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The Definition of Measurement Process and its Importance in Metrology

La Definición de Proceso de Medición y su Importancia en Metrología

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Abstract

The term *measurement process* is used in specialized literature and in the international standards, but is currently not defined in the International Vocabulary of Metrology (VIM). While the third edition of the VIM has a definition for *measurement* that includes *measurement process* as a synonym, other references such as ISO *10012* "measurement management systems - Requirements for measurement processes and measuring equipment" separate the two definitions. The closeness between the two concepts confuses metrologists and provides difficulties for metrology instructors. In order to clarify this idea, authors make a comparison of physical and chemical measurement process, indicating their components. The authors propose a new definition for *measurement process* based on the identification of the type of measurand and other metrological elements at each measurement process identified. The proposal is motivated because one of the strongest challenges currently facing metrology is determining the vocabulary that beginners metrologists should learn.

Key word: measurement process, metrology, vocabulary, core term.

Resumen

El vocabulario internacional de metrología (VIM) no tiene definido el término proceso de medición. EL VIM en su 3° edición ha considerado como sinónimos a los términos medición y proceso de medición, otras referencias tales como ISO 10012 "measurement management systems - Requirements for measurement processes and measuring equipment" tiene definido ambos términos. El usar como sinónimos a los dos conceptos genera confusiones en la comunidad metrológica, principalmente a los metrologos novatos. Los autores proponen una definición del proceso de medición considerando la naturaleza y elementos claves de los procesos químicos y físicos de medición. La propuesta esta motiva para tener un vocabulario adecuado que coadyuve a solucionar los retos actuales de la metrología.

Palabras clave: proceso de medición, metrología, vocabulario, término fundamental.

1. Introduction

Perhaps the most important term in metrology is measurand, which is simply the quantity that is intended to be measured [1].

It follows that once the measurand has been defined, it must be measured. The measurement process (MP) should include all of the elements and tools for a successful measurement and will be dependent on the type of measurand. In general, the measurand can be of three types: chemical, physical, or hybrid. Biological measurands, for example those utilized in nanometrology that combine physical and chemical steps, are examples of hybrid measurands.

Although there are some steps that occur in both physical and chemical processes like method validation or uncertainty estimation, the physical measurement process (PMP) and the chemical measurement process (CMP) are different and have elements that are unique to each process. For example, in CMP sampling and sample preparation are key steps.

In this paper, the authors will show some elements that are essential for distinguishing the differences between PMP and CMP, and will provide a new definition for *measurement process*.

2. The Measurement and Measurement Process Concept

According to the VIM, measurement is defined as the "process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity" [1]. According to the authors, the measurement concept diagram shown in VIM is not a didactic scheme, because the diagram does not show a process. In the VIM diagram it is difficult to identify elements and their hierarchies. The line pattern is confused and there is disorder in the relationships between the various concepts.

The VIM measurement definition is important and influential, but also confusing because it has many elements and concepts. It is a junction or an aggregate of other important concepts, such as measurand, quantity, measurement process, measurement result, measuring system, and so on. There are notes related to the measurement definition in the VIM that expand upon the definition, but they perhaps make it even more difficult to understand the concept.

In metrology MP is routinely performed and it includes much more than just the measurement. The MP includes all elements, tools, and other requirements that are needed to obtain a reasonable measurement result. As

noted, a complete definition for the term *measurement process* is not included in the VIM, but it is defined in other standards documents [2]. Table 1 summarizes these definitions [1,3-8].

To clarify the differences between measurement and MP, the authors will show diagrams related to PMP and CMP in Sections 3 and 4. These diagrams make it possible to observe common and unique elements to each process and to identify the elements that correlate to reasonable measurement results. The GUM [7] and Eurachem [8] guidance methodologies are the platform for our proposed MP definition.

From the table 1, it is possible to note that measurement process is not included as definition in most of the references, however, is an outstanding concept that to be learned and known for an adequate application for an adequate application of the important documents at metrology [10 - 11]. The Eurachem recognize that the VIM need of a support for a better understanding, therefore, Eurachem did an introduction document [12] for VIM, which is clearness of several terms and definitions, between these the measurement process definition.

Table 1. A summary of definitions of "measurement process" contained in standards documents.

Document	MP Definition included	Issues
JCGM 200 (VIM) [1]	Synonymous	Measurement was defined as a process.
BIPM Internationl System of Units (SI) Brochure [3]	No	None
ISO 10012 [4]	Yes	The definition is unclear and may be incomplete because it focuses on a production process.
ISO/IEC 17000 [5]	No	It does not reference any document.
ISO/IEC 170025 [6]	Not included.	A MP definition would improve interpretation and use of the standard.
JCGM 100 (GUM) [7]	Not included, but the GUM presents MP with similar elements to this proposal.	A MP definition would improve interpretation and use of the standard.
EURACHEM Guide [8]	Not included, but presents MP with similar elements to this proposal.	A MP definition would improve interpretation and use of the standard.
IUPAC Recommendations 2005 [9]	Yes	Only chemical measuring process is included

3. Physical Measurement Process (PMP)

Metrology was first developed to determine the physical properties of objects. The physical measurement process (PMP) requires a measurand and a measuring standard (secondary, primary, national, etc., depending on the requirements) in order to realize a

successful measurement. The measurement standard is of the same nature that the measurand, both produce the same quantity. The measurand interacts directly with the measurement standard. When the measurement standard is a measuring system the system is designed to determine one property or parameter of the measurand. In these cases, the process involves no change in the intrinsic properties of matter, but movement, expansion, transmission of light, electric current, that can supply information about the physical properties of the matter, such as mass, volume, conductivity, and son on. On the other hand, when the measurement standard is the same as the measurand, the determination can be a direct comparison between the measurand and the standard.

Traditional physical measurands are temperature, mass, length, melting point temperature, wear resistant (mechanicals properties), weight and optical properties, conductance properties, all properties or phenomena that are not product of a chemical reaction. Some examples of PMP are: a measurement of an object´s displacement due to the application of an external force, or the measurement of the change of temperature of a metallic piece during a heating process.

Usually, the environmental parameters of the standard and measurements system are controlled and monitored, so that the measurement is as accurate as possible. The physical measurand is a natural property of the sample or standard. In general, the physical measurand is not subjected to a sample preparation procedure and sampling. In some cases, however, the sample is cooled, heated, or destructed to obtain an intrinsic property of the sample. There are physical measurands that cannot be measured directly, in which case the measurement system becomes a group of independent sub-systems.

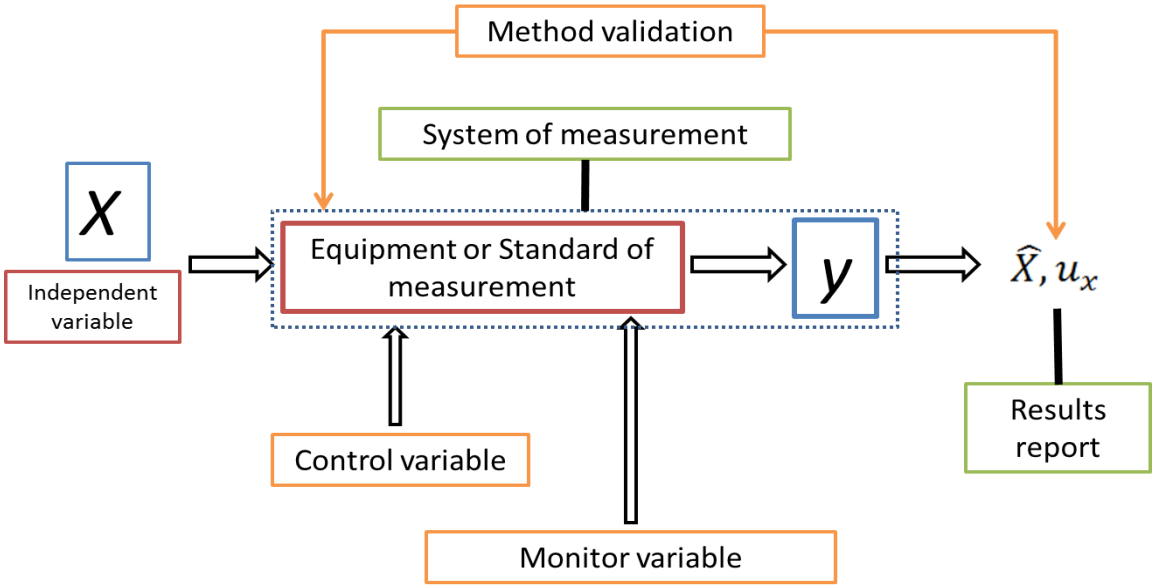


Figure 1. Diagram of the physical measurement process (PMP).

Figure 1 is a diagram of a PMP. There are four main components:

- ✓ The independent variable or property to be measured (measurand);

- ✓ Controls of the processes (control standards, environmental controls and independent controls);
- ✓ Measurement system, which includes the response of the equipment or standard (core component), and
- ✓ The measurement result, which will indicate the quality of the process in its entirety.

Equation (1) shows a physical measurement process. The variable *y* can be defined as the measurement result, the response of the measuring system or a better estimation of the true value of the measurand, μ is the property of the sample that is intended to be measured, the measurand, and *e* is the measurement error,

$$y = \mu + e \cdots \quad \textbf{(1)}$$

4. Chemical Measurement Process (CMP)

The measurement method is crucial for chemical metrology, and by natural consequence the validation of the method should be done prior to the analysis. There are judgments and rules to attend to during the validation [8, 9]. For chemical metrology, the task is to determine the quantity of a specific chemical entity and not purely the "amount of substance".

In a general way, the CMP result produces a new arrangement, due to the complexity of the measurement process in the chemical area the measurand tends to be increasingly specific. For example, "mercury or mercury content" is an ambiguous sentence for any analyst, as more information is needed. Thus, "mercury content in drinking water," "mercury content in waste water," "mercury content in meat," or "mercury content in polyethylene," etc., are more appropriate terms. Furthermore measurement requires a different chemical measurement process due to a matrix effect. Therefore, the sampling step is crucial in a CMP. The sampling stage is a strong influence for the representativity of the analysis and is a basic element for the definition of the measurand. Therefore, it is a paramount characteristic of the CMP.

Another important component from CMP is sample preparation, which is related to measurement quality. It is known that for analysis like spectrophotometry or even microscopy, poor sample preparation leads to ambiguous results [13, 14]. In Fig. 2, it is possible to see the components before or after the measurement. The measurement method is defined for the type of measurand and all measurement methods should be validated prior to the analysis.

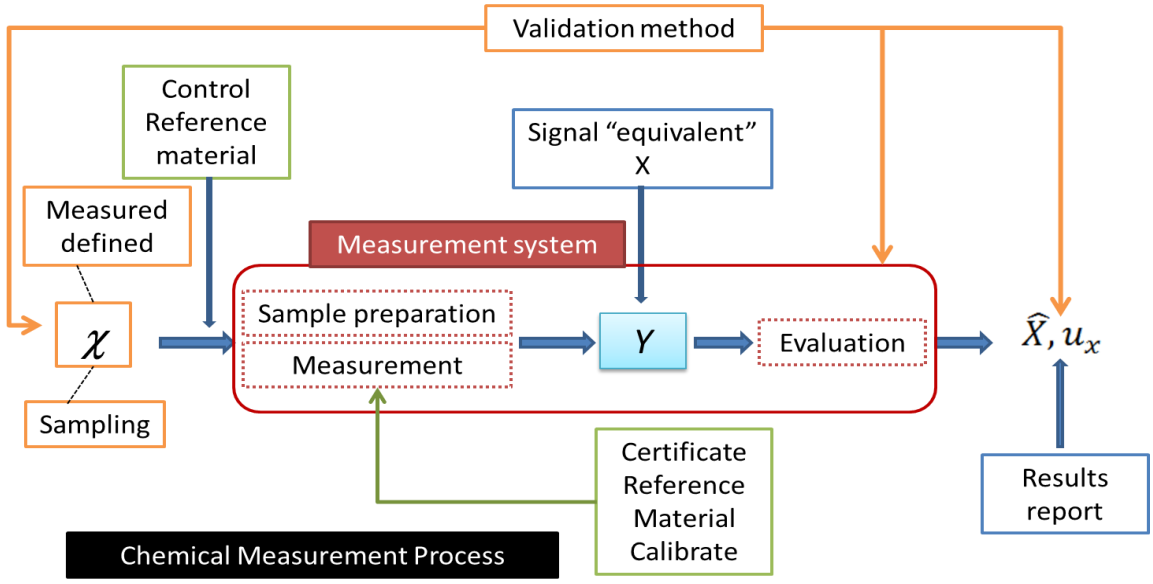


Figure 2. The essential steps of the chemical measurement process (CMP).

The fundamental steps of a CMP are:

- **Identification and definition of measurand** - This first step must be done carefully to guarantee that the next steps will obtain the intended results. An appropriate definition of the measurand is the key to developing an adequate chemical measurement process.
- **Sampling** - When necessary, sampling must be done properly to preserve the defined measurand. The sampling method depends upon the measurand and its definition. The benefits of the sampling are representative measurement results.
- **Control reference material** - This component must be part of a CMP whenever possible. The results obtained with control reference material provide information on the performance of the entire CMP, and helps to identify deviations of the process.
- **Sample preparation** - In almost every case, the sample must undergo a preparation step prior to being measured; this part is fundamental and must be performed taking into account the nature of the measurand and the measurement components.
- **Metrological traceability** - When possible, every component in the measurement process must have evidence of metrological traceability. The uncertainty of measurement results must be estimated following established references.
- **Measurement** - This central component must be accomplished following good laboratory practices. Staffing, equipment, facilities, environmental conditions, and other factors must be considered.
- **Evaluation** - This section must consider factors including: repeatability, reproducibility, results of control material, and uncertainty estimation.

As outlined in the introduction, a CMP differs from a PMP, which can be observed in the IUPAC mathematical model for a chemical measurement process [15],

$$y = B + Ax + e_y, \quad \textbf{(2)}$$

Where y is the signal or response of a measurement system, B is black,
A is sensitivity, x signifies measured, and e_y is the measurement error.

5. Comparison of PMP and CMP

Considering the components previously described for physical and chemical measurements, it is possible to make a comparison among them.

This contrast is shown in Table 2. Note that not all components are present in both measurement processes. Sampling and sample preparation are mandatory in chemical measurement, because they are crucial for measurand definition, but they are rarely used at physical measurements.

The measurand is a central part of any MP, and it is more difficult to define in chemical measurements. As for reference materials used during the measurement, it is clear that for chemical measurement instrument calibration and performance assessment, among others, are necessary for every measurement cycle. Finally, to demonstrate metrological traceability, both processes must estimate the measurement uncertainty associated with the results [16].

The rules and methodology described in the GUM [7] are followed in both cases. The description of the measuring process is closely related to GUM methodology, which has seven steps. (i) Specification of the measurand, [ii] Identification of the possible sources of uncertainty, (iii) Quantification of the uncertainty components, (iv) Calculation of the result of the measurement, (v) Estimation of the standards uncertainty and its combination, (vi) Obtaining the expanded uncertainty and (vii) report of the uncertainty of the measurement.

Diagrams proposed for measurement processes for physical and chemical measurands help our understanding of the principles and concepts that apply in the methodology for uncertainty estimation under GUM guidelines.

An example of the relationship between the MP definition and the methodology of the GUM is reflected in Section 3.3.2 of the GUM [7] where there are many possible sources of uncertainty. These points are included at our proposal schemes.

Table 2. Components of each measurement process (CMP and PMP).

Component	Chemical Measurement Process	Physical Measurement Process
Sampling	Yes	Rare
Sample preparation	Yes	Environmental conditions stabilization. Electronic parts optimization (on/off).
Measurand	Define according to particular situation	Independent Analytic and well defined
Measurement	Indirect measurement depend of the method	Direct measurement
Certificate Reference Material of	Yes, when possible	Yes, Variable control (monitor

Control CRM (c)		temperature, humidity)
Certificate Reference Material of Evaluation CRM (e) or Measurement Standard.	Yes, when possible	Yes, measurement standard
Sensor	Yes, array analytical	Yes, direct response
Transducer	Yes, array analytical	Yes, direct response
Assigned value and uncertitany	X (Eurachem), GUM, home procedure	X home procedure
Metrological Traceability	Measurement standard, i.e. CR and CRM, method,	Measurement standard

6. Proposed Definition for Measurement Process

The measurement process is governed by the physical phenomenon or property, or chemical reaction which is developed, and either of them are the basis for define the measurand for later comparison with a measurement standard. Our proposed definition of measurement process tries to cover the current limitations of the definition of measurement, so it can be used in a broader field of knowledge. Our proposed definition of *measurement process* is as follows:

The gear for sequentially organizing mutually related operations, tools, and activities to provide the best estimate of the value that can reasonably be attributed to the measurand.

The authors consider that this MP definition could be useful for the statement and identification of the uncertainty sources and in the selection of the mathematical model for the assignation of the reference value. This is crucial for modern measurements of food, nanotechnology, environmental, or composite materials.

7. Conclusions

The importance of having two different definitions for *measurement* and *measurement process* has been shown. To clarify the idea, physical and chemical process diagrams are shown, where is easily observed that measurement is only one part of the measurement process. Finally, a proposed definition for *measurement process* is given that helps to identify the mathematical model and uncertainty sources.

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