Pure & Appl. Chem., Vol. 64, No. 10, pp. 1569–1575, 1992.
Printed in Great Britain.

INTERNATIONAL UNION OF PURE
AND APPLIED CHEMISTRY

CLINICAL CHEMISTRY DIVISION
COMMISSION ON QUANTITIES AND UNITS IN CLINICAL CHEMISTRY*

and

INTERNATIONAL FEDERATION OF CLINICAL CHEMISTRY
SCIENTIFIC DIVISION
COMMITTEE ON QUANTITIES AND UNITS†

QUANTITIES AND UNITS FOR METABOLIC PROCESSES AS A FUNCTION OF TIME

(IUPAC Recommendations 1992)

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Quantities and units for metabolic processes as a function of time (IUPAC Recommendations 1992)

Synopsis - The aim of this document is: (i) to analyse the elements of the specifications for time-related quantities in the clinical laboratory; and (ii) to recommend a format that will unify, simplify, clarify and hence improve the reporting and understanding of time-related quantities measured in the clinical laboratory.

1. INTRODUCTION

Time-related quantities are measured in a variety of clinical chemistry investigations, for example endocrine stimulation or suppression tests, in nutritional or therapeutic drug-loading tests, in monitoring physiological and pathological processes and the excretion or secretion of components, and in measuring catalytic activities of an enzyme in a system. The basis of the understanding of the test results lies in biochemical, physiological, pharmacological and pathological studies.

Because of the differences between tests and their applications, results have until now been presented in a variety of ways in clinical chemistry. The aim of this document is:

1.1 to analyse the elements of the specifications for time-related quantities in the clinical laboratory

1.2 to recommend a format that will unify, simplify, clarify and hence improve the reporting and understanding of time-related quantities measured in the clinical laboratory.

2. BASIC CONCEPTS, THEIR TERMS AND DEFINITIONS

2.1 The *concepts* defining a quantity comprise system, component, kind-of-quantity, numerical value and unit (ref. 5.1):

A *quantity*, Q, is a measurable, real property, physical or chemical, of a specified system. Example: substance concentration of triglycerides in the blood plasma of a stated patient.

A *system* is a term that may be applied to any arbitrarily chosen, but stated part of the universe irrespective of form or size. Examples: a specified patient, a tube of plasma.

A *component* is a stated part of of the system

A *kind-of-quantity* is the abstract concept of the property common to a number of real phenomena (quantities). Example: substance concentration.

Numerical value is the number that gives the magnitude of the measured quantity when multiplied by the unit.

Unit is a chosen reference quantity which may be used for comparison of quantities of the same kind. Example: mole (symbol: mol).

It is customary to consider that the quantity, Q, is expressed by the product of a numerical value, $\{Q\}$, and an appropriate unit, $[Q]$, also called the value of the quantity.

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

When speaking of the, e.g., differential of a quantity, dQ, it is the differential of its value that it means.

2.2 *Change* of a quantity is the increment of the value of Q with time. The change may be expressed either infinitesimally at time t by the differential dQ or d$Q(t)$, or in practice it may be expressed by a finite increment over the time interval $(t_1;t_2)$, that is $Q(t_2) - Q(t_1)$ which may be written ΔQ or $\Delta Q(t_1;t_2)$

$$\Delta Q = Q(t_1;t_2) = Q(t_2) - Q(t_1)$$

Examples: Mass change, Δm; amount-of-substance change (short term: substance change), Δn; volume change, ΔV; substance concentration change, Δc.

Note: *Net change* of a quantity in a system is the algebraic sum of the changes of the quantity affected by different processes

$$\mathrm{d}Q\,\mathrm{net} = \sum_{i=1}^{n} \mathrm{d}Qi$$

or in practice it may be expressed by a finite interval $(t_1;t_2)$

$$\Delta Q\,(t_1;t_2)\mathrm{net} = \sum_{i=1}^{n} \Delta Qi\,(t_1;t_2)$$

2.3 *Fractional change* of a quantity may be expressed infinitesimally at time t by the differential d$Q(t)/Q(t)$. For a finite time interval the quotient is

$$\Delta Q(t_1;t_2)/Q(t_1) = [Q(t_2) - Q(t_1)]/Q(t_1)$$

Note 1: The quantities $Q(t_1)$ and $Q(t_2)$ are of the same kind and have the same type of component.

Note 2: Fractional change has dimension one

Examples: Mass fractional change, d$m(t)/m(t)$; amount-of-substance fractional change, d$n(t)/n(t)$ (short form: substance fractional change); amount-of-substance fractional change of concentration, d$c(t)/c(t)$ (short form: substance fractional change of concentration).

2.4 *Change ratio* of a quantity may be expressed infinitesimally at time t by a ratio of differentials d$Q_1(t)$/d$Q_2(t)$ where the kind-of-quantities are the same but for different components in the same system. In practice, the ratio for a finite interval is

$$\Delta Q_1(t_1;t_2)/\Delta Q_2(t_1;t_2)$$

Note: Change ratio has dimension one

Examples: Mass change ratio, d$m_1(t)$/d$m_2(t)$; amount-of-substance change ratio, d$n_1(t)$/d$n_2(t)$ (short form: substance change ratio); amount-of-substance concentration change ratio, d$c_1(t)$/d$c_2(t)$ (short form: substance concentration change ratio).

2.5 *Rate of change* of a quantity is defined by the time derivative $\mathrm{d}Q/\mathrm{d}t$ of the value of the quantity. The differential quotient may also be called derivative (or instantaneous) rate of change.

Examples: Rate of change of mass, $\mathrm{d}m/\mathrm{d}t$ (short form: mass rate); rate of change of amount-of-substance, $\mathrm{d}n/\mathrm{d}t$ (short form: substance rate); rate of change of amount-of-substance concentration, $\mathrm{d}c/\mathrm{d}t$ (short form: substance concentration rate).

Often the change in a quantity is measured as the difference between the values at the two ends of a calendar time interval. Then, the mean rate of change is defined as

$$[Q(t_2) - Q(t_1)]/(t_2 - t_1) = \Delta Q/\Delta t$$

Note 1: The modifier "mean" may be omitted provided the time interval is indicated in the quantity name.

Note 2: If the value of a quantity varies linearly with time, then the rate remains constant and therefore mean rate of change equals derivative rate of change

$$\Delta Q/\Delta t = \mathrm{d}Q/\mathrm{d}t$$

Note 3: For mono-exponential changes, the logarithm of the value of the quantity varies linearly with time and therefore the logarithmic rate of change equals logarithmic derivative rate of change

$$\Delta \ln Q/\Delta t = \mathrm{d}\ln Q/\mathrm{d}t$$

2.6 *Rate of change ratio* is the quotient of two rates where the quantities are of the same kind in the same system for different components

$$(\mathrm{d}Q_1/\mathrm{d}t)/(\mathrm{d}Q_2/\mathrm{d}t)$$

For finite time intervals, mean rate of change ratio is

$$(\Delta Q_1/\Delta t)/(\Delta Q_2/\Delta t) = (\Delta Q_1/\Delta Q_2)/\Delta t$$

Note 1: Rate of change ratio has the dimension one

Note 2: The denominator is often called the reference quantity.

Examples: Mass rate ratio, $(\mathrm{d}m_1/\mathrm{d}t)/(\mathrm{d}m_2/\mathrm{d}t)$; amount-of-substance rate ratio, $(\mathrm{d}n_1/\mathrm{d}t)/(\mathrm{d}n_2/\mathrm{d}t)$ (short form: substance rate ratio); amount-of-substance concentration rate ratio, $(\mathrm{d}c_1/\mathrm{d}t)/\mathrm{d}c_2/\mathrm{d}t)$ (short form: substance concentration rate ratio).

3. PROCESSES AND RELATED QUANTITIES

A *process* is a phenomenon by which change takes place in a system. In physiological systems, a process may be chemical, physical or both.

3.1 *Chemical processes*

3.1.1 *Conversion*

A component may be converted (formed or consumed) by a chemical reaction in a system.

3.1.2 *Extent of reaction*, ξ, is the change of amount-of-substance for a formed component B divided by the stoichiometric coefficient ν_B

$$\xi = \Delta n_B/\nu_B$$

The extent is calculated from the start of the reaction. It is only valid for a time independent stoichiometry.

3.1.3 *Rate of conversion*, $\dot{\xi}$, is the time derivative of amount-of-substance for a product component B, divided by the stoichiometric coefficient ν_B

$$\dot{\xi} = d\xi/dt = (1/\nu_B) \cdot (dn_B/dt)$$

3.1.4 *Rate of reaction*, v, is the rate of conversion divided by the volume, V, of the system in which the process occurs

$$v = \dot{\xi}/V = (1/\nu_B) \cdot (dn_B/dt) \cdot (1/V)$$

This definition is valid for a reaction in which the volume varies with time or for a reaction involving two or more phases (ref. 5.3).

When the volume does not vary with time, the rate of reaction may be expressed in terms of substance concentration:

$$v = (1/\nu_B) \cdot (dc_B/dt)$$

$\dot{\xi}$, and v are by definition quantities having positive values.

Note: When the changes involved in the quantities defined in 3.1.3 and 3.1.4 are only measured at the two ends of a calendar time interval, rates may be called mean rates i.e. mean rate of conversion, mean rate of reaction.

3.2 *Physical processes*

3.2.1 *Transfer* is movement of a component within a system or across its boundary. Transfer may be expressed using different kinds-of-quantities, e.g. rates of change

$$dQ/dt \quad \text{or} \quad \Delta Q/\Delta t.$$

Examples: Mass rate, dm_B/dt or $\Delta m_B/\Delta t$; substance rate, dn_B/dt or $\Delta n_B/\Delta t$; volume rate, dV_B/dt or $\Delta V_B/\Delta t$

Transfer of a component may be specified in relation to the system:

3.2.1.1 *Input, intake, absorption* are transfer of a component into the system considered.

3.2.1.2 *Output, excretion, secretion* are transfer of a component out of the system considered.

3.2.2 *Movement* of a component with respect to the area of a surface or interface may be expressed by:

$$(dQ/dt) \cdot (1/A) \quad \text{or} \quad (\Delta Q/\Delta t) \cdot (1/A)$$

where A is the area of the surface. It is sometimes called flux, but the term flux is used in some disciplines for the kinds-of-quantity defined in section 3.2.1.
The concept may be expressed by areic mass rate, areic substance rate, or areic volume rate (ref. 5.4).

3.3 *Combined processes*

Combination of two or more processes (chemical and/or physical) is usual in physiological systems. In that case, a net change may be calculated (see section 2.2).

4. RECOMMENDATIONS

4.1 The base SI unit for time is the second (symbol s). In the expression of time-related quantities, the second should be used whenever possible so as to retain the advantages of coherent SI units. Minute (min), hour (h) and day (d) are recognized for use with SI, because of their importance and widespread use (ref. 5.2). However in compound units, use of minute, hour and day should be limited. It is recommended that the same unit should be used for time throughout the presentation of a set of data to simplify comparison of different quantities.

4.2 To improve the understanding of results in clinical chemistry a general format for reporting results was formulated (refs. 5.1, 5.4):
System--Component; kind-of-quantity = numerical value · unit.
Such a presentation of a result is adequate for a comprehensive report, provided the purpose is to assess the patient's status at the moment in time when the sample was obtained.
Specifications, especially time specifications, may be added for the system, the component or for the kind-of-quantity:
System(specifications)--Component(specifications); kind-of-quantity (specifications) = numerical value · unit.
Interrelated specifications are given after the kind-of-quantity.

4.3 In clinical chemistry, each report must contain an indication of the day and time at which the sampling was performed. Further time specifications may be necessary:

4.3.1 when a previous event is known to modify the property measured:
System--Component; kind-of-quantity(time,event) = numerical value · unit.

Example: Plasma--Glucose; substance concentration(60 min after an oral load of glucose = 278 mmol) = 8,5 mmol/l
or
Plasma--Glucose; substance concentration change(60 min after an oral load of glucose = 278 mmol) = +3,5 mmol/l

The same format of presentation should be used for suppression or stimulation tests.

4.3.2 When a mean rate is reported, the length or the two ends of the time interval over which the measurements are made need to be stated.

4.3.2.1 The length of the time interval should be stated in seconds (min, h, d), i.e.
System--Component; kind-of-quantity(Δt) = numerical value · unit.

Example: Patient(Urine)--Hydroxyproline; substance rate(3 d) = 150 µmol/d.

4.3.2.2 The limits of the time interval should be stated in full when short-term variations in the measured property as a function of time are recognized, i.e.
System--Component; kind-of-quantity(t_1;t_2) = numerical value · unit.

Examples: Patient(Urine)--Ammonium; substance rate(8:00;16:00) = 180 nmol/s

That result may also be reported as an amount-of-substance in the urine sample
Urine--Ammonium; amount-of-substance(8:00;16:00) = 21 μmol.
or as a substance rate ratio
Patient(Urine)--Vanylmandelate/Creatininium; substance rate ratio(6:00;18:00) = 0,06

That result may also be reported as a substance ratio
Urine--Vanylmandelate/Creatininium; substance ratio(6:00;18:00) = 0,06

4.4 A general format is proposed for the presentation of time-related results in clinical chemistry.

4.4.1 The format, following previous recommendations, includes the name of the system, the component, the kind-of-quantity, the numerical value, and the unit.

4.4.2 When time occurs in the numerator of a "time" quantity, the word time should be part of the kind-of-quantity name.
Example: Plasma--Coagulation, tissue factor induced; time(procedure) = 33 s

4.4.3 When time occurs in the denominator of a derived kind-of-quantity the word rate should be a part of the kind-of-quantity name
Example: Urine--Glucose; substance rate = 1 μmol/s

4.4.4 If necessary for an explicit statement of the quantity, the type of process may be given as a specification to the component, i.e.
System--Component process; kind-of-quantity = numerical value · unit.

Example: Pancreas--Amylase production, catalytic amount rate(30 to 150 min after meal, analytical procedure) = 18 μkat/s (=18 μmol/s^2).

Note that this kind of presentation may be useful especially for metabolic studies of pathophysiological systems in patients, biopsies or isolated cells. The name of the process may be placed in parenthesis after the component.

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***Note a*: Revised and extended edition of the aforementioned 'Manual' has been published as a book under the title *Quantities, Units and Symbols in Physical Chemistry* (Blackwell Scientific Publications, Oxford, 1988).**