here inherited from the definition of "derived metrological unit" (S.18.17).

18.20 The ¦coordinate concept to "coherent derived metrological unit" is

> <u>non-coherent derived metrological unit</u>
> non-coherent derived unit
> **derived metrological unit** (S.18.17) that has a proportionality factor different from one
>
> EXAMPLES - "kilometre"; "millimole"; "thousand"; but not "kilogram"; all in the ¦International System of Units (S.18.33.2)

18.21 A given metrological unit may be too small for convenient expression of the numerical unitary quantity values of measurement results (S.16.21). The *VIM3*, therefore, defines

multiple of a unit: measurement unit obtained by multiplying a given measurement unit by an integer greater than one [132-1.17]

18.22 The following is in accordance with *VIM3*.

> <u>multiple of a metrological unit</u>
> multiple of a unit
> **metrological unit** (S.18.12) obtained by multiplying a given metrological unit by an integer greater than one
>
> NOTE 1 - All the **SI prefixes** (S.18.31) are decimal multiples (or submultiples).
>
> EXAMPLES 1 - "kilometre"; "megagram"; "kilobequerel per kilogram" (even if the ¦term 'kilogram' contains an SI prefix).
>
> NOTE 2 - In the ¦International System of Units (S.18.33.2), the 'given metrological unit' is a **base metrological unit** (S.18.15) or a **coherent derived metrological unit** (S.18.19).
>
> NOTE 3 - The multiple of a given metrological unit usually is, but does not have to be, an **in-system metrological unit** (S.18.34.2). In the case of an **off-system metrological unit** (S.18.34.1), the use of SI prefixes is not recommended.
>
> EXAMPLE 2 - "sixty seconds" termed 'minute'
>
> (cont.)

(cont.)
NOTE 4 - The multiples and submultiples of SI base metrological units and of SI coherent derived metrological units (S.18.19) can now be designated 'SI units' [6-p.106][4].

18.23 The coordinate concept for a smaller unit than a given metrological unit is given by the *VIM3* as

submultiple of a unit: measurement unit obtained by dividing a given measurement unit by an integer greater than one {[132-1.18]

18.24 The proposed version is analogous.

<u>submultiple of a metrological unit</u>
submultiple of a unit
metrological unit (S.18.12) obtained by dividing a given metrological unit by an integer greater than one

EXAMPLES - "micrometre"; "millimole per cubic metre"

Sections 18.22, Notes 1, 2, 3, and 4 apply analogously.

NOTE - The definitions in Sections 8.21 to 8.24 allow the outcome metrological unit to be a base metrological unit (S.18.15), e.g. mm × 10^3 = m.

<SYSTEM OF METROLOGICAL UNITS>

18.25 Homologously to unitary kinds-of-quantity, metrological units are linked together in systems, and the *VIM3* has the definition

system of units: set of base units and derived units, together with their multiples and submultiples, defined in accordance with given rules, for a given system of quantities [132-1.13]

18.26 The characteristics of "system of metrological units" are the following.

[4] See Section 18.32.

18.26.1 The metrological units are elements in a conventionally conceived *system* (S.3.3), which means that they are not just a set, but are related to each other.

18.26.2 The elements and relationships of a system of metrological units must correspond to those of a given system of unitary kinds-of-quantity (S.13.7).

18.26.3 The definition of a base metrological unit (S.18.15) is either related to an artefact or to a measurement method (S.7.2.2) involving a fundamental constant or both, allowing practical embodiments, i.e. instances. In any case, a definition strives to allow the smallest possible measurement uncertainty (S.16.24).

EXAMPLE 1 - The SI base metrological unit of "mass", '1. The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram;' [The 3rd *CGPM*, 1901 declaration, ref. 6-p.143]

EXAMPLE 2 - The SI base metrological unit of "amount_of_substance", '1. 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; its symbol is "mol". 2. 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.' [The 14th *CGPM*, 1971, Resolution 3, ref. 6-p.156]

18.26.4 The coherent derived metrological units are defined by algebraic equations involving multiplication and/or division of base metrological units.

EXAMPLE - For the derived unitary kind-of-quantity "amount-of-substance_concentration", defined as "amount_of_substance" of component divided by "volume" of system, the coherent derived metrological unit is defined as "mole per cubic metre".

18.26.5 A system of metrological units may include multiples and submultiples of base and coherent derived metrological units.

18.27 The following term and definition are proposed.

<u>system of metrological units</u>
system of units
¦set of **metrological units** (S.18.12) with interrelations according to the defining algebraic equations of a given **system of unitary kinds-of-quantity** (S.13.7) and a set of proportionality factors

NOTE - A system of metrological units - such as the ¦International System of Units, SI (S.18.33.2), the CGS systems of units, and the FPS system of units - comprises **base metrological units** (S.18.15) and **coherent derived metrological units** (S.18.19), and may include **multiples of metrological units** (S.18.22) and **submultiples of metrological units** (S.18.24).

18.28 The specific form of "system of metrological units" comprising only base and coherent derived metrological units is given the following *VIM3* definition.

> *coherent system of units*: system of units, based on a given system of quantities, in which the measurement unit for each derived quantity is a coherent derived unit [132-1.14]

The *BIPM* uses the term 'coherent SI units' for the set of base and coherent derived units [6-1.4].

18.29 In the present context, the following is proposed.

<u>coherent system of metrological units</u>
coherent system of units
system of metrological units (S.18.27) comprising **base metrological units** (S.18.15) and **coherent derived metrological units** (S.18.19)

EXAMPLE - The base metrological units, coherent derived metrological units, and their relations of the ¦International System of Units, SI (S.18.33.2)

NOTE - The "kilogram", which is an SI base metrological unit, has the factor "kilo" in its ¦term for historical reasons.

18.30 The concept "SI unit" is not defined explicitly by the *BIPM* [6], the *VIM3* [132], or the *ISO* [64]. However, as the term is much used (and abused), the following may be found useful.

> <u>SI unit</u>
> unit of the SI
> **metrological unit** (S.18.12) adopted by the *General Conference on Weights and Measures (CGPM)*
>
> NOTE 1 - Formerly, the decimal **multiples of metrological units** (S.18.22) and **submultiples of metrological units** (S.18.24) of the SI were not considered to be **SI units** by the *CGPM*, but the *ISO 31* suggested that they should be 'added to the coherent system within the framework of the SI' [64-31-0-2.3.2.3] and the *BIPM* now includes them in the International System of Units (6-1.4). (Cf. also S.18.32.)
>
> NOTE 2 - The *World Health Organization* recommends by Resolution *WHA30.39*, 1977-05 the preferred use of SI units in medicine and especially those involving the mole rather than mass units. The theory and practice of the SI is excellently presented in a booklet [128].

NOTE - Inasmuch as the symbol 'SI' means 'International System of Units' (S.18.33.2), the term 'SI unit' by substitution renders an awkward phrase. The correct term would be 'unit of the SI', but the inverse sequence has become idiomatic in metrology. The problem does not arise in French where the term is 'unité SI'.

18.31 There are two ways to avoid many insignificant zeroes in the numerical unitary quantity values (S.16.16). The first is to give each size of metrological unit a completely separate term.

EXAMPLES
"<u>time</u>" (duration) is expressed in "second"; 60 seconds = 1 "minute"; 60 minutes = 1 "hour"; 24 hours = 1 "day" - all factors being multipla of 12.
"<u>volume</u>" may be expressed in "litre" = one thousandth of a "cubic metre".

The second option is to combine numerical factors with the term or symbol for a metrological unit, thereby creating a new unit. With the SI, decimal factors are used to form non-coherent derived metrological units (S.18.20). The designations of such factors, both terms and symbols, are adopted by the *CGPM* [6-p.121-Tab.5].

The concept "SI prefix" is much used but not defined by the *BIPM*. Consequently, the following is suggested.

> <u>SI prefix</u>
> prefix placed at the beginning of the term for a **base metrological unit** (S.18.15) or a **coherent derived metrological unit** (S.18.19) of the **system of metrological units** (S.18.27), adopted by the General Conference on Weights and Measures (CGPM), to designate a defined decimal factor
>
> EXAMPLES - The current list of terms and symbols for SI prefixes stretches from yotta, Y = 10^{24}, to yocto, y = 10^{-24}, so that one prefix is usually sufficient and then mandatory.
>
> NOTE - The SI prefixes are not to be used with submultiples and multiples of the SI **coherent derived metrological unit** (S.18.19) "one", but can be used with special terms for "one", e.g. radian and neper.

18.32 The statement in the 7th edition of the SI brochure that *SI units* comprise only the "coherent set of units", i.e. "SI base units" and "SI coherent derived units" was not generally understandable to practitioners of laboratory work, who felt that, e.g., the combination of the SI base metrological unit "mole" and the SI prefix "pico" to form the submultiple metrological unit "picomole" should naturally be an SI unit.

The problem was presented to the *Consultative Committee for Units (CCU)* of the *International Committee for Weights and Measures (CIPM)* by *Mills* in stating '... that the rigid restriction of the name "SI unit" to apply *only* to the *coherent* SI units is contrary to common usage, and moreover I believe that it is not a particularly useful meaning to impose on the words.' [103]. The *CCU* supported this view at its 14th Meeting 2001.

The *CCU* formally approached the *CIPM* which followed the advice in 2001 so that '"SI units" and "units of the SI" should be regarded as names that include both the base units and the coherent derived units, and also all units obtained by combining these with the recommended multiple and submultiple prefixes' [6-Appendix 1, p.166].

The proposed definition of "SI unit" (S.18.30) acccords with the new CIPM/BIPM position.

18.33 Regarding a definition of the "International System of Units", there are two authoritative sources.

18.33.1 A formulation can be derived from a Resolution 3 by the *International Committee for Weights and Measures* 1956 as follows.

> *Système International d'Unités*: system founded on the base units adopted by the 10th CGPM [followed by a list of the six base units comprised at that time, a list of two supplementary units, and a list of 27 coherent derived units with the statement that others might be added later]. [Paraphrase on 6-Appendix 1-p.148]

This is an ¦extensional definition which is somewhat unwieldy and needs periodical updating. For example the "mole" became a base unit in 1971 and the supplementary units became derived units in 1995. Furthermore, the coverage is now extended (S.18.32).

18.33.2 The *VIM3* has the ¦intensional definition

> *International System of Units; SI*: coherent system of units, based on the International System of Quantities, their names and symbols, including a series of prefixes and their names and symbols, together with rules for their use, adopted by the General Conference on Weights and Measures (CGPM) [132--1.16]

with a Note presenting a table of seven quantities (i.e. base unitary kinds-of-quantity) and the corresponding seven SI base units on which the SI is currently built (see Section 18.4). This must be considered the closest to a current official definition of the SI.

18.34 The *VIM3* offers the concept

> *off-system measurement unit*; off-system unit: measurement unit that does not belong to a given system of units [132-1.15]

where the term is self-explanatory. No coordinate specific concept of "in-system unit" is given.

For the sake of discussing and constructing concept systems, however, it may be convenient to define two specific coordinate concepts under metrological unit as follows.

18.34.1

<u>off-system metrological unit</u>
off-system unit
metrological unit (S.18.12) that is independent of a given **system of metrological units** (S.18.27)

EXAMPLES - "minute"; "hour"; "day" - all in relation to the SI (S.18.33.2) - and in spite of all being whole number, but non-decimal multipla of "second"

18.34.2

<u>in-system metrological unit</u>
in-system unit
metrological unit (S.18.12) that is a member of a given **system of metrological units** (S.18.27)

EXAMPLE - "second" is an in-system metrological unit of both the SI (S.18.33.2) and the CGS system.

18.35 The *BIPM* speaks of "units outside the SI" or "non-SI units" [6-4] listing them as shown in Table 18.35.

Table 18.35 Examples of metrological units (S.18.12) outside the *Internatiotional System of Units, SI* (S.18.33.2), according to the *BIPM* [6-pp.123-129]

Group	Value in SI unit (S.18.30)
Units used with the SI	
non-SI units accepted for use with the SI	minute = 60 seconds litre = 1 cubic decimetre
non-SI units accepted for use with the SI, whose values in SI units must be obtained experimentally	Dalton, unified atomic mass unit = 1.660 538 86(28) × 10^{-27} kilogram
other non-SI units currently accepted for use with the SI	bar = 10^5 pascal knot = 1 nautical mile per hour = (1852/3600) meter per second
Non-SI units associated with the CGS system of units	erg = 10^{-7} joule poise = 0.1 pascal second

THE METROLOGICAL UNIT "ONE"

18.36 In a system of metrological units, each unit of necessity has at least one term and usually also a symbol. In the SI, the terms are special for metrology with the exception of (the number) "one", symbol '1'. The SI considers this a coherent derived metrological unit (S.18.19) for all unitary kinds-of-quantity having the metrological dimension one, also called dimensionless unitary kinds-of-quantity [6-2.2.3]. Examples are "number of_entities", "entitic_number", "mass_fraction", "relative_time", "refractive_index", and "amount-of-substance_ratio"; many more examples may be found in, e.g., *The Silver Book* [86-Ch.8]. A few of these unitary kinds-of-quantity have special terms for the unit "one", such as "radian", rad, for "plane_angle", and "neper", Np, for a "logarithmic_ratio_quantity".

Except for the unitary kinds-of-quantity with such special terms for "one", numerical unitary quantity values of instantiated unitary quantities of metrological dimension one are customarily given as numbers without specifying the coherent metrological unit.

Furthermore, when the number of zeroes before or after the decimal sign becomes impractical, the *ISO* decrees that 'Decimal multiples and sub-multiples of the unit "one" are expressed by powers of ten. They shall not be expressed by combining the symbol 1 with a prefix.' [64-31-0-2.3.3]. It should be added that neither is the combination of the full prefix term and the term 'one'permitted.

EXAMPLES
700 000 may be written 0.7×10^6 or 700×10^3, but *not* 0.7 megaone, 0.7 M1, or 700 kiloone, 700 k1.

0.000 1 may be written 0.1×10^{-3} or 100×10^{-6}, but *not* 0.1 millione, 0.1 m1, or 100 microone, 100 μ1.

18.37 To avoid the problems with having to communicate powers of ten, especially orally, some unitary kinds-of-quantity allow the use of a redundant unit in the form of a quotient of two metrological units of the same metrological dimension different from one - giving a unit that in the SI is a power of ten, and of metrological dimension one.

EXAMPLE - "mass_fraction" in the units "kilogram per kilogram", kg/kg = 1 and "milligram per kilogram", mg/kg = 10^{-6}

This solution does not work with, e.g., "number_fraction", and "entitic number", where only numbers are involved.

18.38 Another much used solution, mostly for values below one, is a series of terms and symbols for submultiples of "one" as follows [104].

"per cent", % = 10^{-2}
also "parts per hundred", pph

"per mill", ‰ = 10^{-3}
also "parts per thousand", ppt

"parts per million", ppm = 10^{-6}; the symbol can be mistaken for "parts per milliard"

"parts per hundred million", pphm = 10^{-8}

"parts per billion", ppb = 10^{-9} (US); can be mistaken for 10^{-12} (Europe)

"parts per trillion", ppt = 10^{-12} (US); can be mistaken for 10^{-18} (Europe)

"parts per quadrillion", ppq = 10^{-15} (US); can be mistaken for 10^{-24} (Europe)

The *ISO* allows the first, "per cent", but deprecates the rest [64-31-0-2.3.3]. The BIPM allows '%' and even 'ppm' for "parts per million" [6-5.3.7] in spite of the fact that 'm' could be understood to mean "milliard" in Europe.

18.39 It would be both practical and consistent with the SI if the number "one", used as a metrological unit, were to be given a term by the *CGPM* so that SI prefixes could be attached as for other units. This is not least so for laboratory medicine where reports routinely contain results needing factors stretching from 10^{-12} to 10^{12}.

EXAMPLE - A usual number concentration of erythrocytes in human blood is 4.8×10^{12} per litre. Although a correct expression is 4.8 pl^{-1}, the understanding of "reciprocal picolitre" as a unit for a "number concentration" is hardly to be expected from most health care workers.

The problem has been discussed before and recent contributions are helpful.

18.40 *Mills*, in a paper entitled *Unity as a unit*, stated that 'the numeral 1 should be regarded as an SI unit', and continued that 'There is some question as to whether it should be thought of as a derived SI unit, or a base SI unit.' Perhaps the former where division between unitary quantities is involved and the latter for number of entities by counting [104]. Possible terms mentioned were 'heis', symbol I (classical Greek εἷσ, masculine for 'one') in the former case and 'item', symbol I, in the latter.

18.41 *Blackburn* stressed that "one" is a unit of measurement and 'a derived unit of the SI' [10] which should be associated with SI prefixes. For counted quantities, he suggested as a possible term 'entity', symbol ent, or 'item', symbol itm or it.

18.42 The International System of Units, in fact, simply lists '(the number) one' as the name of an SI [coherent] derived unit with symbol '1', and having the "refractive index" as an example of use [6-p.117, Table 2].

The *BIPM*, however, mentions also that for quantities representing a count 'the unit one may instead be regarded as a further base unit' [6-2.2.3].

18.43 The *Consultative Committee for Units* (*CCU* of the *International Committee for Weights and Measures, CIPM*) in 1998 recommended 'the adoption of the special name U or uno, symbol U, for the dimensionless derived unit one, for use with the SI prefixes to express the values of dimensionless quantities which are much greater or less than one.' [25-p.56].

Unfortunately, the *CIPM* subsequently only took note of this recommendation, urging 'wide examination of the proposal.'

Consequently, a background paper and proposal for the term 'uno', symbol 'u', was presented [134] - so far, unfortunately, with no response.

18.44 The concepts proposed in this Chapter around <metrological unit> are shown as a concept diagram in Figures 18.44a and 18.44b.

The latter Figure is drawn separately to avoid crossing lines in the former. The ᑊgeneric and ᑊpartitive concept system in Figure 18.44b is not the basis of the definitions proposed for the four specific concepts as "non-coherent metrological unit" and "coherent metrological unit" are not defined.

Figure 18.44a Mixed ᑊconcept diagram (supplemented by Figure 18.44b) on the ᑊconcepts around <metrological unit> discussed in this Chapter 18.

Terminological dimension (S.2.19)

(1) having a metrological unit (S.18.12);

(2) having a membership in a system of metrological units (S.18.27):

(3) having a conventional dependency of other units in a system of metrological units;

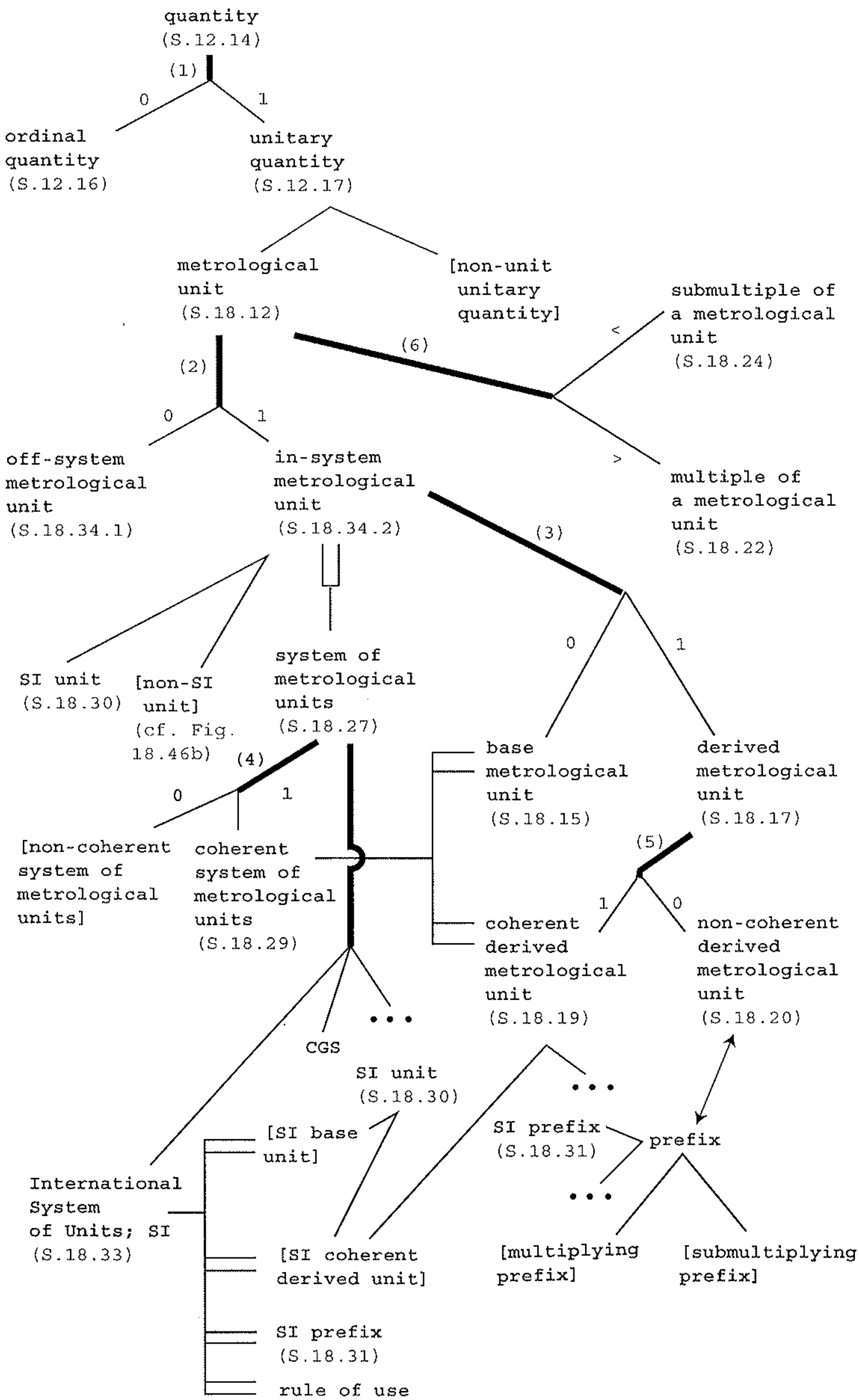
(4) having all proportionality factors equal to one;

(5) having a proportionality factor equal to one;

0 = no; 1 = yes

(6) having a proportionality factor different from one;

< = below; > = above


quantity
(S.12.14)
(1)
0
1
ordinal quantity (S.12.16)
unitary quantity (S.12.17)
metrological unit (S.18.12)
[non-unit unitary quantity]
submultiple of a metrological unit (S.18.24)
(6)
<
>
multiple of a metrological unit (S.18.22)
(2)
0
1
off-system metrological unit (S.18.34.1)
in-system metrological unit (S.18.34.2)
(3)
SI unit (S.18.30)
[non-SI unit] (cf. Fig. 18.46b)
system of metrological units (S.18.27)
0
1
base metrological unit (S.18.15)
derived metrological unit (S.18.17)
(4)
0
1
[non-coherent system of metrological units]
coherent system of metrological units (S.18.29)
(5)
1
0
coherent derived metrological unit (S.18.19)
non-coherent derived metrological unit (S.18.20)
CGS
• • •
SI unit (S.18.30)
• • •
SI prefix (S.18.31)
prefix
• • •
[SI base unit]
International System of Units; SI (S.18.33)
[SI coherent derived unit]
[multiplying prefix]
[submultiplying prefix]
SI prefix (S.18.31)
rule of use

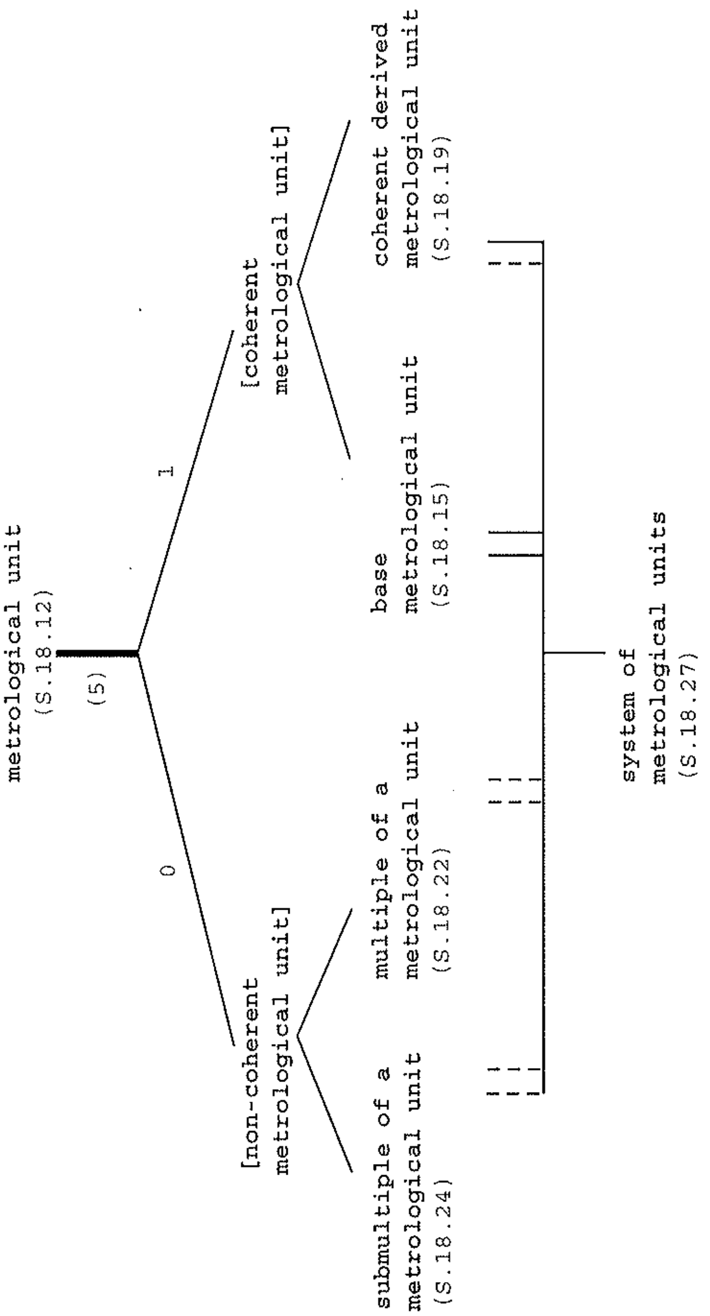


Figure 18.44b Mixed ¦concept diagram, supplementary to that of Figure 18.44a

Terminological dimension (S.2.19)
(5) <u>having a proportionality factor of one;</u>

0 = no; 1 = yes

18.45 As the concept diagram of Figure 18.44a shows a fairly complicated structure of relations, some definitions should be checked for external circularity. This is done in the form of Table 18.45a for "metrological unit" and in Table 18.45b for seven more concepts. It appears in each case that the defined concept in consecutive definitions, starting with those of the initial ¦definiendum, do not lead back to that concept.

Table 18.45a The ¦concept "metrological unit" (as ¦definiendum) in its definition (the ¦definiens) uses two concepts defined in this text; they are indicated by numbers in underlined heavy type. The definitions of these concepts use further defined concepts which for their part require reuse of some of the defined concepts - but not "metrological unit". The eight defining concepts are listed with serial numbers representing their sequential involvement in successive definitions, which could lead to an explicatory definition (S.11.9).

	Definiens							
Definiendum	unitary quantity (S.12.17)	quantity (S.12.13, 12.14)	property[a] (S.5.5)	system (S.3.3)	component (S.3.4)	unitary kind-of-quantity (S.13.3.3)	kind-of-quantity (S.13.3.1)	kind-of-property (S.6.19)
metrological unit	**<u>1</u>**	2	3	4, 6	5	**<u>7</u>**	8	9
(S.18.12)			10	11, 13	12			
			14	15, 17	16			
		18	19	20, 22	21			

[a]Not for S.12.14

Table 18.45b The sequential use of defining ˡconcepts from this text in the ˡdefinitions (ˡdefiniens) of seven concepts (ˡdefinienda) from this Chapter. The structure of each line corresponds to and is explained in Table 18,45a, with the exception that, in this Table for simplicity, the defining concepts in the definitions of "metrological unit" and unitary "kind-of-quantity" are not listed as they would not lead to circularity.
etc. indicates that continuation is found in an appropriate previous line for the concept given in the head.

Definiendum	Definiens: metrological unit (S.18.12)	base metrological unit (S.18.15)	derived metrological unit (S.18.17)	coherent derived metrological unit (S.18.19)	system of metrological units (S.18.27)	unitary kind-of-quantity (S.13.3.3)	base unitary kind-of-quantity (S.13.9)	derived unitary kind-of-quantity (S.13.11)	system of unitary kinds-of-quantity (S.13.7)
base metrological unit (S.18.15)	1					3, 5	2		4
derived metrological unit (S.18.17)	1, 11	10				3, 5, 7 9, 13, 15	6, 12	2	4, 8, 14
coherent derived metrological unit (S.18,19)			1 etc.						
non-coherent derived metrological unit (S.18.20)			1 etc.						
system of metrological units (S.18.27)	1					3			2
coherent system of metrological units (S.18.29)		2 etc.		3 etc.	1 etc.				
off-system metrological unit (S.18.34.1)	1				2 etc.				

SI UNITS REVISITED

18.46 The recent authoritative *BIPM* text on the SI [6] does not give formal definitions of all concepts related to units, but from the context it is possible to construct a concept system as shown in Figures 18.46a on <SI unit> and 18.46b on <non-SI unit>.

NOTE - The *BIPM* terms for metrological units subordinate to "SI unit" are formed in various ways such as 'base SI unit', 'SI base unit', and 'base units of/in the SI' [6]. Here, the modifiers will precede the fundamental term 'SI unit', e.g. 'coherent derived SI unit' rather than 'coherent SI derived unit'.

Comparing Figures 18.44a and b with Figures 18.46a and b, their structures are found different because the former is more general than the latter, which is focused on the SI.

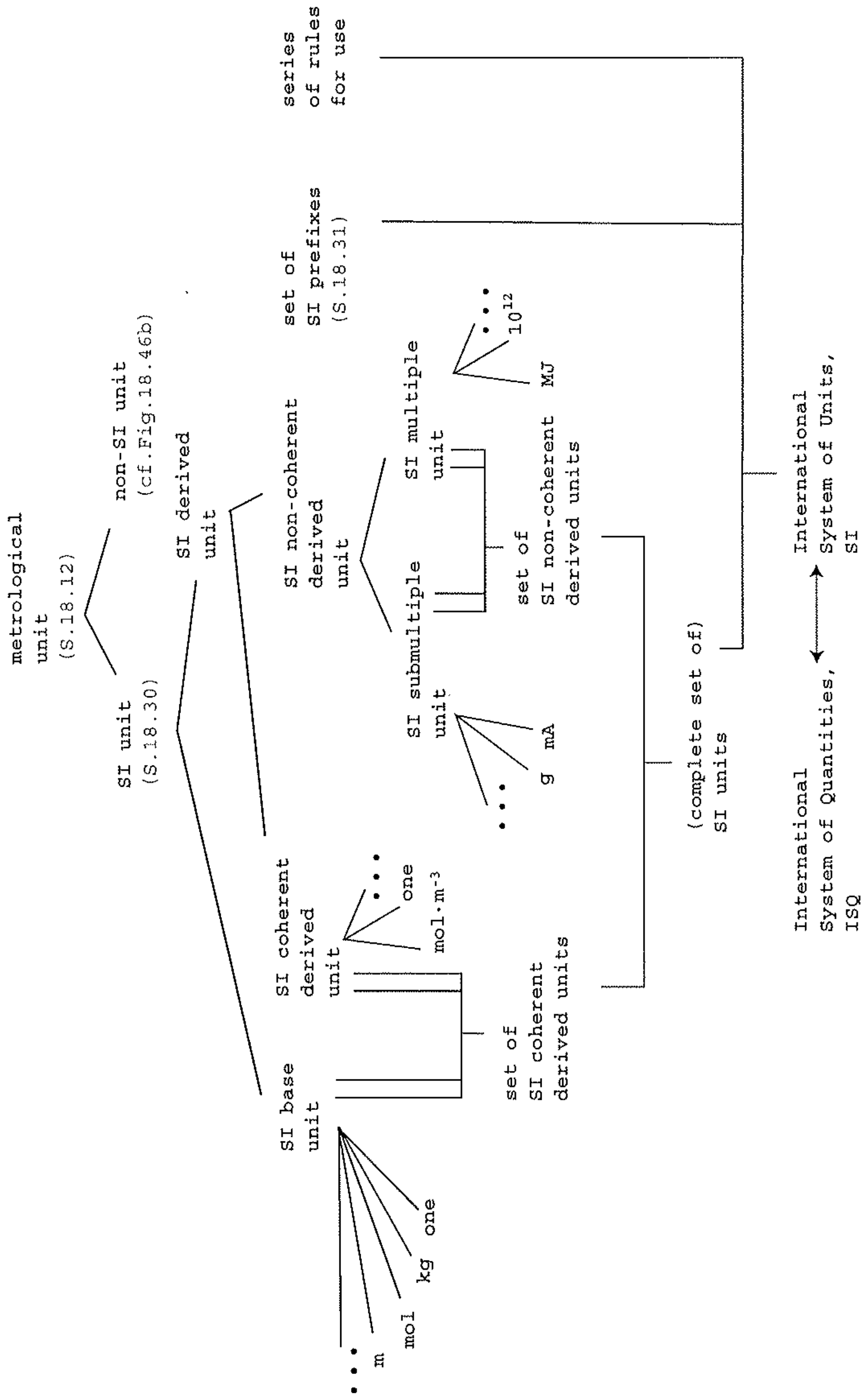


Figure 18.46a Mixed 'concept diagram on <SI unit> according to the text and tables of the '*International System of Units, SI* [6]

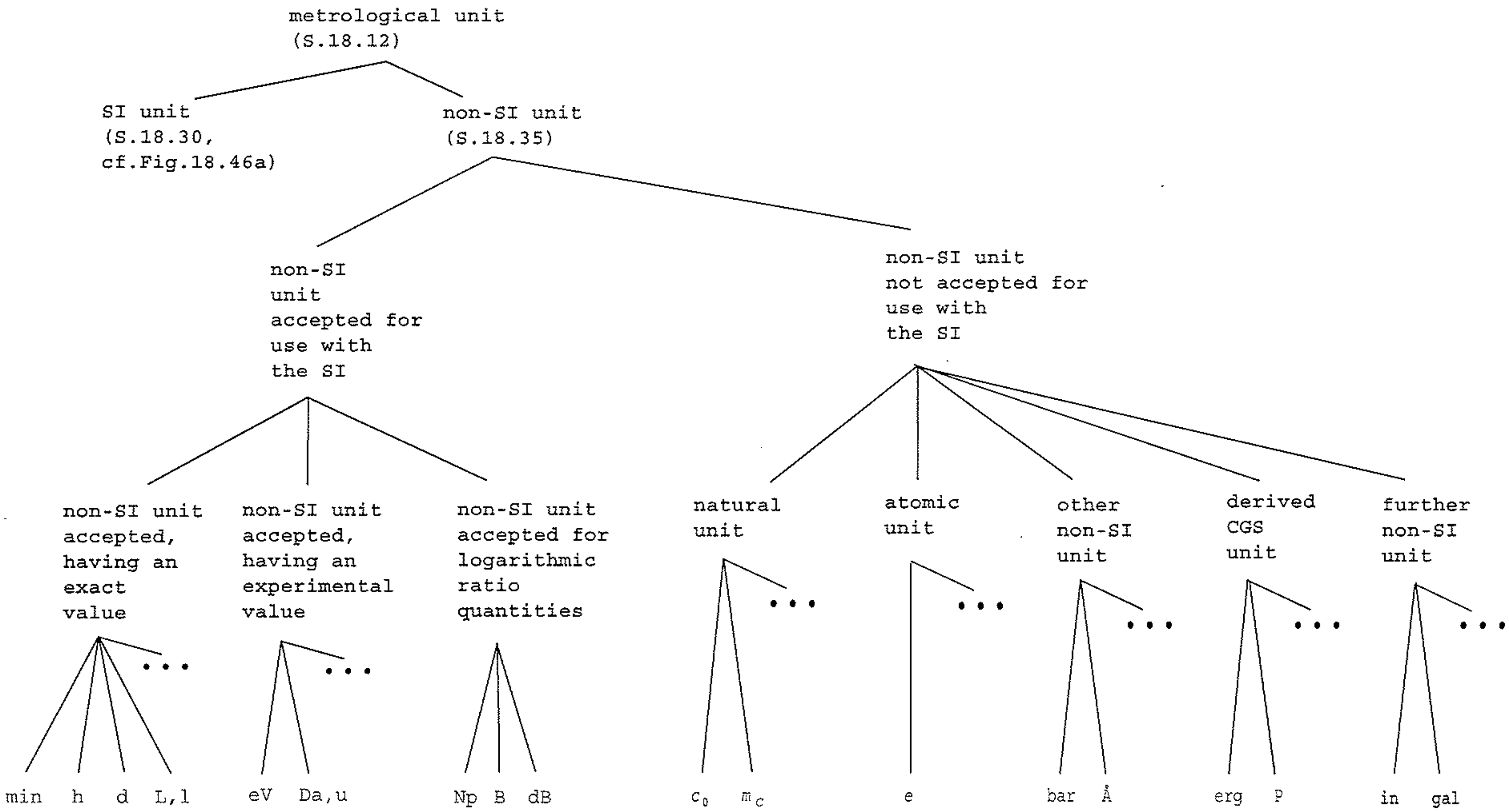


Figure 18.46b Generic 'concept diagram on <non-SI unit> according to the text and tables of the '*International System of Units, SI* [6]

19 MIXED CONCEPT SYSTEM on <METROLOGICAL DIMENSION>

'The striking feature of the subject is that it has remained controversial for so long. I am convinced that the main reason for this is loose terminology, ...'
E.A. Guggenheim, 1942 [56]

19.1 Hitherto, in this text, the |term 'dimension' (or 'metrological dimension') in |relation to |metrology has been used without |defining the |concept, although the metrological literature is not unisonant on the meaning. This |polysemy will be discussed in Section 19.21. The special sense of terminological dimension was defined in Section 2.19.

19.2 In 1873, *Maxwell* in a footnote [99-p.2] credited *Jean Baptiste Joseph Fourier* (1768-1830) with having first advanced the theory of dimensions in his pioneering monograph *Théorie analytique de la chaleur* 1822 [48[5]273]. Indeed *Fourier* wrote that '... chaque grandeur indéterminée ou constante a une *dimension* qui lui est propre, et que les termes d'une même équation ne pourraient pas être comparés, s'il n'avaient point le même *exposant de dimension*.' (p. 154-para 160). In the translation by *Freeman* this became '... every undetermined magnitude or constant has one *dimension* to itself, and that the terms of one and the same equation could not be compared, if they had not the same *exponent of dimension*.' [49].

The terms 'undetermined magnitude' or 'undetermined quantity' seem to cover what is here called base unitary kind-of-quantity (S.13.9). Thus, the dimension of the 'undetermined quantity length', *x*, was listed as the exponent 1 with regard to the unit of "length", exponent 0 with regard to the respective units of "duration" and "temperature" [49-article 161]. The concept of "dimension" was defined by dimensional exponents, but "metrological unit" is also (unnecessarily) involved.

Maxwell adopted this approach, explaining that any |unit has dimensions 'in terms of the three fundamental units', which, for example, in the universe of 'dynamical sciences' were units of "length", "time", and mass. 'When a given unit varies as the *n*th power of one of these units, it is said to be of *n dimensions* as regards that unit.' [99].

19.3 *Lodge* emphasized that 'merely the dimensions of a quantity do not always fix the kind of quantity' and gave as an example "moment of force" and work" [95]. (With the seven unitary kinds-of-quantity (S.13.3.3), corresponding to the SI (see Section 19.22), both have the dimension L^2MT^{-2}. Another example was given in Section 4.5.)

[5] Maxwell abbreviated the title to 'Théorie de Chaleur' and Bridgman reiterated (S.19.4).

19.4 A century after *Fourier*, i.e. in 1922, his ideas were acknowledged by *Bridgman* in his monograph *Dimensional analysis* stating that 'Fourier was the first astute observer' [13-p.51]. Otherwise, *Bridgman* listed the 'primary quantities' [here termed base unitary kinds-of-quantity (S.13.9)] "time", t, "length", l, and "mass", m, [italics for symbols were not used] as having the *dimensional formulae* T, L, and M respectively; accordingly, the 'secondary quantity' [read: derived unitary kind-of-quantity (S.13.11)] "acceleration of gravity" was given the dimensional formula LT^{-2}. However, this concept was defined as

> *dimensional formula of a secondary quantity*: aggregate of the exponents of the various primary quantities which are involved in the rules of operation by which the secondary quantity is measured [13-p.23]

and 'In order to avoid confusion, the exponents are associated with the symbols of the primary quantities to which they belong, that symbol being itself written as raised to the power in question.' Unitary quantities having values that are numbers were characterized as being dimensionless. It is not quite clear whether 'dimension' refers to a set of exponents or a product of factors bearing exponents; this ambiguity is also reflected in several quotes given [13-Ch.2-Appendix]. *Bridgman* echoed *Fourier* in stating that all terms in an equation between [unitary kind-of-]quantities must have the same dimensions.

In a critical review on the theory of dimensions from the same year, *Wallot* gave no definition, but also used the term for each of the exponents in an equation between units, isomorphic to an equation between quantities [125].

19.5 *Guggenheim* - in a chapter on 'Units and dimensions' [56] - did not either define the concept "dimension", but freely used the plural 'dimensions' in phrases such as

- 'A pure number will be said to *have no dimensions* or to be dimensionless.'
- 'If the ratio of two physical quantities is a pure number, the two quantities will be said to *have the same dimensions.*'
- 'Again, in any equations between physical quantities the two sides of the equation must have the same dimensions.' This statement supports *Fourier* and *Bridgman* as a requirement of dimensional analysis.

Furthermore, in a discussion of the number of necessary or useful independent dimensions or corresponding fundamental quantities [here called base unitary kinds-of-quantity (S.13.9)], *Guggenheim* - as already quoted in Section 13.9 - opined that 'if in the same problem or set of problems two authers make a different choice, the one choosing the greater number is likely to be the more competent physicist.'

19.6 *Landolt* mentioned - in agreement with *Bridgman* - that only quantities of the same dimension can be added and that they have the same unit [92], but no definition was offered.

19.7 A formal definition was given by *Häberli* as follows. 'Die "Physikalische Dimension" ist das formelle Symbol für die "Physikalische Qualität"', where *Häberli* used 'Qualität' in the sense of unitary kind-of-quantity. So,

physical dimension: formal symbol for a unitary kind-of-quantity (S.13.3.3) [57-p.66]

and an example given was "energy" having the physical dimension (usually shortened to 'dimension') symbolized

$$\dim W = M\,\frac{l^2}{t^2}$$

where the italic symbols on the right-hand side stood for the physical 'Grunddimensionen' "mass", "length", and "time" respectively. *Häberli* suggested that this symbolism was more evocative than the one-line L^2MT^{-2} and constituted a *representation* ('ein Bild', de) of the unitary kind-of-quantity. The definition, however, is not very descriptive and the representation is not uniquely giving the kind-of-quantity.

19.8 *Fleischmann* described the mathematical characteristics of that which here is called 'system of unitary kinds-of-quantity' (S.13.7) and stated that any unitary kind-of-quantity, X, in such a system could be expressed as an algebraic integral product of powers of the selected base unitary kinds-of-quantity ('Grundgrössenart', de). This product,

$$B_1^{\alpha_1} \;\ldots\; B_n^{\alpha_n}$$

was called 'dimensional product' ('Dimensionsprodukt', de) and the exponent, α_i, 'dimension relative to B_i' [45].

19.9 The classical tome from 1955 by *Stille*, firstly presented the view of various authors [116], some relating dimension to products of base unitary kinds-of-quantity, some to products of base metrological units (S.18.15), e.g., *von Helmholtz* [123-p.389], and some to the exponents of such products. Secondly, he found the dimensional product of a unitary quantity, A, as follows. (The choice of letter symbols used here are different from *Stille*'s for the sake of consistency with *Fleischmann*'s.)

- A set of "Grundgrössenarten", B_i, (here called base unitary kinds-of-quantity) are chosen, e.g. "length", l, "mass", m, and "time", t;

- the unitary quantity (S.12.17) is represented by the unitary quantity equation

$$A = Z \prod_{i=1}^{n} B_i^{\alpha_i}$$

where Z is a number and α_i is an integer;
- each base unitary kind-of-quantity has a corresponding base dimension, symbolized by a sanserif capital letter, e.g. for "length", l, the symbol L;
- the set of base dimensions, B_i, constitutes a system of dimensions, $\{\mathsf{B}_1, \mathsf{B}_2, \ldots \mathsf{B}_n\}$;
- from the expression of A above, any numeral factor, Z, special mathematical operators, such as derivative, d, and vector and tensor symbols are ignored;
- the dimensional product of A is then

$$\mathrm{Dim}\ [A] = \prod_{i=1} \mathsf{B}_i^{\alpha_i}$$

for example "force" has the dimensional product Dim $[F]$ = LMT^{-2};
- if all $\alpha_i = 0$, the unitary quantity (or derived unitary kind-of-quantity (S.13.11)), Y, is dimensionless,

$$\mathrm{Dim}\ [Y] = \prod_{i=1}^{n} \mathsf{B}_i^{0} = 1$$

- whereas each system of base unitary kinds-of-quantity corresponds to only one system of dimensions, the latter may correspond to many coherent systems of metrological units (S.18.29) depending on the choices of magnitudes for the base metrological units.

Stille finally offered a description of

Dimension einer Grösse: die aus den Grössengleichungen als Definitionsgleichungen für die Grössen folgende und als Potenzprodukt der Grundgrössenarten ausgedrückte allgemeine Beziehung der Grösse zu den Grundgrössenarten [116-p.34]

which rather convulated phrase may be translated as

dimension of a unitary quantity: general relation of the unitary quantity (S.12.17) to the base unitary kinds-of-quantity (S.13.9), resulting from the unitary quantity equations in the form of defining equations and expressed as a product of powers of the base unitary kinds-of-quantity [transl. from 116-p.34]

This thorough discussion by *Stille* has two puzzling details. Why is the symbol for dimensional product dim [*A*], where [*A*] is the symbol of the metrological unit (S.18.12) for a unitary quantity *A*? Why does the definition of "dimension of a unitary quantity" speak of expressing it as 'a product of powers of base unitary kinds-of-quantity' when the factors are not symbolized by B_i but by a new symbol B_i?

19.10 A second paper by *Fleischmann* is less clear in terminology as admitted by the author who stated that it is his 'augenblickliche Meinung' and that he used 'verschiedentlich zwei oder drei Worte für den gleichen Mitteilungsinhalt nebeneinander' [47-3]. Thus, 'Dimension', 'Grössenklasse', and 'Grössenart' are synonyms for a concept that was said to describe the qualitative aspects of properties [read: qualitative aspects of unitary quantities, i.e. unitary kinds-of-quantity] and was not attached to an object; but it was also claimed to be a class of infinite many *values* of quantities which are statements about the same measurable property (Merkmal, de). Examples given were "electrical current", "time", and "length". It was stressed that "dimension" is different from "unit". Finally, the symbol dim *A* was used in equations between unitary kinds-of-quantity.

19.11 *Bunge* explained that a 'variety of magnitudes [read: unitary kinds-of-quantity] ... are basically of the same kind. Distance, height, depth and wavelength are just different applications of the length concept: they belong, as we shall say, to the same *magnitude family*. What characterizes this family is the common dimension L'. Furthermore, 'Magnitudes with the same dimension shall be reckoned and measured with the same basic unit.' [15-p.224]. *Bunge* also mentioned the importance of dimensional analysis which was said to be 'an analysis of formulas that either belong to or presuppose some theory.'

19.12 This was later pursued in a paper on the mathematical theory of dimensions giving axioms, theorems, and definitions within a Set-Theoretical approach [16]. Thus, within a given physical theory, *T*, there was said to be a set of all physical quantities, Q_T [read: unitary quantities or sometimes unitary kinds-of-quantity]. Among these, a subset of *undefined basic* physical quantities, Q_T^*, is chosen and any number of *defined derived* physical quantities can be built out of this subset. The physical theory, *T*, also contains a set, D_T^*, of basic dimension values, assigned by postulate, such as *L*, *M*, *T*, which can generate the totality of dimension values D_T where multiplication between the basic dimension values is sanctioned. The set Q_T can be partitioned into homogeneous subsets (species) having the same dimension function, [], such that the dimension value of, e.g., any wavelength, λ, is the dimension species L, i.e. $[\lambda] = L$. (Here the square brackets do not indicate "unit".]

Other partitions of Q_T are into dimensional and dimensionless quantities; dimensional constants, such as the gravitational constant, having no physical instance; and magnitudes [read: unitary kinds-of-quantity]. *Bunge* considered that there are two concepts of dimension, namely dimension function, [], and dimension value, d. 'They are the mathematical objects satisfying the theory expounded ...' [16-1.9].

19.13 The review on quantity calculus by *de Boer* freely used dimensionality in describing systems of rational unitary quantities (S.12.20) and of metrological units, such as the three-dimensional CGS system [30-p.409]. Further, he quoted *Fleischmann*'s dimensional product, given as $A^a \cdot B^b \ldots E^e$, and dimensions, a, b, ..., e, relative to the rational unitary kinds-of-quantity (S.13.3.5) A, B, ..., E. Finally, in a sketch of the formal algebraic structure of quantity calculus [30-Appendix], continuing the ideas of *Wallot, de Boer* defined a set of physical [read: rational unitary] quantities of a given [rational unitary] kind-of-quantity, A - grouped together by an equivalence relation (reflexive, symmetric, and transitive) - as an equivalence class, C(A), and where the whole set of all equivalence classes is the whole set of rational unitary quantities, **Q**. Quantities of the same kind were said to have the same dimension, e.g. dim A. The group of equivalence classes, the group of rational unitary kinds-of-quantity, the metrological units group, **U**, of a coherent system, and the dimension group were claimed to be isomorphic. Finally, each of these groups were described as an infinite commutative group. The dimension group was 'generated by a set of independent "base dimensions" A, ..., D, such that the dimension of every quantity V can uniquely be expressed in the form dim $V = \mathsf{A}^{\alpha} \ldots \mathsf{D}^{\delta}$ (α, ..., $\delta \in \mathbf{Z}$).

There is one problem with this presentation as exemplified by the statement that 'All the so-called "dimensionless quantities" belong to one class of quantities of the same kind; they belong to the equivalence class of "dimensionless" quantities C(I), which contains all quantities which are of the same kind as the unit element I'. It is correct that, e.g., "number of entities" and "mass fraction" have the dimension 1, but they are not of the same rational unitary kind-of-quantity. Likewise, "mass concentration" and "volumic mass" are of dimension $\mathsf{L}^{-3}\mathsf{M}$ although they are different rational unitary kinds-of-quantity - even if the latter becomes equal to the former when the component (S.3.4) equals the system (S.3.3). The information given by a dimension is less than the definition of the corresponding unitary kind(s)-of-quantity.

19.14 Turning to the international documents, the *VIM3* defines

> *quantity dimension*; dimension of a quantity; dimension: expression of the dependence of a quantity on the base quantities of a system of quantities as a product of powers of factors corresponding to the base quantities, omitting any numerical factor [132-1.7]

This definition stresses that dimensionality rests on the choice of a system of unitary kinds-of-quantity, effectively excluding ordinal quantities from having a meaningful dimension.

19.15 The *ISO 31-0-2.2.6* states that a [unitary] quantity, Q, can be expressed as a product (or a sum of products) of powers of base quantities, A, B, ..., from a chosen set, sometimes multiplied by a numerical factor, ξ, i.e. $\xi A^{\alpha}B^{\beta}C^{\gamma}$ .... 'The dimension of the quantity Q is then expressed by the dimensional product

$$\dim Q = \mathsf{A}^{\alpha}\mathsf{B}^{\beta}\mathsf{C}^{\gamma} \ldots$$

where A, B, C, ... denote the dimensions of the base quantities A, B, C, ..., and where α, β, γ, ... are called the *dimensional exponents*.' Any numerical factor ξ different from one is omitted. The dimensional product is also termed 'dimension' [64, 120]. For the seven base unitary kinds-of-quantity of the SI, 'the base dimensions may be denoted by L, M, T, I, Θ, N and J respectively.'

The *ISO* also explains that for a given system of [unitary kind-of-]quantities, 'a coherent system of units is obtained by first defining units for the base [unitary kind-of-]quantities, the *base units*. Then for each derived [unitary kind-of-]quantity, the definition of the corresponding *derived unit* in terms of the base units is given by an algebraic expression obtained from the dimensional product by replacing the symbols for the base dimensions by those of the base units.'

19.16 In a discussion paper to the *Consultative Committee for Units* (*CCU*), *Blackburn* simply noted that 'Dimension is a descriptor which specifies the nature of a quantity ...' [10]. What the nature consists in is not revealed, but the sense seems to be that of the pseudo-definition offered by *Häberli* (S.19.7).

19.17 The German standard *DIN 1313* describes concepts such as "scalar quantity" (= "rational unitary kind-of-quantity") (Grösse, de), "unit of measurement" (= "metrological unit") (Einheit von Grösse, de), and "kind-of-quantity" (Grössenart, de), but also has a clause on Quantity systems and dimensions [33-6]. The latter is defined as

> *dimension of a quantity system*: set of quantity values whioh can be given as the set of multiples of a quantity value different from 0 with arbitrary real coefficients [33-6.4]

Except for one of *Fleischmann*'s suggestions [47], this definition is radically different from previous attempts in relating to quantity values rather than to the mathematical equations between unitary kinds-of-quantity. The term for a dimension is said to be that of a basic kind-of-quantity such as "length" or "mass", thus leading to |homonymy. Both (unitary) quantities, *G*, and their quantity values, *x*, have dimensions, dim *G* and dim *x* respectively. Finally, the specific concepts "base dimension" and "derived dimension" of a system of rational quantities are mentioned.

19.18 So far, the discussion has identified concepts with terms such as 'dimensional formula', '(physical) dimension', 'dimensional product', dimensional exponent', 'base dimension', 'derived dimension', 'dimension function', 'dimensional value', 'dimension species', 'dimensional constant', and 'dimension group' - although with |synonymy, polysemy, and homonymy involved.

The top concept in this |set is <dimension> which - in spite of several diversions - has evolved to have the following |essential characteristics.

- The system of dimensions is dependent upon and isomorphic with a system of unitary kinds-of-quantity with chosen base unitary kinds-of-quantity [30, 45, 56, 116, 132].
- The system is related to a system of metrological units with chosen base metrological units [30, 64, 99, 116].
- Two or more different unitary kinds-of-quantity can have the same dimension and metrological unit [15, 33, 95].
- The structure of the dimension of a given unitary kind-of-quantity as a product of exponential factors of base dimensions, is homomorphic with that of the defining unitary base kinds-of-quantity [30, 64, 116].
- A dimensional product is devoid of any numerical factors (except "one") and mathematical operators (except "multiplication") that may occur in a corresponding defining equation between unitary kinds-of-quantity.
  - A singular unitary quantity (S.6.14.2), its metrological units, and their parent unitary kind-of-quantity have the same dimension in a given system of unitary kinds-of-quantity.
- Each base metrological dimension is currently conventionally symbolized as a unique sanserif capital [30, 64, 116] which is also used as a term.

The first, fourth, and fifth of these characteristics may be considered to be |delimiting characteristics.

19.19 The next to last characteristic above gives the possibility of defining "dimension" primarily in relation to either "unitary kind-of-quantity" or "unitary quantity". Although an explicit distinction between these two concepts is not always made in the reference texts, unitary kind-of-quantity seems to be chosen by *Häberli* [57], *Fleischmann* [45], *Stille* [116], and probably *Bunge* [15], whereas *ISO* [64] and *VIM3* (S.19.14) relate to unitary quantity.

Inasmuch as a singular unitary quantity inherits the characteristics of its ¦superordinate ¦generic unitary kind-of-quantity, it seems reasonable to opt for the latter higher level. It may be added that the examples in the various texts almost invariably mention only kinds-of-quantity.

19.20 Starting with *Häberli* [57], and still used by the *ISO* [64] and *VIM3* [132], the metrological dimension of a unitary (kind-of-)quantity, *Q*, is symbolized by dim *Q*.

19.21 The ¦simple term 'dimension' is not without problems even if *Fourier*'s [49], *Maxwell*'s [99], *Wallot*'s [125], and *Fleischmann*'s [45] classical meaning of an 'exponent in the dimensional product' nowadays is ignored. Their opinion is reflected in common language, where a dimension basically is the extent in one direction of a tridimensional space. The same sense is generalized in algebra. This usage might also be thought to apply in the recent theoretical text by *de Boer* with terms such as the 'three-dimensional CGS system' [30]; this expression, however, is probably just a short version of the 'CGS system having three base dimensions' - each of which having only one 'direction'. A better designation for the characteristic of any singular unitary quantity in a system could be 'dimensional product' as suggested by *Fleischmann* [45] and mentioned by *Stille* [116]. Yet, the latter *defined* (here given in translation) "dimension" as the 'relation of a [unitary] quantity to the base [unitary] kinds-of-quantity' and *expressed* this relation as a 'Potenzprodukt' (S.19.9). *COD* essentially concurs for a derived quantity in physics by stating that its dimension is 'the product of mass, length, time, etc. raised to the appropriate power' [1-p.327].

Although any unitary quantity belonging to a defined system can be said to be a point in a pluridimensional space, it has become customary in the ¦special language of ¦metrology to speak of the dimension of such a quantity and its unitary kind-of-quantity even when several base dimensions are involved.

19.22 The ¦preferred systematic term should make clear the distinction from 'terminological dimension' (S.2.19). Consequently, the following term and definition are proposed.

<u>**metrological dimension**</u>
dimension
dim
reduced product of exponential factors, isomorphic with the product of **base unitary kinds-of-quantity** (S.13.9), defining a given **unitary kind-of-quantity** (S.13.3.3) in a **system of unitary kinds-of-quantity** (S.13.7), except for omitting any numerical factors different from one and mathematical operators apart from the multiplication sign

NOTE 1 - A metrological dimension is conventionally symbolized by a product of powers of factors, each factor symbolized by a sanserif capital letter designating the metrological dimension of a base unitary kind-of-quantity.

EXAMPLE 1 - The set of seven base unitary kinds-of-quantity to which the International System of Units, SI (S.18.33.2) corresponds has the following set of symbols for their respective metrological dimensions.

length	L
mass	M
time	T
electrical current	I
thermodynamic temperature	Θ
amount-of-substance	N
luminous intensity	J

Any **unitary quantity** (S.12.17), its corresponding **metrological unit** (S.18.12) and unitary kind-of-quantity in that system, has a generalized metrological dimension symbolized $\mathsf{L}^{\alpha}\mathsf{M}^{\beta}\mathsf{T}^{\gamma}\mathsf{I}^{\delta}\Theta^{\epsilon}\mathsf{N}^{\zeta}\mathsf{J}^{\eta}$ where the exponents, α, ..., η, are integers (except for some electromagnetic unitary kinds-of-quantity in some systems).

(cont.)

[cont.]
EXAMPLE 2 - The derived **rational unitary kinds-of-quantity** (S.13.3.5) "(amount-of-)energy", E, defined as "mass of a body" multiplied by its "speed of light in vacuo" squared, $m \cdot c_0^2$, and "kinetic energy", E_k, defined as half the product of the "mass of a body" and the square of its "velocity", 0.5 $m \cdot v^2$, both have the metrological dimension $\mathsf{L}^2\mathsf{M}\mathsf{T}^{-2}$.

EXAMPLE 3 - The kelvic enthalpy of system, C, defined as the increase in the "amount-of-heat of system", Q, divided by the increase in "thermodynamic temperature of system", T, (provided that there is no irreversible change in the system), $C = \mathrm{d}Q/\mathrm{d}T$, has the metrological dimension $\mathsf{L}^2\mathsf{M}\mathsf{T}^{-2}\mathsf{I}^0\Theta^{-1}\mathsf{N}^0\mathsf{J}^0 = \mathsf{L}^2\mathsf{M}\mathsf{T}^{-2}\Theta^{-1}$.

NOTE 2 - Compositional and material unitary kinds-of-quantity can have the same metrological dimension.

EXAMPLE 4 - The rational kinds-of-quantity "mass concentration", ϱ_B, and "volumic mass", ϱ_S, both have the metrological dimension $\mathsf{L}^{-3}\mathsf{M}$, but only the first one specifies a **component** (S.3.4).

NOTE 3 - A compositional and a solvent-based unitary kind-of-quantity can have the same metrological dimension.

EXAMPLE 5 - The unitary kinds-of-quantity amount-of-substance content (of component B in system)", ν_B, and "molality (of solute component B in solution)", b_B, where the mass of **system** and of solvent are taken, respectively, both have the metrological dimension $\mathsf{M}^{-1}\mathsf{N}$.

NOTE 4 - The definition of a given unitary kind-of-quantity may contain **derived unitary kinds-of-quantity** (S.13.11), but these may be decomposed into their constituent base unitary kinds-of-quantity to calculate the reduced metrological dimension.

EXAMPLE 6 - The derived rational kind-of-quantity "areic volume" has the (extended) metrological dimension $\mathsf{L}^3\mathsf{L}^{-2}$, reducing to L.

NOTE 5 - In this text, vectors and tensors are excluded.

The proposed definition is not in conflict with those of *Stille* (S.19.9), but diverges from that of the *DIN 1313* (S.19.17) and the *VIM3* (S.19.14).

19.23 From the superordinate generic concept <metrological dimension> (S.19.22), the following ᴵcoordinate specific concepts are fashioned.

19.23.1

> **base metrological dimension**
> base dimension
> **metrological dimension** (S.19.22) having a single factor with exponent one, the rest with exponent zero
>
> EXAMPLE 1 - Each of the seven **base unitary kinds-of-quantity** (S.13.9) corresponding to the **base metrological units** (S.18.15) of the ᴵInternational System of Units, SI (S.18.33.2) have a unique base metrological dimension, see Section 19.22, Example 1.
>
> EXAMPLE 2 - The **rational unitary kinds-of-quantity** (S.13.3.5) "areic volume" and "lineic area" both have the metrological dimension L - respectively reduced from $L^3L^{-2}M^0T^0I^0\Theta^0N^0J^0$ and $L^2L^{-1}M^0T^0I^0\Theta^0N^0J^0$.

The definition agrees with the text of the *DIN 1313*: 'For the base dimensions exactly one of the dimensional exponents is 1 and the others are 0' [33-6.11].

19.23.2

> **derived metrological dimension**
> derived dimension
> **metrological dimension** (S.19.22) having *either* at least one factor with the exponent different from one and zero *or* at least two factors with exponents different from zero *or* all exponents zero
>
> EXAMPLES - "number rate" T^{-1}; "area" L^2; "amount-of-substance rate" NT^{-1}; "number concentration" L^{-3}; "number fraction" 1; "number of entities" 1

19.24 Several times in this Chapter a special type of unitary kind-of-quantity has been mentioned, namely either that which is defined by division between two identical kinds-of-quantity or "number of entities". In both cases the dimensional product consists in factors that all have a reduced exponent of zero, for example in the CGS system dim $Q = L^0M^0T^0 = 1$. Stemming from the time when the exponents were called dimensions, such a unitary kind-of-quantity was termed a 'dimensionless kind-of-quantity' by *Bridgman* [13], *Stille* [116], *Bunge* [16], *de Boer* [30], and *Blackburn* [10], by *de Boer* also 'number'.

As the entire dimensional product is now termed 'metrological dimension' and is regarded as an algebraic entity which in this case equals one, it is both appropriate and evocative to speak of '(unitary kind-of-)quantity of dimension one' - as in the *VIM3* [132-1.8] and the *ISO* [64-2.2.6], although they still have the synonym 'dimensionless quantity'.

The *DIN 1313* points out that 'Die Dimension Eins gehört nicht zu den Basisdimensionen [33-6.10-Anmerkung 1], and this is in accordance with the definition of "derived metrological dimension" (S.19.23.2).

19.25 As mentioned, there are two ways in which the dimensional product becomes equal to one.

- The *direct way* is always taken when the rational unitary kind-of-quantity is "number of entities".
- The *indirect way* will involve reduction when *either* two identical rational unitary kinds-of-quantity are divided; such as "volume (of component)" divided by "volume (of system)" giving "volume fraction"; "plane angle"; "relative molar mass"; "mass ratio"; or when more complicated combinations of rational unitary kinds-of-quantity have metrological dimensions which reduce to one; such as exponential function of ["chemical potential (of component)" divided by the product of "molar gas constant" and "thermodynamic temperature"] giving "absolute activity (of component)".

Blackburn suggested that the two types should not have the dimension 1 or be termed 'dimensionless'. No special term was proposed for the metrological dimension of the first type, but the metrological unit "item" (symbol: it or itm) or "entity" (symbol: ent) would indicate that counting was involved [10]. For unitary quantities of the second type he argued that they should be said to be 'of dimension number', and have the coherent derived metrological unit (S.18.19) "one" (symbol: 1).

Regarding the term, it has been suggested above (S.19.24) that for algebraic reasons 'metrological dimension one' is a proper term for unitary kinds-of-quantity defined by division of two unitary kinds-of-quantity of the same kind. As to a special term when the measurement principle is counting, this principle can be applied even if the unitary kind-of-quantity is not "number of entities", e.g. when measuring an amount-of-substance. Conversely, a number of entities may be measured by other means than direct counting, e.g. by gravimetry or volumetry.

19.26 The *VIM3* does not define "dimension one", but

> *quantity of dimension one;* dimensionless quantity: quantity for which all the exponents of the factors corresponding to the base quantities in its quantity dimension are zero [132-1.8]

19.27 Staying with metrological dimensions, the following term and definition are proposed.

> <u>derived metrological dimension one</u>
> dimension one
> **derived metrological dimension** (S.19.23.2) having all the exponents of the factors reduce to zero
>
> EXAMPLES - "number of entities"; "mass fraction"; "amount-of-substance ratio"; "solid angle"; "relative molar mass" (molecular 'weight'); "pH"; "chemical activity" (= $\exp[\mu_B/RT]$); Prandtl number
>
> NOTE - The term 'dimensionless' is not proper in relation to a unitary kind-of-quantity (S.13.3.3) as the dimensional product reduces to one.

According to Sections 19.23.2 and 19.27, the unitary kind-of-quantity "number of entities" has a derived metrological dimension one. It could be argued, however, that - inasmuch as the metrological unit "one" may be regarded as a base metrological unit for "number of entities" (S.18.40, 18.42) - it would be reasonable to let that unitary kind-of-quantity have a base metrological dimension (S.19.23.1) in contradistinction to other kinds-of-quantity of undoubtedly derived metrological dimension one. Neither the *BIPM* [6] nor the *VIM3* [132] have presented the concepts "base metrological dimension" (S.19.23.1) or "derived metrological dimension" (S.19.23.2).

19.28 It should be noted that in current metrological thinking the metrological dimension of a unitary kind-of-quantity, its singular unitary quantities, and metrological units is *not* a product of powers of defining unitary kinds-of-quantity and is *not* designated by a factorized symbol of italicized letters for such kinds-of-quantity. The metrological dimension is a separate concept with a separate term and symbol of sanserif capital letters. A metrological dimension is less informative than the corresponding definition of the kind-of-quantity, as shown by the last phrase in the definition of metrological dimension ('except for ...') and its Examples 2, 3, and 5 (S.19.22), and it also lacks the magnitude given in an appropriate metrological unit.

19.29 The concepts related to <metrological dimension> discussed here are shown in the mixed ˡconcept diagram of Figure 19.29.

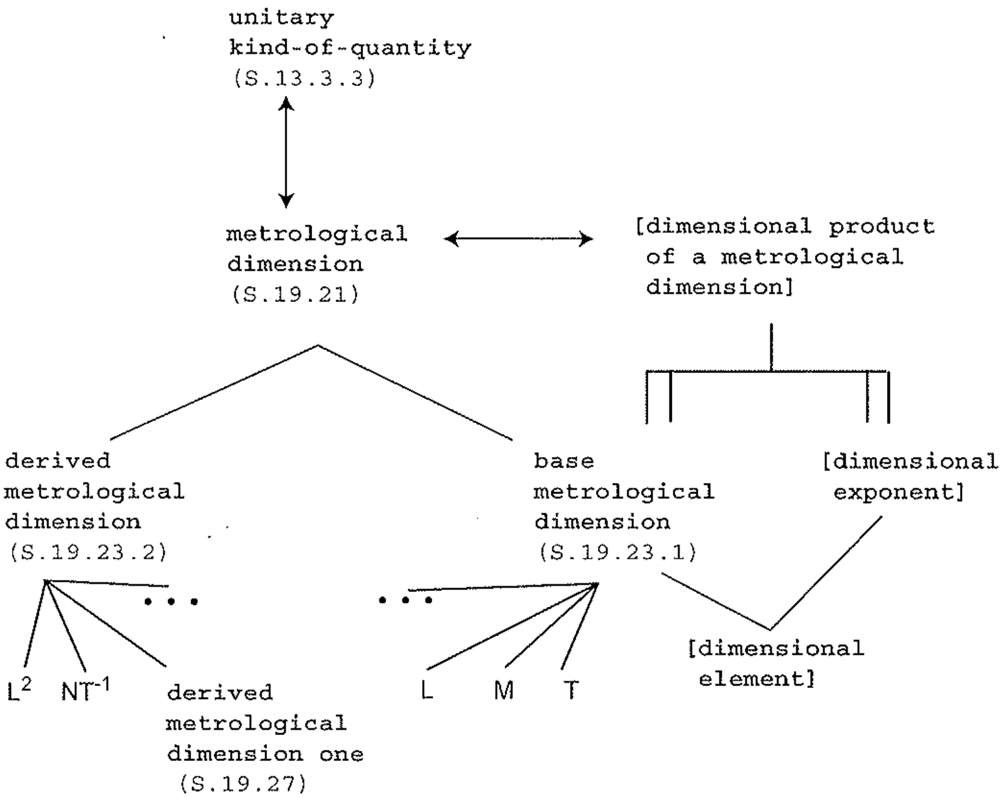


Figure 19.29 Mixed ˡconcept diagram on ˡconcepts related to the top concept <metrological dimension>

20 "DEDICATED KIND-OF-PROPERTY" and SYSTEMATIC TERMS

"DEDICATED KIND-OF-PROPERTY"

20.1 The classical texts on quantities, here called unitary kinds-of-quantity (S.13.3.3), were penned by physicists who were mostly concerned with those material unitary kinds-of-quantity which can describe an entire system (S.3.3) without the need to involve any component (S.3.4). Typical examples are "length", "mass", "volume", "volumic_mass", "length_rate", electrical_current", "energy", "temperature difference", and "molar_mass".

Such ¦concepts were often discussed in isolation - more or less as in Chapter 13 - with only fleeting mention that they relate to a physical system, phenomenon, state, or process [116].

In the description of the chemical aspects of systems, on the contrary, a component is often a necessary ingredient of the ¦definition of the kind-of-property (S.6.19). This is reflected in more complicated ¦appellations of singular properties (S.6.14.1).

20.2 The need to systematize the structure of ¦designations for properties (S.5.5) examined in Laboratory Medicine became clear half a century ago - as mentioned in Chapter 1 - when an increasing number of physico-chemically based measurement procedures (S.14.4.3) were introduced to obtain ever more sophisticated information about the physiological and biochemical state of humans and animals in health and disease.

A set of semantic rules and a syntax was proposed and issued as a *Recommendation 1966* by the *International Union of Pure and Applied Chemistry (IUPAC)* and the *International Federation of Clinical Chemistry (IFCC)* [*R-66* = 39]. The central idea was that three elements are required to designate an ¦instantiated property, namely the ¦terms indicating respective ¦specific concepts under

- sort of system (S.3.3),
- sort of component (S.3.4),
- with kind-of-quantity (S.13.3.1),

and that instantiation is achieved by attaching spatio-temporal coordinates to the sort of system.

NOTE - The modifier 'sort of' used in this Chapter has a function analogous to that of 'kind of' in 'kind-of-quantity', i.e. indicating that the ¦specific concept is at a ¦generically hierarchical level just above that of ¦individual concepts.

20.3 In forms for requests and reports of laboratory data it is useful to designate noninstantiated combinations of generally identified system and component together with a kind-of-property (S.6.19). Examples are

- "mass concentration of protein in urine (of person)",
- "pH of plasma in blood (of person)".

The concepts are not "kinds-of-property" because they have the further ¦characteristic of being associated with a given sort of system (and component) so that the ¦extension is narrower.

20.4 The concept under consideration has been variously termed

- 'quantity' by the *R-66* [39, 128], but that seems to be ¦polysemous;
- 'generic quantity' [37-2.7, 40, 86-5.2.3], but that is ¦terminological language and too general;
- 'type-of-quantity' [41-G.90] that also is too general and may be confused with ¦'type of characteristic' and 'kind-of-quantity';
- 'property' [87, 106] that is polysemous analogously to 'quantity'.
- *Olesen*, speaking for the *IUPAC*'s and the *IFCC*'s work on ¦systematic terms, defined "property" as if it were the concept discussed here (S.5.1.4) [106-4.1].

20.5 A suitable term is not immediately evident. 'System- and component-selected kind-of-property' is not a particularly handy phrase, and it does not help to replace '-selected' by '-assigned', '-committed', or '-connected'. Thus, the whole meaning of the concept cannot be expressed in the term. It is suggested that the modifier 'dedicated' is evocative enough when coupled with 'kind-of-property' to distinguish the concept from "singular property".

20.6 Consequently, it is proposed to define

<u>**dedicated kind-of-property**</u>
kind-of-property (S.6.19) with given sort of **system** (S.3.3) and any pertinent sorts of **component** (S.3.4)

EXAMPLES
"colour of urine"

"mass of person"

"volume fraction of blood in person"

"amount-of-substance concentration of sodium ion in plasma (of blood (of person))"

NOTE 1 - Various specifications may be attached to the given kind-of-property, sort of system, and sort of component.

NOTE 2 - Instantiation is achieved by spatio-temporal coordinates attached to the given sort of system.

20.6.1 The new *CEN* European Standard *EN 1614* [19a] has adopted this concept and term from the first edition of this text [131], but with a modified definition.

> *dedicated kind-of-property*: kind-of-property with a given kind of system and a given kind of component subject for determination [19a-3.6]

The added 'subject for determination' is unfortunate in that such a process is impossible before instantiation by spatio-temporal coordinates.

20.7 In case nominal kinds-of-property (S.13.2.1) are excluded from consideration, the following concept applies.

<u>**dedicated kind-of-quantity**</u>
kind-of-quantity (S.13.4.1) with given sort of **system** (S.3.3) and any pertinent sorts of **component** (S.3.4)

EXAMPLES - The last three Examples of S.20.6 apply.

NOTES - Section 20.6 Note 1 analogously and Note 2 identically apply.

20.8 It is also perfectly possible to define "dedicated nominal kind-of-property", "dedicated unitary kind-of-quantity", "dedicated differential unitary kind-of-quantity", and "dedicated rational unitary kind-of-quantity" if the need should arise.

SYSTEMATIC TERMS FOR DEDICATED KINDS-OF-PROPERTY

20.9 The elements necessary to form an unambiguous appellation of a singular quantity was formulated in the *R-66* (S.20.2) and they can be generalized to apply for a singular property as shown in Table 20.9.

Table 20.9 Elements of a systematic ˡappellation of a singular property (S.6.14.1) based on *R-66* [39]

Individualizing part
- administrative data;
- information about person (appellation, demographic data, other pertinent singular properties);
- information about preparation of person for examination (S.8.4) or sampling;
- information about sampling and sample;
- calendar time or time interval.

Generic part
- ˡspecification to sort of system (S.3.3) about any supersystem (optional);
- term for sort of system;
- specification to sort of system about any subsystem (optional);
- term for sort of component (S.3.4);
- specification to sort of component (e.g. formula unit, production process) (as relevant);
- term for kind-of-property (S.6.19);
- specification to property (e.g. examination procedure (S.7.3), property value scale (S.10.14)) (as relevant).

Supplementary information
- biological reference interval;
- comments, e.g., about sampling.

20.10 Upon examination (S.8.4), the outcome is added as an examination result (S.16.20) comprising

- relational operator, such as = or ≥;
- concluding examined property value (S.9.20) in the form of words and/or numbers;
- multiplied by a metrological unit (S.18.12) if a unitary kind-of-quantity is involved;
- examination uncertainty (S.16.23).

(For extensive discussions, see [22, 40].)

20.11 The syntax of the term for a dedicated kind-of-property, organizing its various elements (cf. Table 20.9 - Generic part), was originally recommended to be (in short form omitting 'term for sort of')

(Supersystem)System(Subsystem)-- [or em dash]
Component(specification),
kind-of-property(specification)

with no space on either side of 'System', after 'Component' and 'kind-of-property' (originally given as 'kind of quantity') [39]. This format was illustrated by a hundred examples of terms with symbolized systems and abbreviated kinds-of-property, such as (in updated detail)

dU--Coproporphyrins(I+III), ams. = 60 nmol

where 'dU' is 24-h urine and 'ams.' is "amount of substance";

B--Coagulation, time diff.(Biggs & al. 1957) = 1,3 ks

where 'B' is blood and 'time diff.' is "time difference";

(B)Erys--Haemoglobin(Fe), subst.c.(average) = 21 mmol/l

where 'Erys' is the erythrocyte compartment, 'Fe' is the elementary entity defining a monomeric part of the tetrameric haemoglobin molecule, and 'subst.c.' is "amount-of-substance concentration".

20.12 Further symbolization and another, inverted syntax was presented by *Siggaard-Andersen* [111]. Its sequence corresponds to that of common English language (S.20.3) and has the structure

*quantity*component(system(supersystem)) where 'quantity' is here called unitary kind-of-quantity. For example,

*V*Ery(B(Pt))

where '*V*' is "volume", 'Ery' (not Erys) is the erythrocyte compartment, and 'Pt' is patient. This is a succinct designation for column headings, but too compressed for general use in most routine laboratory reports.

An alternative abbreviation based on the *R-66* syntax is

(Pt)B--Erys, vol.

20.13 The semantics and syntax proposed in the monograph *R-66* were generally recommended by several international organizations (Table 20.13). The details were taken over either exactly as in the *R-66*, including the original 'kind of quantity' [40, 61, 83, 84], or with the short form 'quantity' [128].

Table 20.13 International organizations recommending the semantics and syntax of systematic terms for dedicated kinds-of-property (S.20.6) as given in *R-66* [39], cf. Table 20.9 and Section 20.11.

European Committee for Standardization (CEN)	[19]
European Council of Clinical and Laboratory Standardization (ECCLS)	[41]
International Committee (now Council) for Standardization in Hematology (ICSH)	[61]
International Federation of Clinical Chemistry (now also: and Laboratory Medicine) (IFCC)	[11, 41, 61, 83, 84, 85, 86, 87, 106, 107]
International Society of Andrology (ISA)	[107]
International Society on Thrombosis and Haemostasis (ISTH)	[11]
International Union of Pure and Applied Chemistry (IUPAC)	[11, 83, 84, 85, 86, 87, 106, 107]
World Association of (Anatomic and Clinical) Pathology Societies (WAPS)	[61]
World Health Assembly (WHA) which recommended the use by the health profession in Resolution WHA30.39 of 1977	[128]
World Health Organization (WHO)	[41]

20.14 The order of '(Supersystem)System(Subsystem)' was changed by the *IUPAC/IFCC* around 1995 for the sake of uniformity or simplicity in alphabetical searching on 'system' into

System(specification, including any super- and subsystem)--
Component(specification);
kind-of-property(specification)

also using the ¦special character semicolon as a punctuation mark instead of comma, and hyphenated 'kind-of-property' instead of 'kind of quantity' [20, 22, 86, 108]. The first-line change is less systematic and possibly ambiguous, but usually unproblematic for the medical laboratorian.

This format now prevails in a list of dedicated kinds-of-property with thousands of entries used in various specialties within laboratory medicine. The database is being produced by the *IUPAC Commission on Quantities and Units in Clinical Chemistry* (now Subcommittee on Nomenclature, Properties and Units) and the *IFCC Committee on Quantities and Units* (now Committee on Nomenclature, Properties and Units). The publication has occurred since 1987 in 16 parts, currently under the general title of *Properties and units in the clinical laboratory sciences* [87 and, e.g., 11, 106, 107, 108][6].

20.15 The list of uniquely alphanumerically (NPUxxxxx) ¦coded entries [108] is freely available on the Internet [87] and is meant to be a standardized bridge in transmission of laboratory requests and reports between any two users - whether clinicians or laboratory workers - each using his or her usual language and format. The exact phrases of the database, however, can well be applied also in practice; not least because a partially abbreviated form is always included in each case. It should be added that each coded entry based on a unitary kind-of-quantity prescribes the use of one specified metrological unit; whenever possible an SI unit (S.18.30). Also, an entry involving "amount-of-substance" and "mole" is mandatory when relevant. Lately analogous entities based on "mass" and "kilogram" are being inserted for convenience. A reference to the examination procedure (S.7.3) and a property value scale (S.10.14) may be put in the ¦specification to kind-of-property. The instantiating data may be inserted in the specification to system.

20.16 The ¦relations between "dedicated kind-of-property" and "term for a dedicated kind-of-property" with its ¦partitive concepts are shown in Figure 20.16. Terms are further discussed in Chapter 21.

[6] Due to its size, the database is affectionately nicknamed 'The Elephant' among aficionados.

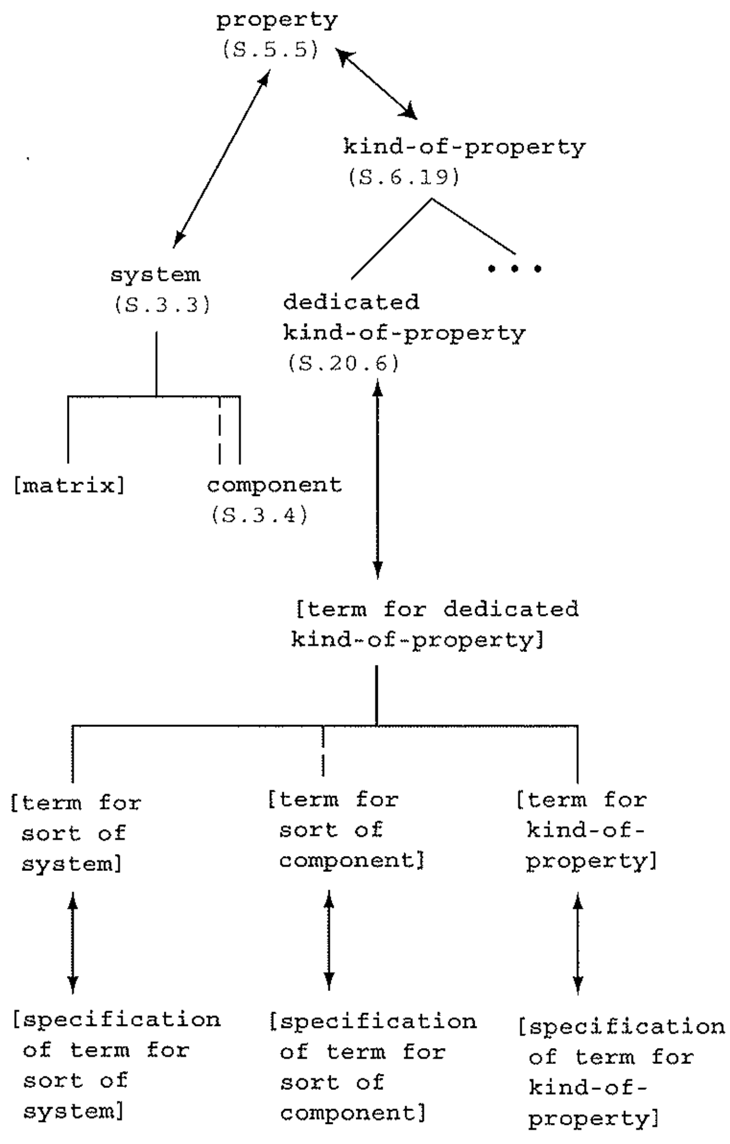


Figure 20.16 Mixed ˡconcept system around "dedicated kind-of-property" (S.20.6) and its ˡterm

21 GENERATION of SYSTEMATIC TERMS for DEDICATED KINDS-OF-PROPERTY ACCORDING to the *ENV 12264*

21.1 The ꜝterms for dedicated kinds-of-property (S.20.6) in laboratory medicine as given in many lists produced during the last four decades have been formed according to the principles recommended in the *R-66* [39]. At that time, prevalent laboratory colloquialisms were modified and supplemented to obtain unambiguous, informative terms, and this was achieved without much use of a ꜝterminological ꜝspecial language.

21.2 In 1995, the *CEN Technical Committee 251 Medical informatics* issued a European Prestandard *ENV 1614* on a *Healthcare informatics - Structure for nomenclature, classification, and coding of properties in clinical laboratory sciences* [19], published at the same time as the *IUPAC/IFCC Silver Book* which includes some terminology [86].

This *ENV* built upon the tripartite structure of the *R-66*, speaking about three axes, each of which may have a specification appended. Thus,

System(specification)--	[or em dash]	(S.3.3)
Component(specification);		(S.3.4)
kind-of-property(specification)		(S.6.19)

is in conformity with the *IUPAC/IFCC* structure (S.20.14). Yet, for the third axis, the Prestandard used the term 'property (in a general sense)' trying to adhere to the *VIM2* [7-1.1].

ꜝConcept diagrams were fashioned using the Object-Oriented Analytical modelling technique and notation of *Martin* and *Odell* [98].

In the way of earlier texts, examples of terms for dedicated kinds-of-property were given without terminological ado.

The final European Standard *Health informatics - Representation of dedicated kinds of property in laboratory medicine EN 1614*:2006 [19a] is much reduced, but still promotes the tripartite structure [131].

21.3 The *Technical Committee 251* also issued another European Prestandard *ENV 12264 Medical informatics - Categorial structures of systems of concepts - Model for representation of semantics* for the systematic production of terms and ꜝdefinitions of ꜝconcepts to be used in medical informatics [21]. As touched upon in Section 2.27, this ambitious ꜝmetalanguage was considered for general application to the present work, but abandoned in favour of the

ISO approach. Nevertheless, the function of the *CEN* model is worth considering when forming terms for dedicated kinds-of-property.

NOTE - The final version *EN 12264*:2005 *Health informatics - Categorial structures for systems of concepts* does not offer a detailed model [21a] and is essentially a vocabulary based on *ISO 1087-1* [72].

21.4 Formally, a |systematic term was said to be produced by a |generative pattern, here chosen to consist of three |base semantic categories, <term-for-(sort-of-)system>, <term-for-(sort-of-)component>, and <term-for-kind-of-property>.

NOTE 1 - The *CEN* European Prestandards referred to here did not distinguish between a concept and the representation of that concept although they are different even if |associated concepts. In the present context an attempt at distinguishing is made and this is also the case of the final *EN 1614* [19a].

NOTE 2 - In the following, for simplicity, the phrase 'sort-of-' is omitted.

The way in which these three elements are considered to be connected may vary with the viewpoint.

21.4.1 If the |target semantic category is <term-for-dedicated-kind-of-property> then <term-for-system> and <term-for-component> may be regarded as being |associated to <term-for-kind-of-property>. This situation is dissected in Table 21.4.1.

The resulting generative pattern in the *CEN ENV 12264* notation [21] is

[<term-for-kind-of-property>{specificaton-to-kind-of-property};
<term-for-component>{specification-to-component}--
<term-for-system>{specification-to-system}]

The sequence corresponds to that of common language, for example "amount-of-substance concentration of haemoglobin in blood" with specifications added. It should be noted that the |relations between the three base semantic categories for term-forming purposes seem different from those between the corresponding concepts where "system" and "component" are obviously in |partitive relation (Fig. 3.5). The *CEN* relations appear also to be different from the |concept system in Figure 20.16. However, the relations were not explicitly given by the *CEN* in the *ENV 12264* and the partitive relations shown in Figure 20.16 are believed to be appropriate for the terms. The same relations were found in the *ENV 1614* although in the *Martin* and *Odell* notation [19-Fig. 4].

Table 21.4.1 Elements of a ¦generative pattern providing ¦systematic terms for the ¦target semantic category <term-for-dedicated-kind-of-property> with <term-for-kind-of-property> as the origin. Notation according to the *CEN ENV 12264* [21]

Terminological concept[a]	**Element in a generative pattern**	**Symbol or ¦abbreviation**	**Example**
semantic link 1	has-term-for-kind-of-property:		
base semantic category 1	<term-for-kind-of-property>	k-of-p	amount-of-substance concentration[b]
differentiating criterion 1	has-term-for-kind-of-property:<term-for-kind-of-property>	k-of-p	amount-of-substance concentration
semantic link 1a	has-specification:	( )	
associated domain 1a	{specification-to-kind-of-property}	spec.$_{k\text{-}of\text{-}p}$	cyanide hemiglobin[c]
differentiating criterion 1a	has-specification:{specification-to-kind-of-property}	(spec.$_{k\text{-}of\text{-}p}$)	(cyanide hemiglobin)
semantic link 2	has-term-for-component:	;	
associated base semantic category 2	<term for component>	C	Haemoglobin
differentiating criterion 2	has-term-for-component:term-for-component>	C;	Haemoglobin;

(cont.)

[a] ¦Definitions are found in Annex A.

[b] Broken double underlining and quotation marks omitted

[c] A short term for a measurement method (S.14.11.2)

Terminological concept[a]	**Element in a generative pattern**	**Symbol or abbreviation**	**Example**
(cont.)			
semantic link 2a	has-specification:	( )	
associated domain 2a	{specification-to-component}	spec.$_{c}$	Fe
differentiating criterion 2a	has-specification:{specification-to-component}	(spec.$_{c}$)	(Fe)
semantic link 3	has-term-for system:	--	
associated base semantic category 3	<term-for-system>	S	Blood
differentating criterion 3	has-term-for-system:<term-for-system>	S--	Blood--
semantic link 3a	has-specification:	( )	
associated domain 3a	{specification-to-system}	spec.$_{s}$	venous
differentiating criterion 3a	has-specification:{specification-to-system}	(spec.$_{s}$)	(venous)

[a] Definitions are found in Annex A.

21.4.2 Another viewpoint is to consider <term-for-system> as having <term-for-component> and being described by <term-for-kind-of-property>. This may lead to the elements of a generative pattern shown in Table 21.4.2.

The formal outcome is the generative pattern

[<term-for-system>{specification-to-system}--
<term-for-component>{specification-to-component};
<term-for-kind-of-property>{specification-to-kind-of-property}]

Table 21.4.2 Elements of a ˡgenerative pattern providing ˡsystematic terms for the ˡtarget semantic category <term-for-dedicated-kind-of-property> with <term-for-system> as the origin. Notation according to the *CEN ENV 12264* [21]

Terminological concept[a]	Element in a generative pattern	Symbol or ˡabbreviation	Example
semantic link 1	has-term-for-system:		
base semantic category 1	<term-for-system>	S	Patient
differentiating criterion 1	has-term-for-system:<term-for-system>	S	Patient
semantic link 1a	has-specification:	( )	
associated domain 1a	{specification-to-system}	spec.$_s$	fasting
differentiating criterion 1a	has-specification:{specification-to-system}	(spec.$_s$)	(fasting)
semantic link 2	has-term-for-component:	--	
associated base semantic category 2	<term-for-component>	C	Oxygen
differentiating criterion 2	has-term-for-component:<term-for-component>	--C	--Oxygen

(cont.)

[a] ˡDefinitions are found in Annex A.

Terminological concept[a]	Element in a generative pattern	Symbol or abbreviation	Example
(cont.)			
semantic link 2a	has-specification:	( )	
associated domain 2a	{specification-to-component}	spec.$_{c}$	O_2; absorbed
differentiating criterion 2a	has-specification:{specification-to-component}	(spec.$_{c}$)	(O_2; absorbed)
semantic link 3	has-term-for-kind-of-property:	;	
associated base semantic category 3	<term-for-kind-of-property>	k-of-p	relative volume rate
differentiating criterion 3	has-term-for-kind-of-property: <term-for-kind-of-property>	; k-of-p	; relative volume rate
semantic link 3a	has-specification:	( )	
associated domain 3a	{specification}	spec.$_{k\text{-}of\text{-}p}$	actual/norm
differentiating criterion 3a	has-specification:{specification}	(spec.$_{k\text{-}of\text{-}p}$)	(actual/norm)

[a] Definitions are found in Annex A.

This sequence may seem more natural towards the formats otherwise used in this text: term-for-System(specification)--term-for Component(specification); term-for-kind-of-property(specification). It should be stressed, however, that the actual presentation of a systematic term does not depend on which of the two generative patterns is chosen.

21.5 Each of the base semantic categories, whether associate or not, is a set of terms for ˡbase concepts which are considered homogeneous. Thus,

<term-for-system> = {Patient, Blood, Liver, Haemoglobin, ...}
<term-for-components> = {Liver, Leukocyte, Coagulation, ...}
<term-for-kind-of-property>= {mass, number concentration, time, ...}

where the first two sets are overlapping.

21.6 The combination of a ˡsemantic link and a(n) (associated) base semantic category forms a ˡdifferentiating criterion covering a set of homogeneous terms for a segment of the terms for dedicated kinds-of-property. For example,

has-term-for-system:<term-for-system>

as one of its possibilities can deliver the term 'Patient' (Tab. 21.4.2). The terms for a component and a kind-of-property are selected homologously.

21.7 The combination of a semantic link and an ˡassociated domain also forms a differentiating criterion, but here covering a non-homogeneous set of mandatory and/or optional terms that are chosen to specify a(n) (associated) base semantic category. This sort of differentiating criterion is called 'specification' for short. For the present purpose, there are three types.

has-specification:{specification-to-system}
has-specification:{specification-to-component}
has-specification:{specification-to-kind-of-property}

Thus, the second one can deliver, e.g., two pieces of specifying data to the term for a component 'Oxygen', namely the formula entity, 'O_2' and a process descriptor, 'absorbed' (Tab. 21.4.2). In the *IUPAC/IFCC* format for terms, the specifications are given in round rather than curly brackets.

21.8 In the entries of the *IUPAC/IFCC* database of terms for dedicated kinds-of-property in laboratory medicine [87], terms for systems and components are generally taken from internationally recommended lists, such as *Nomina anatomica* of the *International Anatomical Nomenclature Committee*, *Enzyme nomenclature* of the *International Union of Biochemistry and Molecular Biology*, and chemical terms of the *IUPAC* and the *Chemical Abstracts Service*

(*CAS*). Terms for kinds-of-quantity are generally in accordance with the *ISO Standards Handbook Quantities and units* [64] when this provides a term.

21.9 A common specifying datum is a reference to an examination procedure (S.7.3). The form may be an ¹appellation or a number used in the local laboratory. Sometimes elements of the examination procedure are listed explicitly, such as calibrator, loading dose, or time interval.

It may be claimed that such information does not apply exclusively to the term for kind-of-property, but rather to the entire term for the dedicated kind-of-property. The placement is a matter of convenience.

21.10 For some dedicated kinds-of-quantity no identified separable component is relevant, for example in "mass of a person". The formal term, then, has identical terms for system and component, i.e. 'Patient--Patient; mass'. In ordinary text, the term for component may be omitted.

21.11 The systematic appellation of a singular property (S.6.14.1), further requires two mandatory data that are part of the specification to term of system, namely a unique address, such as appellation of person and date of birth, and calendar time of sampling or examination of individual.

21.12 The categorial structure and formalism of the *ENV 12264* is rather complicated, but may be useful for designers of terminological systems and software designers as well as for structuring of codes. In addition, the method can be applied in devising definitions in ¹hierarchical ¹concept systems.

21.13 Howsoever the representation of an ¹instantiated property (S.5.5) and its examination result (S.16.20) are created, the elements are the same and can be termed as proposed in this text and exemplified in Figure 21.13.

system (S.3.3) +
supersystem (S.20.14) +
spatial location (Tab.20.9)
identity number (Tab.20.9)
calendar time (Tab.20.9)
punctuation mark (S.20.14) +

Plasma(Blood; Smith JS; 201272-0755; 2002-01-03T08:45)--

specification to system (S.20.11)

spatio-temporal coordinates (S.20.2)

---

component (S.3.4) +
chemical elementary entity (S.20.11) +
punctuation mark +

Haemoglobin(Fe);

specification to component (S.20.11)

---

rational unitary kind-of-quantity (S.13.3.5) +
rational unitary quantity-value scale (S.17.18) +
rational unitary measurement procedure (S.14.6.2) +

amount-of-subst. conc.((<0,3, 0,3, 0,4,...) µmol/l; MP21)

specification to kind-of-property (S.20.11)

---

relational operator
numerical unitary quantity value (S.16.16)
SI prefix (S.18.31)
non-coherent derived metrological unit (S.18.20)
combined standard meas. uncert. (S.16.24)

= 0,5 µmol/l (u_c = 0,1 µmol/l)

measurement result (S.16.21)

quantity value (S.16.7)

Figure 21.13 Representation of a singular rational property (S.6.14.1) with ˡgeneric concepts related to dissected parts of the representation.

The elements marked with a cross point to a ˡterm for a dedicated rational kind-of-property (S.20.6).
(amount-of-subst. conc. = amount-of-substance concentration; meas. uncert. = measurement uncertainty)

22 MATHEMATICAL and LOGICAL REPRESENTATION of <DEDICATED KIND-OF-PROPERTY>

22.1 Mathematization

The mathematization of physics (S.4.3) meant that unitary quantity (S.12.17) and unitary kinds-of-quantity (S.13.3.3) by many ǀmetrologists were regarded as ǀconcepts' which can enter into algebraic equations among variables such as, respectively,

"quantity", Q,
equals
"numerical value", $\{Q\}$
multiplied by
"unit of measurement", $[Q]$

as given in Section 4.2, and

"amount of substance concentration (of component in a system)", c
equals
"amount of substance (of component)", n
divided by
"volume (of system)", V

In the following, rather than beginning the discussion with "quantity" and "kind-of-quantity", the ǀsuperordinate concepts <property> (S.5.5), <kind-of-property> (S.6.19), and <dedicated kind-of-property> (S.20.6) will be modelled according to mathematical and logical theory.

22.2 Mathematical relation according to Set Theory

22.2.1 *Zender* suggested that 'an observation or measurement may be defined as: A [mathematical] relation by which a property maps a system, a domain, onto a value, the range'. Thus the concept "property" was considered to be an open sentence, also called propositional function or relational operator [130]. Here, it will be explored whether a ǀset of singular properties (S.6.14.1) of a given dedicated kind-of-property may reasonably be represented by, not ǀdefined by, a Set-Theoretical ǀrelation.

22.2.2 For the present purpose, a Set-Theoretical relation, R, [58, 94] may be said to comprise at least

two sets, A and B, and an
open sentence, $P(x, y)$, in two variables.

The open sentence defines the relation, R, from A to B so that $P(a, b)$ is either true or false for any ordered pair (a, b) belonging to the Cartesian product $A \times B$. If $P(a, b)$ is true, 'a is related to b'. The subset of A containing the first elements in all such pairs is the domain, D (or dom$R$), of the relation, and the subset of B containing the second elements in the same pairs is the range E (or ran$R$). All the pairs (a, b) for which $P(a, b)$ is true constitute the elements of the solution set, R^*, of the relation, R, and are a subset of $A \times B$.

NOTE - $P(x, y)$ is also called a propositional function defined on $A \times B$.

As a relation may have an open sentence in more than two variables, a general symbolic expression is

$$R = (A, B, C, \ldots, P(x, y, z, \ldots))$$

22.2.3 The following comprehensive set of symbols, also called a dictionary, will be used for selection as appropriate in exploring whether the structure of a Set-Theoretical relation, R, may represent a set of singular properties of systems. More extensive dictionaries are seldom necessary.

S set of space-time coordinated systems of a given sort
s identity variable on S
$S_{v,1}$ set of (distributions of) property values for the defining input properties of a given kind-of-property on the systems S
$s_{v,1}$ input property value variable on $S_{v,1}$
$S_{v,2}$ set of (distributions of) property values for the defining input properties of a given kind-of-property, different from that of $S_{v,1}$, on the systems S
$s_{v,2}$ input property value variable on $S_{v,2}$
$C1$ set of components of a given sort, each within its respective system
$C1_v$ set of (distributions of) property values for the defining input properties of a given kind-of-property on the components $C1$
$c1_v$ input property value variable on $C1_v$
$C2$ set of components of a given sort (different from $C1$) each within its respective system
$C2_v$ set of (distributions of) property values for defining input properties of a given kind-of-property on the components $C2$
$c2_v$ input property value variable on $C2_v$

V set of (distributions of) output property values for the examinands of a given dedicated kind-of-property on the set of systems S including any relevant components $C1$, $C2$, ...

v output property value variable on V

$P(s, s_{v,1}, s_{v,2}, c1_v, c2_v, \ldots, v)$ = "open sentence"

NOTE 1 - The identity variable s applies to S and indirectly to $C1$, $C2$, and V, ensuring a correct coupling between ˡinstances of system (S.3.3) and any of its component(s) (S.3.4) and output property values. In the simplest case where a (distribution of) property values on a system is sufficient, i.e. there is no calculation involving input property values either on system or component(s), the chosen input property values of $S_{v,1}$ are identical with the output property values of V. (An example is given in S.22.2.4.1.) When only one ˡset of property values on system or component is involved, the indices 1 and 2 may be omitted.

NOTE 2 - An instance of "property" is assumed to involve inherently a distribution of (unknowable) true property values (S.9.17, 9.18). As an examinand (S.5.7), the property involves a distribution of possible examined property values, which upon examination (S.8.4) transmutes into a set of examined property values (S.9.20).

To simplify descriptions in the following, the phrase 'space-time coordinated' will be understood for the elements of set S, and the parenthetic phrase 'distribution of' will be understood for the sets $S_{v,1}$, $S_{v,2}$, $C1_v$, $C2_v$, and V. Furthermore, when a dictionary mentions, e.g., 'system', 'component', or 'value', it will be understood to mean 'representation of system', etc. Also, ˡabbreviated ˡterms such as 'value' will be used, and specific kinds-of-property will generally not be indicated by quotation marks and broken double underline.

22.2.4 The simplest situation is a property related to a system without need to regard any of its elements, for example under the ˡgeneral concept "mass of person", i.e. a dedicated kind-of-quantity (S.20.7).

22.2.4.1 A straightforward structure could be

$R = (S, V, P(s, v))$ where

S set of persons; variable s

V set of values for masses of persons; variable v

$P(s, v)$ = "s has mass equal to v"

Here, each value (in a distribution) is a positive number, called the numerical unitary quantity value (S.16.16), multiplied by a metrological unit (S.18.12), for example "kilogram". This format corresponds to the traditional equation of 'quantity = numerical value · unit' (S.4.2).

22.2.4.2 Another expression within the same format of two variables is obtained by changing the definitions of V and $P(s, v)$ to

V set of numerical values for masses of persons; variable v
$P(s, v)$ = "s has mass divided by kilogram equal to v"

22.2.4.3 A variable metrological unit may be introduced as follows.

$R = (S, N, U, V, P(s, n, u, v))$ where
S set of persons; variable s
N set of numerical values for masses of persons; variable n
U set of metrological units for mass; variable u
V set of values for masses of persons; variable v
$P(s, n, u, v)$ = "s has mass of numerical value n times unit u equal to v"

22.2.4.4 In the following examples, the product of numerical property value and metrological unit forming one element - as in Section 22.2.4.1 - will be preferred because the explicit presentation of property values or choice of the metrological unit is not an issue here.

22.2.5 Nominal properties (S.12.4), having non-numerical values, such as "colour (of urine)" may be represented as follows.

S set of urines voided by respective persons; variable s
V set of values for colour of urines voided; variable v
$P(s, v)$ = "s has colour equal to v"

where values such as (pale yellow, yellow, orange, red, ...) are involved (equal-to sign and broken underline omitted for simplicity).

22.2.6 When a component is explicitly involved in the definition of a dedicated kind-of-property - as is mostly the case in laboratory medicine - the following relations may apply for, e.g., "mass concentration of lipid in blood of a person".

22.2.6.1 The detailed expression is

$R = (S, S_v, C, C_v, V, P(s, s_v, c_v, v))$ where
S set of blood compartments in respective persons; variable s
S_v set of values for volumes of blood compartments; variable s_v
C set of lipid components in respective blood compartments
C_v set of values for masses of lipid components; variable c_v
V set of values for mass concentrations of lipid in blood compartments; variable v

$P(s,\ s_v,\ c_v,\ v)$ = "s has mass c_v divided by volume s_v equal to mass concentration v"

where each value in V is zero or a positive real number multiplied by "gram per litre".

22.2.6.2 Alternatively, an open sentence in two variables may be defined by

$R = (S,\ V,\ P(s,\ v))$
$P(s,\ v)$ = "s has mass concentration of lipid equal to v"

where the kind-of-property "mass_concentration" has to be independently defined as 'mass of component divided by volume of system'.

22.2.7.1 In the case of two components in a system being involved, e.g. for the "mass ratio of one component (albumin) over another component (globulin) in the system (plasma of the blood compartment of a given person)", the structure of Section 22.2.6.1 is simply extended so that sets $C2$ and $C2_v$ and variable $c2_v$ apply to the component "globulin", whereas C_1, $C1_v$, and $c1_v$ relate to "albumin". The open sentence then reads

$P(s,\ s_v,\ c1,\ c1_v,\ c2,\ c2_v,\ v)$ = "s has mass $c1_v$ divided by mass $c2_v$ equal to mass ratio v"

22.2.7.2 Alternatively, the structure of Section 22.2.6.2 yields

$P(s,\ v)$ = "s has mass ratio of albumin over globulin equal to v"

In any case, each value in V is zero or a positive real number (except in the unlikely case when the mass of globulin is zero).

22.2.8 In the relations defined in Sections 22.2.4 to 22.2.7, specifications may be introduced to descriptions of set of systems, set(s) of components and/or open sentence, e.g. as follows.

22.2.8.1 In "mass of person" (S.22.2.4.1), the laconic designation 'set of persons' would include individuals irrespective of the mass of their clothing. Specifying, e.g., 'set of persons in underwear without shoes' would decrease most values of instances.

22.2.8.2 In "mass concentration of lipid in blood" (S.22.2.6.1), 'set of lipid components ...' could be specified to read either 'set of lipid components extractable by ether ...' or 'set of lipid components isolated by ultracentrifugation ...'. The original and the two modified sets of definitions would correspond to three different sets of values for "mass concentration", respectively related to different sets of examinands (S.5.7).

22.2.8.3 In "colour of urine" (S.22.2.5), the open sentence has the designation 'colour' which tells nothing about the characteristics of the detector in the examining system. The possible values corresponding to "colour" do not exist meaningfully without the requirements given in the examination procedure (S.7.3), i.e. the value is procedure dependent. Therefore, the value will vary with the designations 'colour by naked eye', 'colour by naked eye in person not being colour blind', or 'colour by reflectoscope'.

22.2.8.4 Thus, instances of a given relation have values that are dependent on the details of all parts of the relation.

22.2.9 The systems hitherto described are residing in or related to persons and have singular properties with unknowable true values. When samples of the system are obtained, such samples are meant to be representative of their respective parent systems and to have closely similar true values of their own. Yet, sampling is an important source of examination uncertainty (S.16.23) because it is the property values in the original system that are of interest.

22.2.10 The common sets of singular properties under a dedicated kind-of-property discussed in this Chapter support the *first possibility* of representation by a Set-Theoretical relation with at least two variables, namely a system identity variable and a value variable. Often, one or more further variables on system and/or components are involved, either directly in the open sentence (S.22.2.6.1, 22.2.7.1) or in an associated definition (S.22.2.6.2).

22.2.11 Many sets of singular quantities (S.6.14.2) have a defining open sentence in which the terminological phrase connecting the two variables can be substituted by an algebraic expression of one or more defining variables of properties operating on system and/or its components.

The representation of a singular property requires specifications, including at least the space-time coordinates of a given system. In laboratory medicine, the immediate system, e.g. "Blood", is often a part of a person as a supersystem which then carries such identification and coordinates.

22.2.12 As mentioned before (S.22.2.1), the idea of regarding "property" in the light of Set Theory was advanced by *Zender* [130] who suggested that 'In terms of logics, the property maps the system onto the value'. Examples given of properties included |mass is|, |concentration was|, |color is|.

22.2.13 There are clear similarities between this description by *Zender* and the formalism detailed in Sections 22.2.1 to 22.2.10, but there are also differences.

22.2.13.1 From a formal point of view, *Zender* used the terms '*relation*' and 'open sentence', but the consistent use of 'domain', 'range', 'mapping', and 'onto the set' as well as the diagram of domain and range linked by an arrow labelled "property" is at least consistent with the structure of a Set-Theoretical *function* [94]. Accordingly, *Zender* stated that 'Often, in metrology, this relation is also a function'. Such a structure will be discussed in Section 22.4.

22.2.13.2 More fundamental is the choice by *Zender* that the relation represents 'an observation or measurement' (here collectively called 'examination') - that is a physical or physiological *activity* - whereas the present model allows a preexaminational existence of an instance of "property of a system", independent of any actual examination.

22.2.13.3 Consequently, the 'range' in *Zender*'s description has elements of observed or measured values, one value for each instance of a relation. The present model suggests a distribution of "true values" or of "possible examined values" for each instance whereas the relation to examined values is a separate matter.

22.2.13.4 Both models allow specifications to system, component(s), and open sentence in accordance with the *R-66* [39]. All general specifications may be put in the open sentence. The instantiating space-time coordinates are a specification to the system as mentioned in Section 22.2.11, para 2.

22.3 Relation according to Object-Oriented Analysis

22.3.1 Object-Oriented Analysis, OOA, defines "relation" in several ways, but a formulation based on *Martin* & *Odell* [98] could be 'concept that applies to a set of tuples', where each tuple may be a couple, triple, or higher *n*-tuple.

> NOTE - This definition is a composite of several definitions where "concept" is also called 'object type', 'set', and 'extension'. (Such synonyms are not consistent with *ISO 1087-1* [72].)

An alternative definition is 'concept with places' where each place is itself a concept.

22.3.2 Based on this understanding of "relation" a *second entry* for a representation of a set of singular properties under a dedicated kind-of-property in its simplest form, only involving couples, could be an Object-Oriented-Analytical relation with a couple representing system and distribution of property values (S.9.15).

This definition resembles the description in Section 22.2.2, but there is an important difference in that the Set-Theoretical relation has *ordered* pairs giving a 'direction' from *S* to *V* whereas the OOA relation has couples that are not necessarily composed of ordered elements. Presently, the former conceptions of "relation" is preferred due to its evident possibilities of a detailed structure.

22.4 Function according to Theory of Sets

22.4.1 It is worthwhile exploring whether, in Set Theory, the special type of relation called a function is an adequate fit for a representation of a set of singular properties under a dedicated kind-of-property.

Bunge stated that 'Functions are the structure of quantitative concepts or *magnitudes*, also called quantities. For example, temperature is a function *T* that maps the set of bodies (generic representative: σ) into the set of real numbers (generic representative: *t*).' [14-p.61] and that 'A *metrical predicate* (numerical functor, quantity, or magnitude) designates a quantitative property. A magnitude, such as length or stimulus strength, is a complex concept that can be analyzed into object variable(s), numerical variable(s), and a function from the former to the latter.' [15-p.198].

Zender later mentioned the possibility of a function in passing [130], but *Bunge* in his recent description of "quantity" [17] simply stated that 'an intrinsic (non-relational) quantitative property ... can be conceptualized as a function from a collection A of (actual or possible) things into a set X of numbers, such as the natural numbers or the real line. That is, $P:A \rightarrow X$. Examples: population, age, and wage.'

NOTE 1 - Strictly speaking, the examples 'age' and 'wage', do not fit the formula as given because their values have metrological units of time and currency respectively.

If metrological units are involved, 'the preceding formula must often be replaced with $P:A \times U_P \rightarrow X$, where U_P stands for the collection of all possible units of P'.

22.4.2 The Set-Theoretical function, *f*, in its simple form as a 2-set function (binary function) may be described as follows [94].

two sets, A (domain of f, dom$f$) and B (co-domain of f) and a function f

where the function assigns to each element, a, (also called the argument) in the set A a unique element, $f(a)$, (the image) (also called the value) in the set B. The function f is said to map A into B, symbolized

$f{:}A \rightarrow B$

Mapping 'into' means that each element in B needs not appear as the image of an element in A. Those elements of B that do appear as an image of at least one element in A constitute the range, $f(A)$ or ran$f$, of the function $f{:}A \rightarrow B$.

22.4.3 Homologously, with the symbolism chosen for relations (S.22.2.3), the following is adopted for a function.

S set of systems (= domain)
V set of (distributions of) values (= co-domain)
f assign to each element in S its element in V

and the typical situations given in some of the previous sections of this Chapter may be reformulated as follows.

22.4.3.1 "Mass of person" (cf. S.22.2.4.1)

S set of persons
V set of values for masses of persons
f assign to each person his or her value for mass

NOTE - The Notes 1 and 2 of Section 22.2.3 apply as appropriate.

22.4.3.2 "Colour of urine" (cf. S.22.2.5)

S set of urines voided by respective persons
V set of values for colour of urines voided
f assign to each urine its value for colour

22.4.3.3 "Mass concentration of lipid in blood" (cf. S.22.2.6.2)

S set of blood compartments in respective persons
V set of mass concentration of lipid in blood compartments
f assign to each blood compartment its value for mass concentration of lipid

NOTE - The simple 2-set function applied here does not accommodate explicitly the separate set for lipid component as in Section 22.2.6.1.

22.4.3.4 "Mass ratio of albumin over globulin in plasma" (cf. S.22.2.7)

- S set of plasma compartments in respective persons
- V set of values for mass ratio of albumin over globulin in plasma compartments
- f assign to each plasma compartment its value for mass ratio of albumin over globulin

NOTE - This 2-set function does not allow separate sets for albumin components and globulin components as in the relation of S.22.2.7.1.

22.4.4 The structure of a Set-Theoretical 2-set function is seemingly simpler than that of a 2-variable relation and seems to represent a set of singular properties under a dedicated kind-of-property just as well. Again, any relationship between input properties defining an output property has to be described separately or is given as a part of the definition of f; a reference to examination procedure may also be incorporated in the function.

22.4.5 The representation of a set of singular properties under a dedicated kind-of-quantity involving a relationship between input properties may be structured as a *product function* [94]. Thus,

$f{:}A \rightarrow B$ and $g{:}B \rightarrow C$, giving the function
$(g \circ f){:}A \rightarrow C$ where
$(g \circ f)(a) \equiv g(f(a))$.

As an example, the "mass concentration of lipid in blood" (S.22.2.6.1) could be expressed as

$(g \circ f){:}S \rightarrow V$ with $f{:}S \rightarrow L$, and $g{:}L \rightarrow V$ where $(g \circ f)(a) \equiv g(f(a))$

- S set of blood compartments in respective persons
- f to each blood compartment, assign its value for mass of lipid
- L set of blood compartments with values for mass of lipid $= f(a)$
- g to each value for mass of lipid assign the reciprocal of the value for the volume of blood compartment
- V set of values for mass concentrations of lipid in blood compartments $= g(f(a))$

22.4.6 For a given instance of "system", there is only one (distribution of) value(s) - whether true or possible examined or examined under stated precision conditions - but not all values in V need to be used, and a given value may be the image of several systems. Therefore, for a given set of singular properties under a dedicated kind-of-property, $f{:}S \rightarrow V$ may be called an 'into function' for which the range is a subset of the co-domain.

22.4.7 Thus, a *third entry* for representation of a set of singular properties under a dedicated kind-of-property could be a Set-Theoretical function mapping a set of representation of system into a set of representation of distribution of property values (S.9.15).

22.5 Function according to Object-Oriented Analysis

The definition of function in Object-Oriented Analysis according to *Martin & Odell* [98] may be phrased 'mapping process that, given an object of one set or an object from each of several sets, returns a set of objects in the same or a different set or in each of several sets'. A function requiring multiple objects for mapping is called a multi-argument function, and a function returning an unspecified number of objects is multivalued.

On this basis, a *fourth description* of a representation of a set of singular properties under a dedicated kind-of-property could be phrased as an Object-Oriented Analytical function that takes one or more representations of distribution of property values pertaining to a system and/or its component(s) as argument(s) and returns the representation of a distribution of property values (S.9.15).

The dedicated kind-of-property "mass concentration of lipid in blood" (cf. S.22.2.6) could be represented by the conventional function "mass concentration", defined as 'mass of component divided by volume of system', which given two arguments "(distribution of) value(s) for mass of lipid in blood compartment" and "(distribution of) value(s) for volume of system" would return the "(distribution of) value(s) for mass concentration of lipid in blood".

22.6 Operational definition in a measurement sense

The Object-Oriented Analytical function (S.22.5) defines "representation of dedicated kind-of-property" in a mathematically operational manner. There is also an early proposal by *McGlashan* [101] that is truly operational in a measurement sense (S.12.18).

> *physical quantity*: complete specification of the operations used to measure the ratio (a pure number) of two instances of the physical quantity

This definition can only apply to instances of properties having values that are a product of numerical value and unit, but a larger extension encompassing instances of nominal properties (S.12.4) and ordinal quantities (S.12.16) might be achieved by some modification. More fundamentally, however, such a definition seems to render the general concept "physical quantity" identical with "measurement procedure" (S.14.4.4). That is an intriguing idea, but it seems that there is a vast difference between the instances of "quantity" describing defined systems and instances of "measurement procedure" that are texts.

22.7 Review of various representations of <dedicated kind-of-property>

22.7.1 Comparing the terminologically derived definition of "property" given in Section 5.5 with those that are mathematized representations of dedicated kinds-of-property and respectively based on

- relation of Set Theory (S.22.2.10),
- relation of Object-Oriented Analysis (S.22.3),
- function of Set Theory (S.22.4.7), or
- function of Object-Oriented Analysis (S.22.5),

these four all - with various wordings - 'relate' or 'map' "system" to "distribution of values". Any relevant components are mentioned in the definition or in notes.

22.7.2 The *open sentence from a 'relation' of Set Theory* is formalized and can be structured to accommodate the elements in any singular property as explicitly as is needed.

22.7.3 The *OOA relation* does not add useful expressions to the Set-Theoretical solution unless detailed formalized graphical representations are needed.

22.7.4 The *function of Set Theory*, is a tempting choice, but the syntax is not as immediately adaptable and explicit as that of the relation.

22.7.5 The *OOA function* does not seem to have structural possibilities above that of the relation of Set Theory.

22.8 Choice of formalism

The Set-Theoretical relation appears to be the best choice among the possibilities discussed, allowing a flexible, exhaustive, and systematically formal description of the elements in a representation of the extension of "dedicated kind-of-property" as a feature of "system" (with relevant "component(s)") related to a "distribution of property values".

A Set-Theoretical relation represents "dedicated kind-of-property" according to the definition given in Section 20.6.

Accordingly, the following definition may be offered.

<u>Set-Theoretical representation of dedicated kind-of-property</u> relation consisting of at least a set of representations of **systems** (S.3.3), a set of representations for each of any relevant **components**, a set of representations of distributions of **property values** (S.9.15), and an open sentence in the corresponding variables that involves at least one **kind-of-property** (S.6.19)

NOTE - The general symbolic expression is $R = (S, C, \ldots, V, P(s, c, \ldots, v))$ where the last element is the open sentence, also termed propositional function, defined on the Cartesian product $S \times C \times \ldots \times V$. All true n-tuples constitute the solution set R^{*}.

EXAMPLE 1 - The simplest relation is

$$R = (S, V, P(s, v))$$

where, e.g., S is a set of representations of persons, V is a set of representations of values of masses, and $P(s, v)$ is the open sentence in two variables, 's has mass equal to v'.

EXAMPLE 2 - When a component in blood is involved the relation

$$R = (S, S_v, C, C_v, V, P(s, s_v, c_v, v))$$

where, e.g., S is a set of representations of blood compartments in respective persons, S_v is a set of values for volumes of blood compartments, C is a set of lipid components in respective blood compartments, C_v is a set of values for mass of lipid components, V is a set of values for mass concentrations of lipid in blood compartments, and $P(s, s_v, c_v, v)$ is the open sentence in four variables "s has mass c_v divided by volume s_v equal to mass concentration v".

23 CONCLUSIONS

The need to present data about the outcome of various types of examination of a multitude of properties of different kinds describing many types of object is typical for laboratory disciplines such as laboratory medicine. The relevant special language is mostly found in texts on metrology, notably the *International vocabulary of metrology* (*VIM3*:2007) [132]. These sources, however, are partially conflicting, have not all been established in a coherent fashion using adequate terminological procedures, and by definition relate only to quantities, ignoring all properties without magnitude.

Drawing on a variety of texts, it proves possible to form a comprehensive domain ontology around "property" with systematic definitions and terms constructed by using the tools provided in recent *ISO* International Standards on terminology work [63, 71, 72], supplemented by a few extra concepts to clarify the discussion.

The backbone of the concept system is furnished by "system" including "component" and associated with "property", further connected by consecutive associative relations to "examination procedure", "examination", "property value", and "property value scale". The description is supplemented by "kind-of-property" to indicate a generic concept for singular, mutually comparable properties.

From each of these vertebral superordinate concepts, specific concepts are intensively defined and given systematic terms using the modifiers 'nominal', 'ordinal', 'differential', and 'rational'. Each of the ensuing coordinate concepts corresponds to a typical allowed mathematical and statistical treatment of the property values, i.e. fundamentally the respective applicability of the operators $(=, \neq)$, $(>, =, <)$, $(+, -)$, and $(\times, :)$ in four increasing sets obtained by cumulation to the right.

For the narrower field of metrology, ignoring nominal properties, an alternative concept system is presented based on "quantity", which covers all properties having magnitude. The following subordinate level separates "ordinal quantity" and "unitary quantity", the latter covering in its turn the specific concepts "differential quantity" and "rational quantity".

Supplementary concepts comprise "examinand" and "measurand", "examination method" and "measurement method", "examination principle" and "measurement principle", "true property value" and "examined property value", as well as "measurement", "quantity value", and "numerical unitary quantity value". Also "examination result" and "measurement result" with respective "examination uncertainty" and "measurement uncertainty", as well as "quantity value scale" are defined.

For differential and rational properties, the concept "metrological unit" is essential to their measurement and expression of unitary quantity values, although the term for a unit does not indicate the kind-of-quantity. Furthermore, great advantage accrues from creating a "system of metrological units", preferably a universal "coherent system of metrological units". Currently, this is the "International System of Units", SI, formed from specific concepts of "base metrological unit" (seven in all) and of "coherent derived metrological unit" (a large number), with multiples and submultiples obtained by SI prefixes; these concepts are defined as well as "off-system metrological unit" and "in-system metrological unit". The lack of a special term for "metrological unit one" is discussed with support for the proposal 'uno' by the *CIPM Consultative Committee for Units*. The *BIPM brochure* on the SI has no formal definitions, but a concept system can be inferred from the text.

The further abstraction of "unitary kind-of-quantity" via "metrological unit" leads to "metrological dimension", which is a powerful tool in "dimensional analysis" based upon the defining algebraic relationship between unitary kinds-of-quantity. As is the case for metrological unit, a metrological dimension does not identify a unique corresponding unitary kind-of-quantity. Also "base metrological dimension" and "derived metrological dimension" can be defined, as well as the much discussed "derived metrological dimension one".

The designations for singular properties have been given a syntactic structure and semantic rules during forty years of work within the *IUPAC*, the *IFCC*, and lately the *CEN*. It is proposed that the tripartite general concept comprising "system", "component", and "kind-of-property" enters into the definition of "dedicated kind-of-property". It is shown that the *CEN Technical Committee 251* originally suggested semantic model for definitions and terms for specific concepts utilizing generative patterns can be applied in forming representations of such dedicated kinds-of-property.

Finally, it proves possible to regard representations of individual concepts under "property" and "property value" in a mathematical and logical formalism operating according to the definition of a given dedicated kind-of-property. Examples are given for relation or function within Set Theory or Object-Oriented Analysis. The Set-Theoretical relation appears most flexible and leads to a definition of "Set-Theoretical representation of dedicated kind-of-property".

The outcome of the investigation is a concept system with definitions and systematic terms permitting unambiguous description of dedicated kinds-of-property (except those involving vectors and tensors), designations for singular properties, and examination results encountered in laboratory work.

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The following abbreviations of organizations are used.

BIPM	Bureau International des Poids et Mesures International Bureau of Weights and Measures
CEN	Comité Européen de Normalisation European Committee for Standardization
IEC	International Electrotechnical Commission
IFCC	International Federation of Clinical Chemistry (and Laboratory Medicine)
ILAC	International Laboratory Accreditation Cooperation
ISO	International Organization for Standardization
IUPAC	International Union of Pure and Applied Chemistry
IUPAP	International Union of Pure and Applied Physics
JCGM	Joint Committee for Guides in Metrology
OIML	Organisation Internationale de Métrologie Légale International Organization of Legal Metrology
WHO	World Health Organization

NOTE - Compared to the list in the previous version of this text [131], several entries have been updated with unchanged numbers or as an additional entry marked 'a'. A few entries have been omitted, indicated by 'void', or added at the end (131, 132, 133, 134).

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ANNEX A

Alphabetical vocabulary of terminology and metrology

The entries concern concepts having terms that are used in the main text without definitions (except for discussion in a few cases).

The abbreviated source of the term and definition of a concept is stated with the following meaning.

[CEN-subclause no.] for
CEN. Medical informatics - Categorial structures of systems of concepts - Model for representation of semantics. European prestandard ENV 12264. Brussels: CEN, 1997:55 pp. [21]

[ISO-subclause no.] for
ISO. Terminology work. Vocabulary. Part 1: Theory and application. ISO 1087-1. 1st ed. Geneva: ISO, 2000:viii + 42 pp. [72]

[ISO 3534-1-subclause no.] for
ISO. Statistics - Vocabulary and symbols - Part 1: General statistical terms and terms used in probability. ISO 3534-1. 2nd ed. Geneva: ISO, 2006:viii + 105 pp. [65]

[ISO 5127-subclause no.] for
ISO. Information and documentation. Vocabulary. ISO 5127. Geneva: ISO, 2001:iv + 152 pp. [62]

[VIM-subclause no.] for
JCGM. International vocabulary of metrology - Basic and general concepts and associated terms. English and French. In the name of BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP, OIML. JCGM 200, 2008. Geneva: ISO/IEC Guide 99: 2007:xiv + 92 pp. [132]

The preferred term is given in **underlined bold type**.

An admitted term is given in lightface type.

Any term in a definition of a concept defined elsewhere in this vocabulary is given in **bold type**.

When the reference is preceded by ≈, the definition has been modified to obtain homogeneity. ≠ means 'different from'.

A given entry may not contain the notes and examples of the corresponding source entry.

abbreviation: **designation** formed by omitting **words** or letters from a longer form and designating the same **concept** [ISO-3.4.9]

acronym: **abbreviation** made up of the initial letters of the components of the full form of the **designation** or from syllables of the full form and pronounced syllabically [ISO-3.4.10]

admitted term: **term** rated according to the scale of the term acceptability rating as a synonym for a **preferred term** [ISO-3.4.16]

appellation; name: verbal **designation** of an **individual concept** [ISO-3.4.2]

associated concept: concept connected to a base concept by a semantic link [CEN-3.23] associated domain: set of associated concepts not considered as establishing a semantic category [CEN-3.25]

associated semantic category: semantic category standing for a set of associated concepts [CEN-3.24]

associative relation; pragmatic relation: relation between two concepts having a non-hierarchical thematic connection by virtue of experience [ISO-3.2.23]

attribute: quality ascribed to a person or thing [1]

base concept: concept used systematically as superordinate concept in intensional definitions [CEN-3.20]

base quantity: quantity in an conventionally chosen subset of a given system of quantities, where no subset quantity can be expressed in terms of the others [VIM-1.4]

base semantic category: semantic category standing for a set of base concepts [CEN-3.21]

borrowed term: term taken from another language or from another subject field [ISO-3.4.6]

broader concept - see superordinate concept

calibration: operation that, under sapecified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication [VIM-2.39]

categorial structure: reduced concept system to describe the organization of the semantic categories in a particular concept system [≈ CEN, 3.28]

causal relation: associative relation involving cause and its effect [ISO-3.2.26]

characteristic: abstraction of a property of an object or of a set of objects [ISO-3.2.4] ≠ [70-3.5.1]

code (2): set of data transformed or represented in different forms according to a pre-established set of rules [≈ ISO 5127-1.1.4-07]

coherent derived unit: derived unit that, for a given system of quantities and for a chosen set of base units, is a product of powers of base units with no other proportionality factor than one [VIM-1.12]
EXAMPLE - In the International System of Units, mol m^{-3}, not mol l^{-1} $= 10^3$ mol m^{-3}

complex term: term containing two or more roots [ISO-3.4.5]

comprehensive concept: concept in a partitive relation viewed as the whole [ISO-3.2.17]

concept: unit of knowledge created by a unique combination of characteristics [ISO-3.2.1]

concept diagram: graphic representation of a concept system [ISO-3.2.12]

concept field: unstructured set of thematically related concepts [ISO-3.2.10]

concept system; system of concepts: set of concepts structured according to the relations among them [ISO-3.2.11]

context: text which illustrates a concept or the use of a designation [ISO-3.6.10]

conventional reference scale: quantity-value scale defined by formal agreement [VIM-1.29]

coordinate concept: subordinate concept having the same nearest superordinate concept and same criterion of subdivision as some other concept in a given concept system [ISO-3.2.19]

corpus: collection of language data brought together for analysis [ISO-3.6.9]

correction: compensation for an estimated systematic effect [VIM-2.53]

<u>correction factor</u>: numerical factor by which the uncorrected **measurement result** is multiplied to compensate for systematic error [≈ 7-3.16]

<u>definiendum</u>: **concept** to be described

<u>definiens</u>: description of the meaning of a **concept**

<u>definition</u>: representation of a **concept** by a descriptive statement which serves to differentiate it from related concepts [ISO-3.3.1]

<u>delimiting characteristic</u>: **essential characteristic** used for distinguishing a concept from related concepts [ISO-3.2.7]

<u>derived quantity</u>: **quantity**, in a system of quantities, defined in **terms** of the base **quantities** of that system [VIM-1.5]

<u>designation</u>; designator: representation of a **concept** by a sign which denotes it [ISO-3.4.1]

designator - see designation

<u>differentiating criterion</u>: group of **characteristics** used as basis for the establishment of systematic divisions in a **concept system** [≈ CEN-3.26]

dimension - see quantity dimension

dimensionless quantity - see quantity of dimension one

domain - see subject field

<u>entity</u>; item: that which can be individually described and considered [68-1.1]

<u>equivalence</u>: **relation** between **designations** in different languages representing the same **concept** [ISO-3.4.21]

error - see measurement error

<u>essential characteristic</u>: **characteristic** which is indispensable to understanding a **concept** [ISO-3.2.6]

<u>estimate</u>: observed value of an estimator [ISO 3534-1-1.31]
EXAMPLE - 4,7 mmol l^{-1} for experimental standard deviation

etalon - see measurement standard

<u>extension</u>: totality of **objects** to which a **concept** corresponds [ISO-3.2.8]

<u>extensional definition</u>: description of a **concept** by enumerating all of its **subordinate concepts** under one criterion of subdivision [ISO-3.3.3]

<u>general concept</u>: **concept** which corresponds to two or more **objects** which form a group by reason of common properties [ISO-3.2.3]

<u>generative pattern</u>: expression to generate **systematic terms** for a subset of **concepts** of a given **target semantic category** [≈ CEN-3.27]

<u>generic concept</u>: **concept** in a **generic relation** having the narrower **intension** [ISO 3.2.15]

<u>generic relation</u>; genus-species relation: **relation** between two **concepts** where the **intension** of one of the concepts includes that of the other concept and at least one additonal **delimiting characteristic** [ISO-3.2.21]

genus-species relation - see generic relation

<u>glossary</u>: terminological dictionary which contains a list of **designations** from a **subject field** together with **equivalents** in one or more languages [ISO-3.7.3]

<u>hierarchical relation</u>: **relation** between two **concepts** which may be either a **generic relation** or a **partitive relation** [ISO-3.2.20]

<u>homonymy</u>: **relation** between **designations** and **concepts** in a given language in which one designation represents two or more unrelated concepts [ISO-3.4.25]

identifier - see systematic term

<u>individual concept</u>: **concept** which corresponds to only one **object** [ISO-3.2.2]

<u>instance</u>: single **object** among an **extension**

<u>intension</u>: set of **characteristics** which makes up the **concept** [ISO-3.2.9]

<u>intensional definition</u>: **definition** which describes the **intension** of a **concept** by stating the **superordinate concept** and the **delimiting characteristics** [ISO-3.3.2]

<u>International System of Units, SI</u>: system of units, based on the International System of Quantities, their names and symbols, including a series of prefixes and their names and symbols, together with rules for their use, adopted by the General Conference on Weights and Measures (CGPM) [VIM-1.16]

item - see entity and object

language for special purposes - see special language

LSP - see special language

<u>measurand</u>: **quantity** intended to be measured [VIM-2.3]

<u>measurement</u>: process of experimentally obtaining one or more **quantity values** that can reasonably be attributed to a **quantity** [VIM-2.1] (see also S.15.14.1, 15.14.2)

<u>measurement error</u>; error of measurement; error: measured quantity value minus a reference quantity value [VIM-2.16]

<u>measurement method</u>; method of measurement: generic description of a logical organization of operations used in a **measurement** [VIM-2.5]

<u>measurement principle</u>; principle of measurement: phemomenon serving as a basis of a **measurement** [VIM-2.4]
EXAMPLE - atomic absorption spectrometry applied to the measurement of the amount-of-substance concentration of calcium(II) in human blood plasma

<u>measurement result</u>; result of measurement: set of **quantity values** being attributed to a **measurand** together with any other available relevant information [VIM-2.9]

<u>measurement standard</u>; etalon: realization of the definition of a given **quantity**, with stated **quantity value** and associated **measurement uncertainty**, used as a reference [VIM-5.1]
EXAMPLES - 1 kg mass standard, standard hydrogen electrode, cortisol in human serum for calibration

<u>measurement uncertainty</u>; uncertainty of measurement; uncertainty: non-negative parameter characterizing the dispersion of the **quantity values** being attributed to a **measurand**, based on the information used [VIM-2.26]
EXAMPLE - half width of an interval around a measured quantity value having a stated coverage probability (see also S.16.24)

<u>measurement unit</u>; unit of measurement; unit: particular **quantity**, defined and adopted by convention, with which any other quantity of the same kind can be compared to express the ratio of the two quantities as a number [VIM-1.9]

<u>measuring system</u>: set of one or more measuring instruments and often other devices, including any reagent and supply, assembled and adapted to give information used to generate measured quantity values within specified intervals for **quantities** of specified kinds [VIM-3.2]

<u>metalanguage</u>: language or symbolic system used to discuss, describe, or analyze another language or symbolic system [118]

method of measurement - see measurement method

<u>metrology</u>: science of **measurement** and its application
NOTE - Metrology includes all theoretical and practical aspects of measurement, whatever the **measurement uncertainty** and field of application [VIM-2.2]

<u>microstructure</u>: arrangement of data in each entry of a collection [ISO-3.7.8]

<u>monosemy</u>: **relation** between **designations** and **concepts** in a given language in which one designation only relates to one concept [ISO-3.4.23]

name - see appellation

narrower concept - see subordinate concept

neologism - see neoterm

<u>neoterm</u>; neologism: new **term** coined for a given **concept** [ISO-3.4.7]

<u>nomenclature</u>: **terminology** structured systematically according to pre-established naming rules [ISO-3.5.3]

<u>numerical quantity value</u>; numerical value of a quantity; numerical value: number in the expression of a **quantity value**, other than any number serving as he reference [VIM-1.20]

numerical value - see numerical quantity value

<u>object</u>: anything perceivable or conceivable [ISO-3.1.1 = 92-3.1.2.11 for item; object; entity]

<u>off-system measurement unit</u>; off-system unit: **measurement unit** that does not belong to a given system of units [VIM-1.15]
EXAMPLES - minute, degree Fahrenheit, WHO international units, with respect to the **International System of Units**

off-system unit - see off-system measurement unit

<u>onomasiology</u>: linguistic discipline giving **terms** to **concepts**

<u>parameter</u>: index of a family of distributions [≈ ISO 3534-1-2.9]

<u>partitive concept</u>: **concept** in a **partitive relation** viewed as one of the parts making up the whole [ISO-3.2.18]

<u>partitive relation</u>; part-whole relation: **relation** between two **concepts** where one of the concepts constitutes the whole and the other concept a part of that whole [ISO-3.2.22]

part-whole relation - see partitive relation

<u>polysemy</u>: **relation** between **designations** and **concepts** in a given language in which one designation represents two or more concepts sharing certain **characteristics** [ISO-3.4.24]

pragmatic relation - see associative relation

<u>preferred term</u>: **term** rated according to the scale of the term acceptability rating as the primary term for a given **concept** [ISO-3.4.15]

principle of measurement - see measurement principle

<u>quantity</u>: property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference [VIM-1.1] (see also S.12.13, 12.14)

<u>quantity dimension</u>; dimension of a quantity; dimension: expression of the dependence of a **quantity** on the **base quantities** of a system of quantities as a product of powers of factors corresponding to the base quantities, omitting any numerical factor [VIM-1.7]
EXAMPLE - ML^{-3} for mass concentration and mass density

<u>quantity of dimension one</u>; dimensionless quantity: **quantity** for which all the exponents of the factors corresponding to the **base quantities** in its **quantity dimension** are zero [VIM-1.8]
EXAMPLES - number of entities, mass fraction, relative time, pH

<u>quantity value</u>; value of a quantity; value: number and reference together expressing magnitude of a **quantity** [VIM-1.19]

<u>random variable</u>: function defined on a sample space where the values of the function are ordered k-tuplets of real numbers [ISO 3534-2.10] [= 65]

<u>reference material, RM</u>: material, sufficiently homogeneous and stable with reference to specified properties, which has been established to be fit for its intended use in **measurement** or in examination of nominal properties [VIM-5.13]

<u>relation</u>: abstract connection between two entities

result of a measurement - see measurement result

RM - see reference material

<u>semantic category</u>: **concept** chosen to stand for a specified **set** of **subordinate concepts**, considered homogeneous [CEN-3.16]

<u>semantic link</u>: unidirectional part of an **associative relation** from a **base concept** [modified from CEN-3.22]
NOTE - A *direct* semantic link may take the form 'has-noun:'; the *inverse* semantic link is then 'is-noun-of:'.

<u>semasiology</u>: linguistic discipline studying the meaning of **words**

<u>sequential relation</u>: **associative relation** based on spatial or temporal proximity [ISO-3.2.24]

<u>set</u>: finite or infinite collection of **objects** or **concepts**

SI - see International System of Units

<u>simple term</u>: **term** containing only one root [ISO-3.4.4]

<u>special character</u>: graphical character that is not an alphanumerical character [ISO 1087-2:2000-5.8] [73]

<u>special language</u>; language for special purposes; LSP: language used in a **subject field** and characterized by the use of specific linguistic means of expression [ISO-3.1.3]

<u>specific concept</u>: **concept** in a **generic relation** having the broader **intension** [ISO-3.2.16]

<u>specification</u>: **differentiating criterion** grouping miscellaneous **characteristics** that are necessary for exact identification of a **concept** [paraphrase on CEN-4.4 d)]

<u>statistic</u>: completely specified function of **random variables** [ISO 3534-1-1.8] [= 65]

<u>subject field</u>; domain: field of special knowledge [ISO-3.1.2]

<u>subordinate concept</u>; narrower concept: **concept** which is either a **specific concept** or a **partitive concept** [ISO-3.2.14]

<u>superordinate concept</u>; broader concept: **concept** which is either a **generic concept** or a **comprehensive concept** [ISO-3.2.13]

<u>symbol</u>: graphic representation of a **concept** that has meaning in a specific context [ISO/IEC 2382-1-01.02.07] [76]

<u>synonymy</u>: **relation** between or among **terms** in a given language representing the same **concept** [ISO-3.4.19]

<u>systematic term</u>; identifier: **terminological phrase** created according to pre-established rules and used as a **term** for a **target concept** [≈ CEN-3.19]

<u>target concept</u>: **concept** whose **designation** is intended to be used in applications [CEN-3.17]

<u>target semantic category</u>: **semantic category** standing for a **set** of **target concepts** [CEN-3.18]

<u>temporal relation</u>: **sequential relation** involving events in time [ISO-3.2.25]

<u>term</u>: verbal **designation** of a **general concept** in a specific **subject field** [ISO-3.4.3]

<u>terminography</u>: part of **terminology work** concerned with the recording and presentation of terminological data [≈ISO-3.6.2]

<u>terminological entry</u>: part of a terminological data collection which contains the terminological data related to one **concept** [ISO-3.8.2]

<u>terminological phrase</u>: phrase containing at least one **term** and a number of other lexical **entities** the choice of which being restricted by the term in question [≈ CEN-3.15]

<u>terminologization</u>: process by which a general language **word** or expression is transformed into a **term** [ISO-3.4.8]

<u>terminology 1</u>: set of **designations** belonging to one **special language** [ISO-3.5.1]

terminology 2; terminology science: science studying the structure, formation, development, usage and management of **terminologies** in various **subject fields** [ISO-3.5.2]

terminology science - see terminology 2

terminology work: work concerned with the systematic collection, description, processing and presentation of **concepts** and their **designations** [ISO-3.6.1]

test: determination of one or more **characteristics** according to a procedure [ISO 9000-3.8.3] [= 70]

true quantity value; true value of a quantity; true value: **quantity value** consistent with the **definition** of a **quantity** [VIM 2.11]
There usually is a distribution of quantity values consistent with the definition of a particular quantity.

true value - see true quantity value

type of characteristics: category of **characteristics** which serves as the criterion of a subdivision when establishing **concept systems** [S.2.14.2]

uncertainty of measurement - see measurement uncertainty

unit of measurement - see measurement unit

value - see quantity value

variant: any form of a **designation**

variate - see random variable

vocabulary: terminological dictionary which contains **designations** and **definitions** from one or more specific **subject fields** [ISO-3.7.2]

word (1); orthographic word: smallest linguistic unit conveying a specific meaning and capable of existing as a separate unit in a sentence [ISO 5127-1.1.2-07] [= 62]

ANNEX B

Alphabetical glossary of metrological and terminological concepts with quoted, working, or proposed definition in the main text

A term referring to a proposed definition is given in **underlined bold type**.

A term leading to a working definition or a formulation for discussion is given in *italics*.

A term in lightface type corresponding to a quoted definition is followed by '(q)'.

Admitted terms are given in lightface type, followed by '(a)'.

transl. = translated; de = German

Each entry ends with the number of the chapter (Ch.), section (S.), or table (T.) where at least a definition is found.

analyte (a) S.3.4

base dimension (a) S.19.23.1

base metrological dimension S.19.23.1

base metrological unit S.18.15

base metrological unit S.18.15.1

base quantity (q) S.13.8

base unit (a) S.18.15

base unit (q) S.18.14

base unitary kind-of-quantity S.13.9

category of quantities (q) T.6.5-9

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characteristic (transl. q) S.5.1.1

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