Concept for study group Bioanalytics

Main purpose of this group is besides „listing“ of methods and „applications“ a help for deciding which to use for what and warn about pitfalls. It might be a help for those using analytics in fields like life science, environment and food analysis and not being a really well-trained Analyser. Tools should be provided.

1. General

1.1 Find classification according to

1.1.1 Analytical Method

1.1.2 Targeted Molecule

1.1.3 Application

1.2 Key list for literature search (fundamental books, review articles….)

- Analytical Chemistry: A Modern Approach to Analytical Science, 2nd Edition,
  Robert Kellner (Editor), Jean-Michel Mermet (Editor), Matthias Otto (Editor), Miguel Valcárcel (Editor), H. Michael Widmer (Editor)
  ISBN: 978-3-527-30590-2, 1209 pages, Wiley-VCH, Weinheim, 2004
- Principles of instrumental analysis, Douglas A. Skoog, F. James Holler, Stanley R. Crouch. Belmont, CA : Thomson, Brooks/Cole, 1039 pages, ISBN 978-0-495-01201-6, Thomson, 2007.1998.
- Chemical Instrumentation: A Systematic Approach, 3rd Edition, Howard A. Strobel, William R. Heineman, Wiley, ISBN: 978-0-471-61223-0, 1248 pages, 1989
- Bioanalytics, (Analytical Methods and Concepts in Biochemistry and Molecular Biology), Lottspeich / Engels, 2018. 1000 S. Hardcover, Wiley-VCH ISBN 978-3-527-33919-8
- A. Manz, P. S. Dittrich, N. Pamme, D. Iossifidis. Bioanalytical Chemistry, 2nd ed., Imperial College Press, Londom, 2015
- G. Evans. A Handbook of Bioanalysis and Drug Metabolism, CRC Press, Boca Raton (2004).
- Electrochemical Sensors in Bioanalysis, R.I. Stefan, J.F. van Staden and H.Y. Aboul-Enein, Marcel Dekker Inc., New York, USA, 2001.

1.3 Decision tree combining method, application, problem

1.3.1 Tutorial using analytics (adds and odds of methods)

During EuCheMS in Liverpool has been a session “**ABCs of Analytics”** where developments are described, and advice on using instrumentation and evaluation procedures in the field of life sciences, environment and food analysis is given. First, young scientists receive information about publishing in analytical journals; at the end, there will be a panel discussion about challenges and solutions in analytics.

In TrAC Trends in Analytical Chemistry frequently tutorials are published on analytical methods.

1.3.2 Short courses organized at conferences such as EUROANALYSIS, EUCHEMs – for training of new researchers in the field

1.3.3 Tutorials given at meeting of Analytical Divisions of European Chemical Societies

1.4 Classification of Bioanalytics

1.4.1 Definition

Analytical methods in biosciences like biochemistry, biology, biotechnology, molecular biology, molecular genetics, medicine, pharmacy as well as in environmental sciences. Methods are used to get information on macromolecules related to their

- structure,
  - E. Buxbaum. Fundamentals of Protein Structure and Function, Springer International Publishing (2015).
- dynamics,
  - A. Liwo (Ed.), Computational Methods to Study the Structure and Dynamics of Biomolecules and Biomolecular Processes: From Bioinformatics to Molecular Quantum Mechanics, Springer Series on Bio- and Neurosystems, Vol 8, Springer Nature Switzerland AG, Cham 2019
- effects and impact

1.4.2 Bioinformatics

Especially in live sciences big data are produced using imaging techniques, high-throughput, arrays, dynamic measurements. Treatment of big data with artificial intelligence or by machine learning algorithms is an upcoming filed.

- J. Pevsner. Bioinformatics and Functional Genomics, 3rd ed., John Wiley and Sons Ltd, Chichester, UK (2015).
- R. Meier et all, Bioinformatics can boost metabolomics research, Journal of Biotechnology, 261, 2017, 137-141
- K. Lan et all, A Survey of Data Mining and Deep Learning in Bioinformatics, Journal of Medical Systems (2018) 42: 139
- Ch. Satyanarayana et all, Computational Intelligence and Big Data Analytics (Applications in Bioinformatics) in SpringerBriefs in Applied Sciences and Technology: Forensic and Medical Bioinformatics, A. Kumar et all (Eds.), Springer Nature, Singapore, 2019

2 Analytical methods/techniques

IUPAC recommendations have been published in 2018 concerning the terminology of methods of bioanalytical chemistry. Terms related to samples, enzymatic and immuno-analytical methods, methods for –omics and to interaction of biomolecules are defined.

- J. Labuda et al., Terminology of bioanalytical methods (IUPAC Recommendations 2018), Pure Appl. Chem. 2018; 90(7): 1121–1198

2.1 Separation sciences

2.1.1 GC, HPLC

Chromatography is a technique for analysis of complex mixtures. The term chromatography literally means color writing, and denotes a method by which the sample to be analyzed is poured into a vertical glass tube containing an adsorbent, the various components of the substance moving through the adsorbent at different rates of speed, according to their degree of attraction to it, and producing bands of color at different levels of the adsorption column. The term has been extended to include other methods utilizing the same principle, although no colors are produced in the column.

The mobile phase of chromatography refers to the fluid that carries the mixture of substances in the sample through the adsorptive material. The stationary or adsorbent phase refers to the solid material that takes up the particles of the substance passing through it. Kaolin, alumina, silica, and activated charcoal have been used as adsorbing substances or stationary phases.

Classification of chromatographic techniques is done accordingly with the type of stationary phase, the nature of the adsorptive force, the nature of the mobile phase, or the method by which the mobile phase is introduced.

The technique is a valuable tool for bioanalytics, e.g. chromatography is used to detect and identify in body fluids sugars, amino acids, interleukins, etc.

Affinity chromatography is based on a highly specific biologic interaction such as that between antigen and antibody, enzyme and substrate, or receptor and ligand. Any of these substances, covalently linked to an insoluble support or immobilized in a gel, may serve as the sorbent allowing the interacting substance to be isolated from relatively impure samples; often a 1000-fold purification can be achieved in one step.

Exclusion chromatography is the one in which the stationary phase is a gel having a closely controlled pore size. Molecules are separated based on molecular size and shape, smaller molecules being temporarily retained in the pores.

In gas chromatography the mobile phase is an inert gas. Volatile components of the sample are separated in the column and measured by a detector. The method has been applied in the clinical laboratory to separate and quantify steroids, barbiturates, and lipids.

Ion exchange chromatography that utilizing ion exchange resins, to which are coupled either cations or anions that will exchange with other cations or anions in the material passed through their meshwork.

Paper chromatography is a form of chromatography in which a sheet of blotting paper, usually filter paper, is substituted for the adsorption column. After separation of the components as a consequence of their differential migratory velocities, they are stained to make the chromatogram visible. In the clinical laboratory, paper chromatography is employed to detect and identify sugars and amino acids. Thin-layer chromatography in which the stationary phase is a thin layer of an adsorbent such as silica gel coated on a flat plate is similar to paper chromatography.

Partition chromatography is a process of separation of solutes utilizing the partition of the solutes between two liquid phases, namely the original solvent and the film of solvent on the adsorption column.

Literature

- o Chromatography and its applications, Ed S. Dhanarasu, InTech, Croatia, 2012.
- o A Handbook of Chromatography, Ed M. Braga Scholar's Press Verlag Omniscriptam, Deutschland, Germany, 2017

Chances and pitfalls

- o Reliable qualitative and quantitative analysis
- o Suitable for complex samples analysis
- o High selectivity

Applications

- Clinical analysis;
- Pharmaceutical analysis;
- Environmental analysis
- Food analysis

2.2 Spectrometry

2.2.1 Mass Spectrometry

2.3 Spectroscopy

2.3.1 Colorimetric

2.3.2 Raman

- SERS

2.3.3 Fluorescence

Fluorescence measurements allow very low LODs. Fluorescence excitation wavelength should be at higher wavelengths to avoid photodegradation and scattering. Some biomolecules show self-fluorescence (bioluminescence). Fluorescent markers are preferable which have a large Stokes shift. Mostly the fluorescence intensity is measured using the concentration intensity relationship. Wavelength-ratiometric probes provide quantitative determination of many analytes. However, The fluorescence lifetime results in an absolute measure independent of concentration in contrast to steady state intensity, which is relative (photobleaching). It allows to get dynamic information on changes in the nanoenvironment by viscosity, pH, polarity, or solvation and molecular interactions.

- o Joseph R. Lakowicz, Principles of Fluorescence Spectroscopy, 3rd edition (2006), Springer-Verlag, Heidelberg
- o Fluorescence Spectroscopy, New Methods and Applications, Otto S. Wolfbeis (Ed.) (1993), Springer-Verlag, Heidelberg
- o J. Zhou et al. (2019) Two-component ratiometric sensor for $Cu2+$ detection on paper-based device, Anal. Bioanal. Chem. 412

2.3.4 Direct optical methods

Measurement of product of refractive index times physical thickness of a layer

- Refractometric
  surface plasmon resonance, grating coupler, Mach-Zehnder, prism coupler, …..
- Reflectometric
  ellipsometry, reflectometric interference spectroscopy

o Details in Handbook of Spectroscopy (Editors: G. Gauglitz, D.S. Moore), 2nd Completely Revised and Enlarged Edition, Vol. 3, "Direct Optical Detection in Bioanalytics" (G. Gauglitz, N.J. Goddard), Wiley-VCH 2014

2.4 Mass sensitive methods

The gravimetric chemical sensors respond to modifications of the ambient chemical composition through changes in their mass.

o Chemical and Biochemical Sensors, 1. Fundamentals, Nicolae Barsan, Günter Gauglitz, Alexandru Oprea. Edwin Ostertag, Günther Proll, Karsten Rebner, Klaus Schierbaum, Frank Schleifenbaum, Udo Weimar, Ullmann's Encyclopedia of Industrial Chemistry, Chapter 2.5, Wiley online Library, https://doi.org/10.1002/14356007.b06_121.pub2

2.4.1 QMB sensors

The first piezoelectric devices were produced as small wafers from piezoelectric single crystals, provided with a pair of electrodes on opposite faces. The mechanical oscillation type and the resonance frequency depend on the thickness and cut direction of the wafer (Sauerbrey equation). Viscosity has to be considered especially in bioanalytics.

2.4.2 SAW sensors

Surface acoustic wave sensors are piezoelectric substrates which produce from an electrically modulated signal a mechanical (acoustic) wave which is transformed back into an electrical signal. Changes at the sensor surface or in the volume influence amplitude, phase, frequency, or time-delay between the input and output electrical signals and correlate to sensing effects.

2.4.3 Cantilevers based sensors

Cantilevers are gravimetric devices as a beam or a plate able to elastically bend under mechanical stress which can be optically detected. Its modulation of vibrational frequency correlates to sensing.

2.5 Thermal Conductivity and Calorimetry

The operation principle of a thermal conductivity sensor uses two metal coils, typically made of platinum, or thermistors of small sizes in two different compartments, called sampling and reference tube. The coils or thermistors are arranged in a Wheatstone bridge circuit and are self-heated by passing an electric current through them. Their resistances depend on the adjusted temperature, which is given by the temperature-coefficient of the wire or thermistor material. In contrast to thermal conductivity sensors, in calorimetric sensors chemical reactions with the analyte come into play. The by far most important category of calorimetric sensors is the catalytic bead sensor, also called pellistor.

o Chemical and Biochemical Sensors, 1. Fundamentals, Nicolae Barsan, Günter Gauglitz, Alexandru Oprea. Edwin Ostertag, Günther Proll, Karsten Rebner, Klaus Schierbaum, Frank Schleifenbaum, Udo Weimar, Ullmann's Encyclopedia of Industrial Chemistry, Chapter 2.4, Wiley online Library, https://doi.org/10.1002/14356007.b06_121.pub2

2.6 Electrochemistry

2.6.1 Potentiometric methods

Potentiometric sensors are electrochemical cells operating in open circuit configuration, whose potential is modulated by the chemical information. The detected analyte has to be electrically charged. The sensor readout is a voltage measuring device with high input impedance (electrometer or suitable integrated circuits). They follow the Nernst equation. There exist Potentiometric enzyme sensors, Solid State Potentiometric Sensors.

2.6.2 Amperometric and Voltametric methods

The amperometric measurements are in principle current measurements made at a given value of the potential. The voltammetric measurements use single or multiple voltage sequences to generate a time dependent current in the electrochemical cell. Conductometric and Impedimetric Electrolytes are ionic conductors and, in the case of some solid state materials, also electronic conductors. When a voltage below the range over which electrochemical processes occur is applied between two electrodes immersed in the electrolyte, a current starts to flow, usually proportional to voltage; the proportionality constant is the sample conductance (Ohm's law). The specific conductance (conductivity) is the product of ion mobility, concentration, and charge. Impedance spectroscopy (EIS) investigates the interface at the electrode. EIS uses the frequency sweep of a small a.c. voltage modulated over a d.c. bias in order to extract the equivalent circuit configuration. The d.c. bias sets the electrochemical properties of the interfaces. The circuit configuration is actually obtained from the plots of the imaginary and real part of the impedance (Cole–Cole or Nyquist diagram). The apparatus size and complicated data interpretation hinder the use of EIS operation principle for real sensors, but laboratory setups are utilized for sensing purposes.

- Electrochemical Sensors in Bioanalysis, R.I. Stefan, J.F. van Staden and H.Y. Aboul-Enein, Marcel Dekker Inc., New York, USA, 2001.
- Chemical and Biochemical Sensors, 1. Fundamentals, Nicolae Barsan, Günter Gauglitz, Alexandru Oprea. Edwin Ostertag, Günther Proll, Karsten Rebner, Klaus Schierbaum, Frank Schleifenbaum, Udo Weimar, Ullmann's Encyclopedia of Industrial Chemistry, Chapter 2.1, Wiley online Library, https://doi.org/10.1002/14356007.b06_121.pub2

2.7 Hyphenated techniques

2.7.1. HPLC-MS

2.7.2 HPLC-FLUORESCENCE

2.7.3. MS-MS

2.7.4. GC-MS

2.8 Biosensors

2.8.1 Principle

Biosensors are devices capable of providing specific quantitative or semi-quantitative analytical information using a biological recognition element which is in contact with a transduction element. Such a biosensor contains:

- a transduction element (electrochemical, optical, thermos, micro-balanced, surface-acoustic wave …). It transfers an effect offered by a biomolecular interaction process to an electronic signal;
- recognition elements (realizing biomolecular interaction processes between antigene/antibodies, analyte/biomimetics, proteins/proteins, peptide libraries), is responsible for selectivity; forming the sensitive layer, which inserts an effect to the transduction element;
- a shielding layer to suppress or avoid nonspecific interaction (especially in complex matrices such as blood or milk) and acting as an anchor layer for the recognition elements
- electronic read-out and data processing unit

There exist some definitions of a sensor, the most appropriate is considered the Cambridge definition: "Chemical sensors are miniaturized devices which can deliver real-time and on-line information on the presence of specific compounds or ions in even complex samples" (K. Cammann, E. A. Guibault, H. Hall H, R. Kellner, O.S. Wolfbeis, The Cambridge Definition of Chemical Sensors, In: Proceedings of the Cambridge Workshop on Chemical Sensors and Biosensors (1996) Cambridge University Press, New York),

However, a biosensor might have problems to be real-time (reversible) and to be used on-line. Therefore Thevenot modified it for electrochemical biosensors. Real-time is possible, but reversible has to be substituted by regeneration. Further information Nagl/Wolfbeis.

- D. R. THEÂVENOT et al. ELECTROCHEMICAL BIOSENSORS: RECOMMENDED DEFINITIONS AND CLASSIFICATION (Technical Report), Pure Appl. Chem., Vol. 71, No. 12, pp. 2333-2348, 1999
- D. Thevenot, K.Toth, R. Durst, G. Wilson. Electrochemical biosensors: recommended definitions and classification. Biosensors and Bioelectronics, Elsevier, 2001, 16, pp.121 - 131.
- S. Nagl, O. S. Wolfbeis, Classification of Chemical Sensors and Biosensors Based on Fluorescence and Phosphorescence, The final version of this book chapter was published in 2008 in Standardization and Quality Assurance in Fluorescence Measurements I, Springer Series on Fluorescence Volume 5, 2008, pp 325-346 and is available online at http://link.springer.com/chapter/10.1007%2F4243_2008_022

2.8.2 Biosensor Literature

A large number of reviews on principles, on transduction methods, recognition elements, read-out possibilities and data evaluation are available

- Biosensing for the 21st century (Series Editor: T. Scheper; Volume Editors: R. Rennebert, F. Lisdat; Advances in Chemical Engineering/Biotechnologies 109; Springer Heidelberg, 2008
- Biosenors for Environmental Monitoring (Editors: U. Bilitewski, A.P.F. Turner); harwood academic publishers, 2000
- Biosensors and Biodetection Methods and Protocols (Editors: A. Rasooly, K.E. Herold), Methods in Molecular Biology 503; Springer Protocols; Methods and Protocols, Vol. 1, Optical-Based Detectors, Humana Press 2017
- Handbook of Biophotonics (Editors: J. Popp, V.V. Tuchin, A. Chiou, S.H. Heinemann), Vol. 3: Photnics in Pharmaceutics, Bioanalysis and Environmental Research; Wiley-VCH 2012
- Handbook of Spectroscopy (Editors: G. Gauglitz, D.S. Moore), 2nd Completely Revised and Enlarged Edition, Vol. 3, "Direct Optical Detection in Bioanalytics" (G. Gauglitz, N.J. Goddard), Wiley-VCH 2014

- Handbook of Spectroscopy (Editors: G. Gauglitz, D.S. Moore), 2nd Completely Revised and Enlarged Edition, Vol. 3, “Immunoassays” (G. Proll, M. Ehni), Wiley-VCH 2014

2.8.3 Congresses

- Biosensors; international congress, every other year on a different continent in a different country;
- European Biosensor Symposium; every other year in a different European country;
- Workshop on Biosensors & Bioanalytical Microtechniques in Environment, Food & Clinical Analysis; every other year in different countries;

2.8.4 Chances and pitfalls

Experienced handling of detection method, recognition elements, and evaluation of data is essential to avoid the following pitfalls

- Avoiding nonspecific interaction;
- Suitable detection element
- selecting the best assay type (direct, competitive, binding inhibition, Sandwich);
- determination of limits of detection and limits of quantification because of sigmoid calibration curve;
- evaluation of binding curves (equilibrium, association and dissociation rate constants)
  - G. Gauglitz, (2018) Analytical evaluation of sensor measurements, Anal. Bioanal. Chem. 410, 5-13

2.8.5 Applications

Biosensors are used for many analytical problems, e.g. trace analysis in case of environmental problems, diagnostics, and biomolecular interaction analysis

- imaging of DNA strands;
- protein/protein interactions;
- peptide libraries for biomarker identification
- point-of-care diagnostics
- high through-put screening
- water quality

2.9 Stochastic sensors

2.9.1 Principle

Stochastic sensors are new tools developed for bioanalysis, based on a very simple principle: channel conductivity. When a molecule is entering the channel, it blocked it, and the current is getting to zero value until the molecule is entering the channel (this time is called toff and is used for qualitative analysis), the time spent in the channel is called ton and it is used the the quantitative measurements. Such a sensor contains:

- a membrane/active site of the sensor containing channels or pores.

2.9.2 Literature

- Pattern recognition of 8-hydroxy-2’-deoxyguanosine in biological fluids, Anal Bioanal Chem, RI Stefan-van Staden et al., January 2018, Volume 410, Issue 1, pp 115–121

- Engineering of protein nanopores for sequencing, chemical or protein sensing and disease diagnosis, S Wang et al., Current Opinion in Biotechnology, Volume 51, June 2018, Pages 80-89
- Stochastic sensors inspired by biology, H. Bayley & P.S. Cremer, Nature, 413, pages 226–230 (13 September 2001).
- Stochastic sensors, J. Schmidt, Journal of Materials Chemistry, 2005,15, 831-840.
- Stochastic nanopore sensors for the detection of terrorist agents: Current status and challenges, A. Liu et al., Anal.Chim.Acta, 675, Issue 2, 24 August 2010, Pages 106-115

2.9.3 Chances and pitfalls

- Reliable qualitative and quantitative analyses can be performed
- Suitable for multianalyte detection
- High selectivity
- Capable to perform analysis from very complex matrices because both quantitative and qualitative analysis are not influenced by the nature and complexity of the matrix from where the analytes are determined;

2.9.4 Applications

Stochastic sensors are used for trace and ultra trace analysis in:

- Environmental analysis;
- Clinical analysis, including point-of-care diagnostics
- High through-put screening
- Pharmaceutical analysis
- Food analysis

3 Type of molecules to be determined

- Proteins
- Peptides
- Amino acids
- DNA/RNA
- Carbohydrates
- Lipids

4 Special Applications

- ✓ **Screening of biological samples for early diagnosis**

- ✓ **-omics**
  - A. Lesk. Introduction to Genomics, Oxford University Press (2012).
  - R. J. Reece. Analysis of Genes and Genomes, John Wiley & Sons Hoboken, NJ (2004).
  - M. S. Poptsova, ed. Genome Analysis: Current Procedures and Applications, Caister Academic Press, Norfolk, UK (2014).
  - G. P. Rédei. Encyclopedia of Genetics, Genomics, Proteomics, and Informatics, Springer Science & Business Media (2008).

- W. W. Grody, R. M. Nakamura, F. L. Kiechle, C. Strom, eds. Molecular Diagnostics: Techniques and Applications for the Clinical Laboratory, 1st ed., Academic Press/Elsevier, London, UK (2009).
- R. Westermeier, T. Naven, H.-R. Höpker. Proteomics in Practice: A Guide to Successful Experimental Design, John Wiley & Sons (2008).
- M. Soloviev. Peptidomics: Methods and Protocols, Humana Press (2010).
- T. Palzkill. Proteomics, Kluwer Academic Publishers, New York (2002).
- P. K. Ghosh. Introduction to Protein Mass Spectrometry, Academic Press, London, UK (2016).
- S. G. Villas-Boas, J. Nielsen, J. Smedsgaard, M. A. Hansen, U. Roessner-Tunali. Metabolome Analysis: An Introduction, John Wiley & Sons (2007).
- M. Lämmerhofer, W. Weckwerth, eds. Metabolomics in Practice: Successful Strategies to Generate and Analyze Metabolic Data, John Wiley & Sons (2013).
- W. L. Cabrera, J. S. Knapp, eds. Metabolomics: Metabolites, Metabonomics, and Analytical Technologies, Nova Science Publishers (2011).
- T. O. Metz. Metabolic Profiling, Springer (2011).

✓ **Glycosciences**
- A. Varki, R. D. Cummings, J. D. Esko, H. H. Freeze, G. W. Hart, M. E. Etzler, eds. Essentials of Glycobiology, Cold Spring Harbor Laboratory Press, USA (2008).
- H.-J. Gabius, ed. The Sugar Code: Fundamentals of Glycosciences, John Wiley & Sons (2011).

✓ **Screening of food samples for quality control**
- J. A. Capobianco, J. Lee, Ch. M. Armstrong, A. G. Gehring, Rapid detection of *Salmonella enterica* serotype Typhimurium in large volume samples using porous electrodes in a flow-through, enzyme-amplified immunoelectrochemical sensor, Anal. Bioanal. Chem. 411, 5233-5242

✓ **Quality control of pharmaceutical samples**

✓ **Enantioanalysis of biological samples**
- U. Boesl, A. Bornschlegl, Ch. Logé, K. Titze, Resonance-enhanced multiphoton ionization with circularly polarized light: chiral carbonyls, Anal. Bioanal. Chem., 405, 6913-6924

✓ **Identification and characterization of new biomolecules in biological samples, environment**

5 Web-Links

- http://b-analytics.net/

Literature recommended for bioanalytics

Terminology of electrochemical methods of analysis (IUPAC Recommendations 2019), Jose M. Pingarron, Jan Labuda, Jiři Barek, Christopher M. A. Brett, Maria Filomena Camoes, Miroslav Fojta and D. Brynn Hibbert, Pure Appl. Chem. 2020; 92(4): 641–694

Mass and volume in analytical chemistry (IUPAC Technical Report), Pure Appl. Chem. 2018; 90(3): 563–603

Nomenclature of flavonoids (IUPAC Recommendations 2017), Pure Appl. Chem. 2018; 90(9): 1429–1486

Vocabulary on nominal property, examination, and related concepts for clinical laboratory sciences (IFCC-IUPAC Recommendations 2017), Gunnar Nordin, René Dybkaer, Urban Forsum, Xavier Fuentes-Arderiu, Françoise Pontet, Pure Appl. Chem. 2018; 90(5): 913–935

Terminology of separation methods (IUPAC Recommendations 2017), Pure Appl. Chem. 2018; 90(1): 181–231

Vocabulary of concepts and terms in chemometrics (IUPAC Recommendations 2016), Pure Appl. Chem. 2016; 88(4): 407–443

Glossary of terms used in extraction (IUPAC Recommendations 2016), Pure Appl. Chem. 2016; 88(5): 517–558

Glossary of terms used in medicinal chemistry. Part II (IUPAC Recommendations 2013), Pure Appl. Chem. 2013, 85(8), 1725–1758.

Definitions of terms relating to mass spectrometry (IUPAC Recommendations 2013), Pure Appl. Chem. 2013, 85(7), 1515–1609.

Human errors and reliability of test results in analytical chemistry, Accred Qual Assur (2013) 18, 3–9.

Methods of measurement and evaluation of natural antioxidant capacity/activity (IUPAC Technical Report), Pure Appl. Chem. 2013, 85(5), 957–998.

Terminology for biorelated polymers and applications (IUPAC Recommendations 2012), Pure Appl. Chem. 2012, 84 (2), 377–410.

Metrological traceability of measurement results in chemistry: Concepts and implementation (IUPAC Technical Report), Pure Appl. Chem. 2011, 83(10), 1873–1935.

Proteomics principles and challenges, Pure Appl. Chem. 2004, 76 (4), 829–837.

Quantities and units for electrophoresis in the clinical laboratory (IUPAC Recommendations 1994), Pure Appl. Chem. 1994, 66(4), 891-896.

Books:

Compendium of Terminology and Nomenclature of Properties in Clinical Laboratory Sciences: Recommendations 2017, Georges Férard, René Dybkaer, Xavier Fuentes-Arderiu, Royal Society of Chemistry, 2017, 182 pp.

Gennady Evtugyn, Biosensors: Essentials, Springer, 2014

Electrochemical DNA Biosensors, Mehmet Ozsoz Ed., Pan Stanford, 2012.

Nucleic Acid Biosensors for Environmental Pollytion Monitoring, M. Mascini, I. Palchetti, Eds., RSC, 2011

Peter Gruendler, Chemische Sensoren, Springer, 2004

U. Wollenberger, R. Renneberg, F.F. Bier, F.W. Scheller, Analytische Biochemie, Wiley VCH, 2003

Commercial Biosensors: Applications to Clinical, Bioprocess, and Environmental Samples, G. Ramsay Ed., Wiley, 1998

Journals publishing papers on bioanalytics:

1. Analytical and Bioanalytical Chemistry
2. Biosensors and Bioelectronics
3. Bioanalysis
4. Journal of Applied Bioanalysis
5. International Journal of Analytical and Bioanalytical Methods
6. Journal of Bioanalysis & Biomedicine
7. Journal of Pharmaceutical and Biomedical Analysis