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QUANTITIES AND UNITS FOR CENTRIFUGATION IN THE CLINICAL LABORATORY

(IUPAC Recommendations 1994)

Prepared for publication by
M. LAURITZEN
Novo Nordisk A/S, Novo Allé, DK-2880 Bagsvaerd, Denmark

*†The combined Memberships of the Commission and the Committee during the preparation of this report (1987–93) were as follows:

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‡deceased 1991

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Quantities and units for centrifugation in the clinical laboratory (IUPAC Recommendations 1994)

The centrifuge is a widely used instrument in clinical laboratories for the separation of components. For example, in laboratories performing biochemical analyses on body fluids it is routinely used to separate blood cells from plasma, to separate sediment from urine, to measure the volume fraction of erythrocytes in blood (the hematocrit), and to separate bound from free components in protein binding and immunoprocedures. In less routine use, centrifugation is used for example for separation of lipoproteins in reference procedures for their measurement, separation of cellular components, and separation of DNA fragments. Various quantities are used for the description and the calculation of the separation processes at centrifugation. The aim of this document is to provide manufacturers and users of centrifuges with a list of quantities and units for centrifugation consistent with the International System of Units, SI, and standards of the International Organization for Standardization (ISO).
The document includes an alphabetic list of 35 commonly used kind-of-quantities for centrifugation with names, definitions, symbols and SI unit. A few practical examples of their use in calculations are also given.

Introduction

The centrifuge is a widely used instrument in clinical laboratories for the separation of components. For example, in laboratories performing biochemical analyses on body fluids it is routinely used to separate blood cells from plasma, to separate sediment from urine, to measure the volume fraction of erythrocytes in blood (the hematocrit), and to separate bound from free components in protein binding and immunoprocedures. In less routine use, centrifugation is used for example for separation of lipoproteins in reference procedures for their measurement, separation of cellular components, and separation of DNA fragments. Various quantities are used for the description and the calculation of the separation processes at centrifugation. The aim of this document is to provide manufacturers and users of centrifuges with a list of quantities and units for centrifugation consistent with the International System of Units, SI, and standards of the International Organization for Standardization (ISO).

1. General definitions of quantities and units

1.1. Quantity

A quantity is a measurable property, physical or chemical, of a specified system. It can be expressed as a product of a numerical value and a unit:

quantity = numerical value · unit.

1.2. Base kind-of-quantities and base units

By convention of the International System of Units, SI, quantities are organized in a dimensional system built upon seven *base kind-of-quantities*, each of which is regarded as having its own dimension and is considered to be dimensionally independent of the other base kind-of-quantities. For each base kind-of-quantity, a *base unit* is defined.

TABLE 1. *BASE KIND-OF-QUANTITIES AND SI BASE UNITS*

Quantity		*SI Unit*	
Name	*Symbol*	*Name*	*Symbol*
length	l	metre	m
mass	m	kilogram	kg
time	t	second	s
electric current	I	ampere	A
thermodynamic temperature	T	kelvin	K
amount of substance	n	mole	mol
luminous intensity	I_v	candela	cd

The symbols for the kind-of-quantities are recommended symbols

1.3. Derived kind-of-quantities and derived units

All other kind-of-quantities are *derived quantities* defined algebraically from base quantities. *Derived units* are defined analogously.

2. Alphabetic list of kind-of-quantities and units for centrifugation

KIND-OF-QUANTITY		*COHERENT SI UNIT*
name, *synonym(s), definition, comment(s)*	*Symbol*	*Symbol*

acceleration — a — $m\ s^{-2}$

Definition: Rate of change of velocity

$a = dv/dt$

Comment: Acceleration is a vector quantity

acceleration of free fall — g — $m\ s^{-2}$

Synonym: Acceleration due to gravity

Definition: Acceleration at a free fall in vacuo due to gravity

Comment: Acceleration of free fall is a vector quantity

Avogadro constant — L, N_A — mol^{-1}

Definition: Number of entities in a system divided by the amount of substance of these entities

$L = N/n = 6{,}022\ 136\ 7 \cdot 10^{23}\ mol^{-1}$

Boltzmann constant — k, k_B — $J\ K^{-1}$

Synonym: Molecular gas constant or entitic gas constant

Definition: Molar gas constant divided by the Avogadro constant

$k = R/L = 1{,}380\ 658 \cdot 10^{-23}\ J\ K^{-1}$

centrifugal acceleration — a_{rot} — $m\ s^{-2}$

Definition: Acceleration of a component as a result of a uniform rotational motion

Comment: Centrifugal acceleration is a vector quantity

centrifugal force — F_{rot} — N

Definition: Force acting on a body as a result of centrifugal acceleration $= \mathrm{kg\ m\ s^{-2}}$

$F_{rot} = m\, a_{rot}$

Comment: Centrifugal force is a vector quantity

The centrifugal force equals the product of mass and the centrifugal acceleration of the body

The name of the SI unit for centrifugal force is newton

centrifugal radius r m

Definition: Radius at which a component is spinning at the end of the period of centrifugation

Comment: For a component sedimented from a dilute suspension, it can be equated with radius of rotation at the bottom of the centrifuge tube

circular frequency ω $\mathrm{s^{-1}}$

Synonym: Angular frequency $= \mathrm{rad\ s^{-1}}$

Definition: 2π times the frequency

$\omega = 2\pi f$

diffusion coefficient (of component B) D_B $\mathrm{m^2\ s^{-1}}$

Definition: Absolute value of the product of local number concentration of the component and local average velocity of particles of that component divided by number concentration gradient in the direction of movement

$D_B = |C_B\, v_B| / \mathrm{grad}\ C_B$

force (acting on a body) F N

Definition: Product of the mass of a body and its acceleration $= \mathrm{kg\ m\ s^{-2}}$

$F = m\, a$

Comment: Force is a vector quantity

The resultant force acting on a body is equal to the rate of change of momentum of the body

The name of the SI unit for force is newton.

kinetic energy (of a body in uniform motion) E_k J

Definition: Half of the product of mass and square of velocity of the body $= \mathrm{kg\ m^2\ s^{-2}}$

$E_k = \frac{1}{2} m\, v^2$

Comment: The name of the SI unit for kinetic energy is joule.

mass concentration (of component B) γ_B, ρ_B kg m^{-3}

Definition: Mass of the component divided by the volume of the system

$\gamma_B = m_B/V$

mass density ρ kg m^{-3}

Synonym: Volumic mass

Definition: Mass of the system divided by its volume

$\rho = m/V$

mass density gradient grad ρ kg m^{-4}

Synonym: Volumic mass gradient

Definition: Differential change of mass density with distance in direction x

$\text{grad}_x\, \rho = \text{d}\rho/\text{d}x$

Comment: Colloidal components may be fractionated by centrifugation in a fluid with a gradient obtained by a suitable solute, for instance potassium bromide in water. Mass density gradient is a vector quantity

mass fraction (of component B) w_B 1

Definition: Mass of the component divided by mass of all components in the system

$w_B = m_B/\Sigma m_i$

molar gas constant R J K^{-1} mol^{-1}

Definition: Universal constant of proportionality in the ideal gas law

$p\, V_m = R\, T$

$R = 8{,}314\,511$ J K^{-1} mol^{-1}

Comment: The gas constant equals the product of the Avogadro constant and the Boltzmann constant

molar mass (of component B) M_B kg mol^{-1}

Definition: Mass of the component divided by its amount of substance

$M_B = m/n_B$

molar volume (of component B) $V_{m,B}$ m^3 mol^{-1}

Definition: Volume of the component divided by its amount of substance

$V_{m,B} = V/n_B$

moment of inertia (of a body about an axis) | I | kg m^2

Synonym: Dynamic moment of inertia

Definition: Sum (or integral) of the products of the mass elements of a body and the squares of their respective distances from the axis

$I = \Sigma\, m_i r_i^2$

number concentration (of component B) | C_B | m^{-3}

Definition: Number of entities of stated type for that component divided by the volume of the system

$C_B = N_B/V$

Comment: Besides molecules or particles, the type of entity may, for instance, be a chemical group within molecules or an ionic charge, and is therefore broader than the kind-of-quantities "molecular concentration" and "particle concentration"

number concentration gradient (of component B) | grad C_B | m^{-4}

Definition: Differential change of number concentration of component B with distance in direction x

$\mathrm{grad}_x\, C_B = \mathrm{d}C_B/\mathrm{d}x$

Comment: Number concentration gradient is a vector quantity

partial mass density (of component B) | ρ_B | kg m^{-3}

Synonym: Partial volumic mass

Definition: Change in mass of the component due to addition of a differentially small amount of that component, divided by the change in volume of the system

$\rho_B = \mathrm{d}m_B/\mathrm{d}V$

partial specific volume (of component B) | ν_B | m^3 kg^{-1}

Synonym: Partial massic volume

Definition: Change in volume of a system when a differentially small amount of a component is added, divided by the mass of that component

$\nu_B = \mathrm{d}V/\mathrm{d}m_B$

Comment: Partial specific volume is used in estimation of molar mass of colloidal particles (e.g. viruses or nucleic acids) from the sedimentation coefficient

pressure	p	Pa
Definition: Force divided by area		$= \mathrm{N\ m^{-2}}$
$p = F/A$		$= \mathrm{kg\ s^{-2}\ m^{-1}}$
Comment: The name of the SI unit for pressure is pascal		

rate coefficient (of a suspended component B in a fluid)	k_B	$\mathrm{s^{-1}}$

Definition: Number fraction of particles of the component passing a given position in the direction of gravitational or centrifugal acceleration, divided by time of passage

$k_B = -dN_B/(N_B\ dt) = -(d\ln N_B)/dt$

rotational frequency	f_{rot}	Hz
Definition: Number of rotations divided by time		$= \mathrm{s^{-1}}$

$f_{rot} = dN/dt$

Comment: The synonyms: rate of rotation, rate of revolution, centrifugal speed, centrifugation speed, and the traditional units of rotational frequency such as revolutions per minute, r.p.m., rpm, rev./min, r/min, are not recommended

The name of the SI unit for rotational frequency is hertz

sedimentation coefficient (of a suspended component B in a fluid)	s_B	s

Definition: Reciprocal of the rate coefficient of the component passing a given position in the direction of gravitational or centrifugal acceleration

$s_B = (k_B)^{-1} = -N_B\ dt/dN_B = -dt/d\ln N_B$

Comment: Use of the "Svedberg unit", $\mathrm{Sv} = 10^{-13}$ s, is not recommended

In current usage, subscripts are added to the symbol to indicate temperature and medium, and superscripts to indicate concentration

sedimentation velocity (of a suspended component B in a fluid)	v_B	$\mathrm{m\ s^{-1}}$

Definition Velocity of the component relative to the fluid in the direction of gravitational or centrifugal acceleration

$v_B = dl_B/dt$

Comment: Sedimentation velocity is a vector quantity

specific volume — v — $m^3\ kg^{-1}$

Synonym: Massic volume

Definition: Volume of a system divided by its mass

$v = V/m = \rho^{-1}$

Comment: Specific volume is the reciprocal of mass density

standard acceleration of free fall — g_n — $m\ s^{-2}$

Definition: Acceleration of free fall at sea level for the latitude 45 °

$g_n = 9{,}806\ 65\ \ m\ s^{-2}$ exactly

substance concentration (of component B) — c_B — $mol\ m^{-3}$

Definition: Amount of substance of the component divided by the volume of the system

$c_B = n_B/V$

time of centrifugation — t — s

Definition: Time difference from switching on until switching off

Comment: The time for deceleration is not included

velocity — v — $m\ s^{-1}$

Definition: Distance travelled divided by time of travel

$v = dl/dt$

Comment: Velocity is a vector quantity

viscosity — η — Pa s

Synonym: Dynamic viscosity

Definition: Constant of proportionality for shear stress, τ_{xz}, in a fluid moving with a velocity gradient, dv_x/dz, perpendicular to the plane of shear

$\tau_{xz} = h\ dv_x/dz$

Comment: This definition applies to laminar flow for which $v_z = 0$

volume — V — m^3, l, L

Comment: The unit litre, $L = 0{,}001\ m^3$, is customarily used in clinical laboratories instead of m^3 for reporting of analytical results and is recognized for use with SI

3. Appendix: Examples of calculation

centrifugal acceleration, a_{rot}

The centrifugal acceleration may be calculated from a stated radius and the rotational frequency:

$a_{rot} = 4\pi^2 r f_{rot}^2$

Centrifugal acceleration is commonly expressed in terms of standard acceleration g_n.

$1 \text{ m s}^{-2} = (1/9{,}806\ 65)\ g_n$

$a_{rot} = (4\pi^2/9{,}806\ 65)\ (r/\text{m})\ (f_{rot}/\text{Hz})^2\ g_n$

Example:

Radius at which the component is spinning at the end of centrifuging: $r = 170$ mm

Rotational frequency: $f_{rot} = 50$ Hz ($= 50 \text{ s}^{-1} = 3000 \text{ min}^{-1}$)

$a_{rot} = (4\pi^2/9{,}807)\ (170 \text{ mm/m})\ (50 \text{ Hz/Hz})^2\ g_n$

$a_{rot} = (4{,}0257)\ (170 \cdot 0{,}001)\ (50)^2\ g_n = 1711\ g_n$

kinetic energy, E_k

The kinetic energy of a *rotating body* may be calculated by summation of all contributions from partial masses m_i of the body at distances r_i from the axis of rotation:

$E_k = 2\pi^2 f_{rot}^2\ \Sigma(m_i\ r_i^2) = 2\pi^2\ f_{rot}^2\ I$

For a *uniform disc* :

$E_k = \pi^2\ m\ r^2\ f_{rot}^2$ (m is total mass)

For a *uniform ring* with outer radius r and inner radius r_i :

$E_k = \pi^2\ m\ r^2\ f_{rot}^2\ (1 - (r_i/r)^2)$

molar mass (of component B), M_B

Molar mass of an entity B, sedimentating in a fluid, may be calculated from the "Svedberg equation"

$M_B = (R\ T\ s_B)\ /\ (D_B\ (1 - v_B\ \rho))$

Example:

$R = 8{,}315 \text{ J K}^{-1} \text{ mol}^{-1}$ ($= 8{,}315 \text{ kg m}^2 \text{ s}^{-2} \text{ K}^{-1} \text{ mol}^{-1}$) ; $T = 293$ K

$s_B = 2{,}10 \cdot 10^{-13}$ s (sedimentation coefficient) ; $D_B = 6{,}72 \cdot 10^{-11} \text{ m}^2 \text{ s}^{-1}$ (diffusion coefficient)

$v_B = 0{,}722$ L/kg (partial specific volume) ; $\rho = 1{,}00$ kg/L (mass density of fluid)

$M_B = (8{,}315 \text{ J K}^{-1} \text{ mol}^{-1} \cdot 293 \text{ K} \cdot 2{,}10 \cdot 10^{-13} \text{ s})\ /\ (6{,}72 \cdot 10^{-11} \text{ m}^2 \text{ s}^{-1}\ (1 - (0{,}722 \text{ L/kg})\ (1{,}00 \text{ kg/L})))$

$M_B = 27{,}4 \text{ kg mol}^{-1}$

3.2. Greek letter symbols

Gamma	γ	mass concentration
Eta	η	viscosity
Rho	ρ	mass density and partial mass density
Omega	ω	circular frequency

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