Nomenclature of Thermal Analysis (IUPAC Recommendations 201x)*

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1. Scope
The scope of this document is to provide scientists working in the field of thermal analysis with a consistent “definitions of terms” that are commonly used within the field to allow precise communication and understanding. Since the scope of the International Confederation for Thermal Analysis and Calorimetry (ICTAC) also covers calorimetry, a further document dealing with this latter part of nomenclature is planned, once a satisfactory international consensus is reached on this matter.

In considering all the matters of nomenclature, the current Committee has followed the advice of the late Robert Mackenzie in that:

- terminology should be simple;
- abbreviations kept to a minimum;
- names based on particular instruments should be discouraged.

2. Intent
This document acknowledges that nomenclature develops – without regulated definition – as the field of thermal analysis develops. Some terms used by authors and scientists rapidly become accepted by the scientific community, even if the term is not consistent with past definitions, science or grammatically correct. However, if such a term is widely used and understood, it is reported here.

3. Definition of the field of Thermal Analysis (TA)

Thermal Analysis (TA) is the study of the relationship between a sample property and its temperature as the sample is heated or cooled in a controlled manner.
4. Techniques
A technique exists for each property or physical quantity that is measured versus temperature – a summary of some of these are presented below.

<table>
<thead>
<tr>
<th>Property or Physical Quantity</th>
<th>Technique</th>
<th>Abbreviation(s)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td>Calorimetry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Thermometry</td>
<td></td>
<td>May also be described as heating or cooling curves.</td>
</tr>
<tr>
<td>Temperature Difference</td>
<td>Differential Thermal Analysis</td>
<td>DTA</td>
<td>A technique where the temperature difference between a sample and a reference material is measured.</td>
</tr>
<tr>
<td>Heat Flow Rate</td>
<td>Differential Scanning Calorimetry</td>
<td>DSC</td>
<td>A technique where the heat flow rate difference into a sample and a reference material is measured.</td>
</tr>
<tr>
<td>Mass</td>
<td>Thermogravimetry or Thermogravimetric Analysis</td>
<td>TG, TGA</td>
<td>The abbreviation TG has been used, but should be avoided, so that it is not confused with $T_g$ (glass transition temperature)</td>
</tr>
<tr>
<td>Dimensional and Mechanical Properties</td>
<td>Dynamic Mechanical Analysis</td>
<td>DMA, TMA</td>
<td>Moduli (storage / loss) are determined. Deformations are measured. Dimensions are measured.</td>
</tr>
<tr>
<td>Dimensional and Mechanical Properties</td>
<td>Thermomechanical Analysis</td>
<td>TMA</td>
<td></td>
</tr>
<tr>
<td>Dimensional and Mechanical Properties</td>
<td>Thermodilatometry</td>
<td>TD</td>
<td></td>
</tr>
<tr>
<td>Electrical Properties</td>
<td>Dielectric Thermal Analysis</td>
<td>DEA</td>
<td>Dielectric Constant / Dielectric Loss measured.</td>
</tr>
<tr>
<td>Electrical Properties</td>
<td>Thermally Stimulated Current</td>
<td>TSC</td>
<td></td>
</tr>
<tr>
<td>Magnetic Properties</td>
<td>Thermomagnetometry</td>
<td></td>
<td>Often combined with TGA</td>
</tr>
<tr>
<td>Gas flow</td>
<td>Evolved Gas Analysis</td>
<td>EGA</td>
<td>The nature and/or amount of gas / vapour is determined. Trapped radioactive gas within the sample is released and measured.</td>
</tr>
<tr>
<td>Gas flow</td>
<td>Emanation Thermal Analysis</td>
<td>ETA</td>
<td></td>
</tr>
<tr>
<td>Property</td>
<td>Technique</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>----------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Pressure</td>
<td>Thermomanometry</td>
<td>Evolution of gas is detected by pressure change. Pressure exerted by a dense sample on the walls of a constant volume cell is studied.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermobarometry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optical Properties</td>
<td>Thermoptometry</td>
<td>A family of techniques in which an optical characteristic or property of a sample is studied. Emitted light measured.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermoluminescence</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acoustic Properties</td>
<td>Thermosonimetry or Thermoacoustimetry</td>
<td>Techniques where the sound emitted (sonimetry) or absorbed (acoustimetry) by the sample is studied.</td>
<td></td>
</tr>
<tr>
<td>Structure</td>
<td>Thermodiffractometry</td>
<td>Techniques where the compositional or chemical nature of the sample are studied.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermospectrometry</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Terminology and Glossary

**NOTE:** For all the techniques listed here, the terminology defines the property that is measured, and each definition may be completed by adding... “as a function of temperature”. For example: dynamic mechanical analysis (DMA), n- a technique where moduli are determined as a function of temperature.

adiabatic, adj- indicating that the experiment is carried out so that no heat enters or leaves the system.

atmosphere, n, - the gaseous environment of the sample, which may be controlled by the instrumentation or generated by the sample.

calorimetry, n- techniques where heat is measured as a function of temperature.

combined, adj – the application of two or more techniques to different samples at the same time. This can include thermal and non-thermal analytical techniques.

controlled-rate thermal analysis (CRTA), n- a sample-controlled method where the heating is exclusively controlled by the rate of transformation

controlled temperature program, n – the temperature history imposed on the sample during the course of the thermal analysis experiment.
cooling curve, n - the experimental result of measuring the temperature of the sample as a function of time during cooling. The technique is thermometry, and heating curves are obtained for temperature-time experiments during heating.

derivative, adj – pertaining to the 1st derivative (mathematical) of any curve with respect to temperature or time.

dielectric thermal analysis (DEA), n- a technique where dielectric properties are measured.

differential, adj – pertaining to a difference in measured or measurable quantities usually between a sample and a reference or standard material.

differential scanning calorimetry (heat-flow DSC), n – technique where the heat flow rate difference into a sample and a reference material is measured.

differential scanning calorimetry (power compensation DSC), n – technique where the electrical power difference into a sample and a reference material is measured.

differential thermal analysis (DTA), n – a technique where the temperature difference between a sample and a reference material is measured.

dynamic, adj- a prefix indicating that a parameter changes continuously during the experiment. The opposite of static.

dynamic mechanical analysis (DMA), n- a technique where moduli are determined.

emanation thermal analysis (ETA), n- a special type of EGA where the emanation of previously trapped radioactive gas is measured.

evolved gas analysis (EGA), n- a family of techniques where the nature and/or amount of gas or vapour evolved is determined. The term evolved gas detection (EGD) has also been used where the nature of gas is not determined.

gas flow, n - the passage of gas from one part of the system to another, either by sorption by the sample, evolution from it, or chemical reaction.

high pressure, (HP...), adj – a prefix applied to the technique name to indicate that the pressure of the experiment is above ambient.

Note: As an example a TGA experiment carried out under elevated pressures would be High Pressure Thermogravimetric Analysis (HP-TGA)

isobaric, adj- a prefix indicating the experiment is carried out at constant pressure.

isothermal, adj, - a prefix applied to a technique to indicated that the temperature is maintained constant throughout the experiment.
material, n-, the substance which is studied and from which the sample is taken.

micro-, adj- a prefix used to denote that the technique measures small quantities, either with respect to the amount of sample studied, or with respect to the change in the properties measured.

**Note:** This prefix has been applied to many thermal methods, and the equipment associated with them, for example micro-balance, micro-reactor, micro-calorimeter and also to the technique itself: micro-thermal, microscopic and the property studied: micro-structural.

**Note:** The opposite prefix, macro- is also occasionally used.

modulated, adj- a prefix indicating that a parameter changes in a periodic manner during the experiment.

**modulated temperature, (MT...), adj** - a prefix applied to the technique name to indicate that a temperature modulation has been applied to the temperature program.

**Note 1:** As an example a DSC experiment carried out with a modulated temperature program would be Modulated Temperature Differential Scanning Calorimetry (MT-DSC)

**Note 2:** Other modulated techniques are possible, such as modulated force TMA, modulated rate SCTA etc.

**Note 3:** The use of the prefix MT is preferred to TM.

photo-, adj - prefix to indicate that the experiment involves the illumination of the sample or measures the amount of light emitted from a sample. Where possible the wavelength range of the light should be specified.

sample, n- the material under study during the entire experiment (starting material, intermediates and final products) and its close atmosphere. This is equivalent to the thermodynamic system.

**sample-controlled, adj** – prefix applied to the technique to indicate that a property of the sample is used either continuously or discontinuously to control the sample heating. With no prefix, it is assumed that the experiment is following a controlled-temperature program.

**Note:** the generic term for all TA techniques making use of such a feed-back is Sample-Controlled TA (SCTA), whereas specific names will be of the form Sample-Controlled TGA (SC-TGA) etc.

scan, n- a term used to describe the data produced from a thermal analysis experiment. More correct usage is a **thermal analysis curve**, or, for a specific technique **thermogravimetric curve**, etc.

scanning, adj - a prefix indicating a specified experimental parameter, usually temperature, is changed in a controlled manner.

**simultaneous, adj** – the measurement of two or more properties of a single sample at the same time.
Note: A hyphen is used to separate the abbreviations of the techniques; for example, simultaneous measurement of mass and heat flow rate (thermogravimetric analysis and differential scanning calorimetry) would be TGA-DSC.

static, adj- indicating a constant parameter during the experiment. The opposite of dynamic

stepwise, adj – prefix indicating discrete, discontinuous changes in an experimental parameter, e.g. force, temperature etc.

tan δ, n – is the dimensionless ratio of energy lost to energy returned during one cycle of a periodic process. For example tan δ = E'' / E’, in DMA.

temperature-programmed desorption (TPD), n - EGA using an inert atmosphere or vacuum, in the absence of sample decomposition.

temperature-programmed oxidation (TPO), n - Experiment using an oxidising atmosphere, usually oxygen. Oxidation is monitored by any appropriate technique (EGA, TGA, gas sorption, etc.).

temperature-programmed reduction (TPR), n - Experiment using a reducing atmosphere, usually hydrogen. Reduction is monitored by any appropriate technique (EGA, TGA, gas sorption, etc.).

thermal curve, n – any graph of any combination of property, time, temperature derived from a thermal analysis technique.

Note: thermal curve is a lose abbreviation of the more correct term thermoanalytical curve

thermally stimulated current (TSC), n- a technique where the current from the relaxation of sample polarisation is measured.

thermo-, adj- a prefix indicating the use of changing temperature during the experiment.

thermoacoustimetry, n- a technique where the characteristics of sound waves passing through the sample are measured.

thermoanalytical, adj – of, or pertaining to, thermal analysis.

thermodiffractometry, n- a technique where the X-ray diffraction of the sample is measured.

thermodilatometry,(TD), n- a technique where one or more dimensions of the sample is measured under negligible load

thermogravimetric analysis, (TGA), n- a technique where the mass of the sample is measured.

thermogravimetry, (TG), n- see thermogravimetric analysis, which is to be preferred
thermoluminescence, n- a technique where light emission from the sample is measured.

thermomagnetometry, n- a technique where a magnetic property of the sample is measured.

thermomanometry, n- a technique where the pressure is measured.

thermomechanical analysis, (TMA), n- a technique where the deformation of the sample is measured under constant load.

thermometry, n- a technique where the temperature of the sample is measured.

thermomicroscopy, n- a technique where the optical properties of the sample are observed and measured through a microscope.

thermoptometry, n- a technique where the optical properties of a sample are measured.

thermosonimetry, n- a technique where the sound emitted by the sample is measured.

thermospectrometry, n- a group of techniques where a spectrum of the sample is measured.

torsional braid analysis (TBA), n- a dynamic mechanical analysis technique where the sample is supported on a braid.

6. Experimental Conditions

The specifics of how the technique is used, additional experimental parameters and constraints should, of course, be reported alongside the data in all published work. It is important to separate the technique (instrumentation) from the way in which it is used (experiment). The make and model number should be included in all reports, papers and studies as well as an experimental section that describes in full all experimental parameters.

Note: For example in a Thermomechanical Analysis (TMA) experiment the sample may be subjected to no force, a constant force, an increasing force or a modulated force – or any combination of the above – during a single experiment. The technique (TMA) has not changed, only the experimental variables for that technique.

The reader is referred to the ICTA publication [7] specific guidelines.

It must also be stressed that it should be normal practice to use the standard IUPAC quantities, units and symbols when reporting any work in thermal analysis. These are listed in the “Green Book” Quantities, Units and Symbols in Physical Chemistry [11] and other texts.

7. Symbols used specifically in Thermal Analysis.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol for quantity</th>
<th>Symbol for unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>l</td>
<td>m</td>
</tr>
</tbody>
</table>
Symbols describing specific events or materials.

- In general, symbols for physical quantities should be in italic type, or, if vectors, in bold italic type.
- The symbols for units do not take plural.
- Subscripts should generally be restricted to single letters.
- If the subscript relates to an object or property, it should be a CAPITAL letter:
  
  \[ m_s = \text{mass of sample } S. \]
  
  \[ T_R = \text{temperature of reference } R. \]
  
  \[ T_C = \text{Curie temperature} \]

- If the subscript refers to a phenomenon, it should be lower case:

  \[ T_{\text{fus}} = \text{melting temperature} \]
  
  \[ T_g = \text{glass transition temperature} \]

- If the subscript refers to a specific event, time or point, it should be lower case or figures:

  \[ T_i = \text{initial temperature} \]
  
  \[ m_f = \text{final mass} \]
  
  \[ T_p = \text{peak temperature} \]
  
  \[ t_{1/2} = \text{time of half reaction} \]

- Changes in extensive thermodynamic quantities \( X \) due to an event \( y \) should be represented by \( \Delta_y X \):

  \[ \Delta_{\text{vap}} H = \text{enthalpy of vaporization} \]
  
  \[ \Delta G = \text{Gibbs free energy of reaction} \]

- Symbols for the physical state of the material should be put in brackets after the formula symbol:

  \[ \Delta_{\text{vap}} H = H(g) - H(l) \]

8. Overview and Historical Matters

ICTA (until 1992) and then ICTAC (including calorimetry) always tried to provide its international community with an operative nomenclature of thermal analysis. From the beginning in the late sixties, this task was carried out by a special “ICTAC Nomenclature Committee”, initially chaired by late Dr Robert MacKenzie, from the Macaulay Institute for Soils, in Aberdeen, UK. The work of the ICTA Nomenclature Committee resulted, in the seventies in a number of publications and, when the whole set of recommendations was
considered to be “ripe”, IUPAC, to which ICTA was associated since 1974, was then proposed to endorse it, in order to give it the broadest acceptance possible. This endorsement gave rise, in 1985 in Pure and Applied Chemistry, to a joint publication by the IUPAC Commission on Analytical Nomenclature and the ICTA Nomenclature Committee, as “IUPAC-ICTA Nomenclature, 1985”. [12]

The ICTAC Nomenclature Committee continued to be open to the needs and novelties of our community of thermal analysis and carried out an important updating of the nomenclature, which resulted, two decades later, in a completely recasted document which was eventually adopted in 2006 by the ICTAC Council (made up of representatives of the 25 National Associations confederated in ICTAC).

This document is concerned with providing definitions of common terms that are used by thermal analysts to report, present and explain their work.

The ICTAC Nomenclature Committee was initiated in 1965 under the guidance of Robert Mackenzie and with the secretarial expertise of Cyril Keattch. This document acknowledges the debt to previous members of the Committee under their succeeding Chairmen, including John Sharp (1984-8), Ed Gimzewski (1988-1992) and Wolfgang Hemminger (1992-2001) who continued the discussions and published their findings as listed in references 1-10.

The task of the current committee has been to rationalise the work of all proceeding committees and to deliver a document that covers current practice in thermal analysis that can be accepted internationally.

Thanks are due to recent members of the Nomenclature Committee listed in Appendix 1 for their contributions to the deliberations and to others for the advice received:

9. References

1. R.C.Mackenzie, Talanta, 1969, 16, 1227
3. R.C.Mackenzie et al., J. Thermal Anal., 1975, 8, 197
4. R.C.Mackenzie et al., Thermochim. Acta, 1979, 28, 1
5. R.C.Mackenzie et al., Thermochim Acta, 1981, 46, 333
# Appendix 1: Recent Members of the ICTAC Nomenclature Committee

<table>
<thead>
<tr>
<th>Name</th>
<th>Years</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roger Blaine</td>
<td>(2001-6)</td>
<td></td>
</tr>
<tr>
<td>Edward Charsley</td>
<td>(2001-6)</td>
<td></td>
</tr>
<tr>
<td>P.C. Gravelle</td>
<td>(1992-2001)</td>
<td></td>
</tr>
<tr>
<td>Peter Haines</td>
<td>(1997-2006, Secretary 2003-6)</td>
<td>(Chairman, 1992-2001);</td>
</tr>
<tr>
<td>Wolfgang Hemminger</td>
<td>(Chairman, 1992-2001);</td>
<td></td>
</tr>
<tr>
<td>Trevor Lever</td>
<td>(Chairman, 2001-6);</td>
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<tr>
<td>Takeo Osawa</td>
<td>(2001-6);</td>
<td></td>
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<tr>
<td>Duncan Price</td>
<td>(2001-6, Secretary, 2001-3);</td>
<td></td>
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<tr>
<td>Stefan Sarge</td>
<td>(1992-2001, Secretary, 2000-1);</td>
<td></td>
</tr>
<tr>
<td>Don Burlett</td>
<td>(2001-6);</td>
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<tr>
<td>Valter Fernandez</td>
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<td>B.O. Haglund</td>
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<td>Gerrit Hakvoort</td>
<td>(1992-2001);</td>
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<tr>
<td>Marianne Odlyha</td>
<td>(1991-2001);</td>
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<tr>
<td>Michael Reading</td>
<td>(1991-7);</td>
<td></td>
</tr>
<tr>
<td>Judit Simon</td>
<td>(1992-2001);</td>
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