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Analytical Nanoscience and Nanotechnology: Where we are and where we are heading☆

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ABSTRACT

The main aim of this paper is to offer an objective and critical overview of the situation and trends in Analytical Nanoscience and Nanotechnology (AN & N), which is an important break point in the evolution of Analytical Chemistry in the XXI century as they were computers and instruments in the second half of XX century. The first part of this overview is devoted to provide a general approach to AN & N by describing the state of the art of this recent topic, being the importance of it also emphasized. Secondly, particular but very relevant trends in this topic are outlined: the analysis of the nanoworld, the so "third way" in AN & N, the growing importance of bioanalysis, the evaluation of both nanosensors and nanosorbents, the impact of AN & N in bioimaging and in nanotoxicological studies, as well as the crucial importance of reliability of the nanotechnological processes and results for solving real analytical problems in the frame of Social Responsibility (SR) of science and technology. Several reflections are included at the end of this overview written as a bird's eye view, which is not an easy task for experts in AN & N.

1. Introduction

As in many other areas, Nanoscience and Nanotechnology (N & N) have had a deep impact in Analytical Chemistry. The revolutionary and transformer character of them was predicted in 2005 in an editorial of the science journal [1] and confirmed 10 years later. AN & N [2,3] can be defined from different points of view as can be seen in Fig. 1. On the one hand, analytical chemists welcome the challenge and opportunities that N & N offer in this area because of both the powerful nanotools to improve analytical properties of results of analytical processes and analysis of the nanoworld. On the other hand, the basic (Nanoscience) and applied (Nanotechnology) developments and achievements need information from the nanoworld to fulfil their respective objectives and to make founded and timely decisions. The mixed approach shown in Fig. 1 is, in fact, the correct definition of AN & N because both points of view are combined.

The impact of instrumentation (e.g., pH-meters, potentiometric and voltammetric electrodes, photometers, fluorimeters, gas and liquid chromatographs, X-Ray spectrometers among many others) from the middle of XXI century was undeniable because of their great possibilities as regards titrimetries and gravimetries and classical methods of qualitative analysis. The second break point in the evolution of Analytical Science in the transition between XX and XXI centuries was the use of computers to improve the analytical processes by supporting automation, miniaturization, simplification, and implementation of quality systems, as well as the data treatment. Nowadays, research or routine analytical laboratories are unimaginable without the support of computers. This is the situation of many areas (e.g. air transportation or train managements, hospitals, universities, etc.). The irruption in the XXI century of AN & N can also be considered a break point in the global evolution of Analytical Chemistry, taking into account its mixed definition depicted in Fig. 1. A great range of possibilities has been opened up to initiate analytical research lines and to solve a great variety of analytical problems that cannot be solved without the involvement of N & N. It is interesting to point out that at the end of the XX century many analytical chemists described nanotools in papers of reputed journals without mentioning the word "nanotechnology". Such is the case of the use of fullerene as sorbent for preconcentration of traces of

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Nomenclature

AC	Analytical Chemistry
AChE	acetylcholinesterase
Al_2O_3 NPs	alumina nanoparticles
AN&N	Analytical Nanoscience and Nanotechnology
AF4	asymmetric field-flow fractionation
AFM	atomic force microscopy
AgNPs	silver nanoparticles
AuNPs	gold nanoparticles
BET	Brunauer, Emmett and Teller particle analysis
CARS	coherent anti-Stokes Raman
CE	capillary electrophoresis
CM	confocal microscopes
CNDs	carbon nanodots
CNTs	carbon nanotubes
CQD	carbon quantum dot
DCS	differential centrifugal sedimentation
DLS	dynamic light scattering
DMA	dynamic mechanical analysis
DSC	differential scanning calorimetry
EDS	energy-dispersive X ray spectrometry
EELS	electron energy loss spectroscopy
ELSD	evaporating light scattering detectors
ESEM	environmental scanning electron microscopy
FFF	field-flow fractionation
FIA	flow injection analysis
FL	fluorescence spectroscopy
FTIR	Fourier transform infrared spectroscopy
GC	gas chromatography
GO	graphene oxide
GQDs	graphene quantum dots
HDC	hydrodynamic chromatography
ICP-MS	inductively coupled plasma mass spectrometry.
ICP-OES	inductively coupled plasma optical emission spectrometry
LC	liquid chromatography
LIPS	laser induced plasma spectroscopy
MALS	multiangle light scattering
MNPs	magnetic nanoparticles
MOF	metal organic framework
MWCNT	multiwalled carbon nanotube
NC	nanocellulose
NIR	near-infrared
N&N	Nanoscience and Nanotechnology
NP	nanoparticle
NTA	nanoparticle tracking analysis
PIXE	particle-induced X-ray emission
QCM	quartz crystal microbalances
SAED	selected area electron diffraction
SEC	size exclusion chromatography
SEM	scanning electron microscopes
SERS	surface-enhanced Raman scattering
SiO_2NPs	silica nanoparticles
SLS	static light scattering
SQDs	semiconductor quantum dots
spICP-MS	single particle inductively coupled plasma mass spectrometry
SPR	surface plasmon resonance
SPME	solid-phase microextraction
SR	social responsibility
SWCNTs	single walled carbon nanotubes
TEM	transmission electron microscopes
TGA	thermogravimetric analysis
TiO_2NPs	titanium dioxide nanoparticles
TERS	tip-enhanced Raman scattering
UV	ultraviolet
0D	zero dimensions
1D	one dimensions
2D	two dimensions
3D	three dimensions

metal ions [4,5].

Between XX and XXI centuries there are other more unusual, but also very relevant analytical advances. For example, bioanalysis, sustainable methods of analysis, imaging, quality-Social Responsibility binomial, automation, miniaturization, simplification, instruments based on new physic-chemical principles, among others. Each specialist in analytical research can introduce his/her keywords in Fig. 2. As can be seen in the Fig. 3A and B, the growing of AN & N articles is impressive during the last few years. But this spectacular increment will diminish in the next few years to achieve a plateau where AN & N will be a consolidated presence in many sub-areas of Analytical Sciences. From a scientific point of view, it will be very difficult to find out real innovative research topics. By now, the prefix "nano" is a key to open many "doors" but in an immediate future, in papers dealing with nanotechnology, this word will slowly disappear from the title, summary,

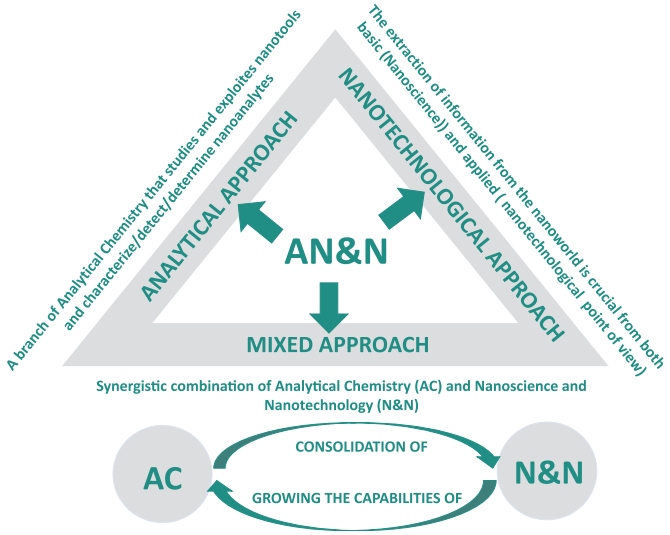

Fig. 1. Complementary definitions of Analytical Nanoscience & Nanotechnology according to three points of view and two way relationships between analytical chemistry (AC) and Nanoscience & Nanotechnology (N & N).

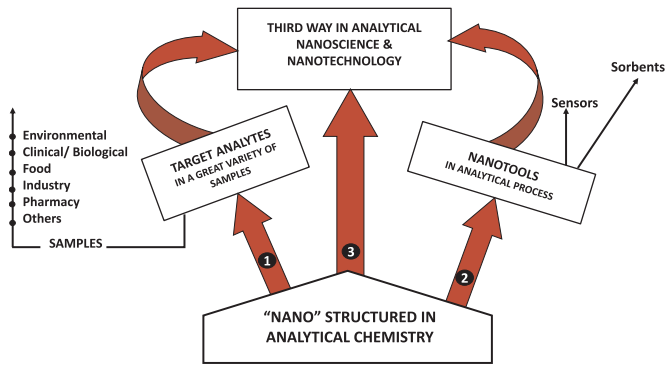

Fig. 2. The three main roles of "nano" structured materials in analytical processes: (1) as analytes in a great variety of samples; (2) as analytical tools; and (3) as tools and analytes in the same analytical process in the so called "third way in AN & N" which is the combination of the two previous ones.