# Glossary of Terms Used in Extraction (IUPAC Provisional Recommendations)

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GLOSSARY OF TERMS USED IN EXTRACTION (IUPAC Provisional Recommendation)

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Abstract: Approaches for analytical-scale extraction are developing rapidly as new strategies are implemented to improve sample throughput and to minimize material use in laboratory methods and to develop on-site capabilities. In this contribution, definitions and recommendation for symbols for the terms used in analytical extractions are presented. Exhaustive, microextraction, elevated temperature, microwave- and ultrasound-assisted, parallel batch, flow through systems, and membrane extraction approaches are discussed. An associated tutorial titled “Extraction” provides a detailed introduction to the topic.

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INTRODUCTION

The general procedure for the analysis of complex samples typically consists of several steps identified as sampling, sample preparation, separation, quantification, statistical evaluation, and decision-making. Each step is critical to obtain informative results for optimum decision making. In many cases, the key step is the selection of the most appropriate sample preparation step for a particular task. The objective of this step is to isolate target analytes from a matrix, because most analytical instruments are designed to handle the analytes but are frequently incapable of accommodating the analytes and matrix together. Sample preparation usually involves extraction procedures and can also include "clean-up" procedures for very complex, "dirty" samples. This step must also concentrate the analytes to a level suitable for detection, and therefore, sample preparation methods typically include enrichment. The fundamental basis for extraction processes are often substantially different to those employed in chromatographic separations or other traditional disciplines of analytical chemistry. Analytical-scale extractions generally resemble the corresponding engineering processes but on a smaller scale. There is a tendency to name the extraction techniques according to random criteria. The objective of this contribution is to develop a consistent nomenclature for terms to be used to describe the extraction processes. An associated tutorial titled “Extraction” provides a detailed overview of the extraction processes (IUPAC Technical Report 2015, under review).

If a reference is given to a PAC Recommendation without qualification, then the term and definition are unchanged from the earlier version. If the reference reads “Adapted from Reference [xx]”, where [xx] is a PAC Recommendation, then some changes have been made. Terms from the JCGM VIM [1] are cross referenced without repeating the definition. A qualifying term in parentheses after a term is used to restrict the scope for a term with use in other fields of chemistry or science.

The terms in this Recommendation will form the basis of a chapter in the fourth edition of the Compendium of Terms in Analytical Chemistry (the Orange Book). General terms in Analytical Chemistry used in this Recommendation (analyte, matrix, etc.) will be defined in Chapter 1 of the revised Orange Book.

ALPHABETICAL ENTRIES

1. General Terms

1.1 absorption (extraction)

Process leading to extraction where analytes are partitioned from their matrix into a liquid sorbent.

Note: The use of term absorption here should be distinguished from the use of absorption in spectroscopy for the phenomenon in which radiation transfers some or all of its energy to matter.

Adapted from reference: [2].
1.2 active sampling

Continuous extraction with movement of the sample matrix with respect to the extraction phase.

1.3 adsorbent

Condensed phase where adsorption of analytes occurs at the surface.

Adapted from reference: [2].

1.4 adsorption

Increase in the concentration of a dissolved substance at the interface of a condensed and/or liquid phase due to the operation of surface forces.

Note: Adsorption can also occur at the interface of a condensed and a gaseous phase.

Reference: [2].

1.5 batch extraction

Extraction in which the extraction phase is placed in direct contact with the sample.

1.6 boundary layer or diffusion layer (concentration boundary layer)

Region in the vicinity of the interface between the sample and extraction phase where mass transfer is determined by diffusion.

1.7 boundary layer thickness

Distance from the interface beyond which mass transfer is determined by convection.

1.8 breakthrough volume

Sample volume that can be processed before the analyte concentration at the outlet of the sampling device reaches some arbitrary, but defined, ratio of the analyte concentration in the sample.

Note 1: The breakthrough volume, $V_B$, for a particular compound and sampling device is determined by its breakthrough curve, Figure 1 [4].
Note 2: Defined amounts are usually given as a percentage vol/vol of the sample volume (e.g., 1%, 5% or 10%, etc.).

Reference: [4].

Figure 1 Typical breakthrough curve indicating the breakthrough volume $V_B$ and the sample volume corresponding to the saturation capacity of the sorbent $V_C$ ($V_R$ corresponds to the chromatographic elution volume and $\sigma V$ the standard deviation of the derivative of the curve).

1.9 continuous extraction

*Extraction* in which the sample is continuously introduced into the extraction device.

1.10 distribution constant

Ratio of the analyte activity coefficient in the *extraction phase* to the concentration in the sample at equilibrium.

Note: At low concentrations the distribution constant is equivalent to the concentration ratio.
1.11 dynamic extraction

Extraction in which clean (or recycled) extraction phase is continuously passed through the sample.

Note: The extraction phase can be a gas or a liquid.

1.12 enrichment factor

Ratio of the sensitivity of the extraction method (slope of the calibration curve) to the equivalent value obtained without preconcentration.

1.13 equilibration

Operation by which a system of two or more phases is brought to a condition where further changes with time do not occur.

Note: This term is not synonymous with pre-equilibrium and should not be used in that sense.

Reference: [5].

1.14 exhaustive extraction

Type of extraction performed under conditions where close to 100% recovery of target analytes is obtained after completion of the process.

1.15 external calibration

Calibration [VIM 2.39 [1]] employing a simplified sample matrix spiked with target analyte embodying a reference value of the measurand [VIM 2.3 [1]].

1.16 extract

Separated phase that contains material isolated from another phase.

1.17 extractant

Liquid or fluid phase used for extraction.
1.18 extraction

Transfer of analytes from one phase to a separate location where further processing and analysis occur.

Note: The separate location is usually a liquid but extractions into the gas phase and onto a solid are also common.

Adapted from reference: [5].

1.19 extraction phase

Liquid, solid or gaseous material contacted with the sample for the purpose of removal of analytes from the sample matrix.

1.20 extraction recovery

fraction extracted

Ratio of the amount of analyte extracted under specified conditions to the amount of analyte in the sample.

Note: Extraction recovery is typically expressed as a percentage. Units of extraction recovery are usually mol/mol, or g/g.

1.21 fluorous extraction

*Extraction* in a biphasic system in which the main component of one phase is a highly fluorinated solvent (liquid-liquid extraction) or highly fluorinated sorbent (*solid-phase extraction*).

Reference: [6].

1.22 flow-through extraction

Process used to enhance the rate of *extraction* in which the *extraction phase* or sample move continuously with respect to each other.

1.23 fraction extracted

See *extraction recovery*. 
1.24 fractionation (of analytes)

*Extraction* of an analyte, or a group of analytes, from a sample according to physical (e.g., size, solubility) or chemical (e.g., bonding, reactivity) properties.

Adapted from reference: [7].

1.25 ion-pair extraction

Transfer of ions from an aqueous phase to an immiscible liquid (or solid) phase by adding an ion of complementary charge to the aqueous phase.

1.26 leaching

Dissolution of material from a solid phase with a liquid in which it is not wholly soluble.

Adapted from reference: [5].

1.27 liquid sorbent

Liquid *extraction phase* characterized by a high diffusion coefficient.

Note: Diffusion coefficients are typically greater than about $10^{-7} \text{ cm s}^{-1}$.

1.28 mass transfer

Movement of material in a heterogeneous system.

1.29 matrix-matched calibration

*Calibration* [VIM 2.39 [1]] employing external calibration in which standard solutions of target analytes are prepared in a solution of analyte-free matrix.

Note: Matrix-matched calibration is used to minimize the matrix effect on the measurement of target *measurands* [VIM 2.3 [1]]. [8, 9]

Reference: [8, 9].

1.30 microextraction

*Extraction* method in which the volume of the *extraction phase* (liquid or solid) is substantially smaller than the sample volume resulting in low *extraction* recoveries under equilibrium conditions.
1.31 **multiphase equilibrium**

Equilibrium involving more than one phase in a matrix and/or an *extraction phase*.

1.32 **optimisation of extraction**

Multivariate adjustment of extraction parameters to facilitate the most efficient *extraction*.

Related terms: *design of experiments, optimisation*.

1.33 **passive sampling**

Continuous extraction process driven by diffusion of analytes towards the *extraction phase*.

1.34 **preconcentration**

Any process used to increase the relative concentration of the analytes prior to extraction.

1.35 **sampling rate**

**kinetics of extraction**

Rate at which analytes are transferred from sample matrix to *extraction phase*.

1.36 **saturation capacity**

Volume of a sample at which the concentration of analyte at the exit of a sampling device is the same as the sample concentration.

*Note 1:* Corresponds to \(V_C\) in Figure 1.

*Note 2:* Corresponds to the sample volume that results in the isolation of the maximum amount of analyte but with a lower overall recovery because a fraction of the sample is lost.

1.37 **sequential extraction**

*Extraction* wherein *extractants* of increasing strength or different chemical character are used in order to extract analytes of interest.

*Note:* The most commonly used approaches in elemental analysis are the so-called BCR [10] (now termed Standards, Measurement and Testing Program) and Tessier [11] procedures.
Reference: [10, 11].

1.38 sorbent

Condensed phase where extraction of analytes occurs simultaneously at the surface (adsorption) and in the bulk (absorption).

Note: Widely used to describe a process where extraction occurs by more than one mechanism or the true mechanism is unknown.

1.39 speciation analysis

Identification and/or measurement of the quantities of one or more unique chemical forms of an element or compound in a sample.

Adapted from reference: [7].

1.40 static extraction

Extraction in which the extracting solvent and sample are brought into contact and allowed to comingle for a prescribed time to attain a constant composition before the phases are separated.

Note 1: If the substance is initially present as a solute in an immiscible liquid phase the process is synonymous with liquid-liquid extraction.

Note 2: If an extractable material is present as a solid the term leaching may be more appropriate.

1.41 steady state extraction

A continuous extraction process operating in such a way that the concentration of solutes in exit streams remains constant with respect to time for a constant feed.

1.42 time-weighted average sampling

TWA sampling

A passive or active sampling strategy over a relatively long time during which the amount of analyte recovered is proportional to its concentration.
Extraction Techniques

2 Gas-Phase Extraction

2.1 charcoal tube

Tube filled with carbon typically used to adsorb analytes from the gas or liquid phase.

2.2 chemical hydride generation, (CHG)

Type of chemical vapour generation wherein volatile hydrides are generated by reaction with borane complexes in aqueous solution.

Reference: [12].

2.3 chemical vapour generation, (CVG)

Extraction of analyte from sample by a chemical reaction generating gaseous species.

Note: The analyte is usually an element.

2.4 closed-loop extraction

Extraction by a fixed volume of gas continuously recycled through the sample and a sorbent trap by a pump in a closed-circuit arrangement.

Note 1: A typical apparatus is shown in Figure 2 [13, 14].

Note 2: Closed-loop extraction was developed for trace analysis of volatile compounds (at mass concentrations of ng L\(^{-1}\)) in drinking water.

Reference: [13, 14].
2.5 cryogenic trap

Device used to concentrate volatile analytes from the gas phase by condensation on a cold surface.

Note: Typically, cryogenic traps have a low thermal mass to respond rapidly to changes in temperature and are prepared from short lengths of capillary tubing. Sub-ambient temperatures are required for the efficient collection of analytes from a flowing gas stream and above ambient temperatures for evaporation into a flowing gas stream for analysis, usually by gas chromatography or atomic spectrometry.

2.6 denuders

Apparatus for the extraction of volatile analytes from a flowing gas stream by diffusion to the wall of a collection vessel where they are retained by chemisorption or strong physisorption by the wall coating.

Note 1: There are many design variations [15].

Note 2: Both liquid and solid sorbents are used for trapping.

Reference: [15].
2.7 **dynamic headspace analysis**

Continuous removal of *headspace* above a sample by a flow of inert gas over or through the sample. Sample vapours are typically transferred to a *sorbent trap* or *cryogenic trap* for collection.

**Note 1:** Purge-and-trap is a version of dynamic headspace analysis in which volatile compounds are purged from solution by a continuous stream of gas bubbles and transported through the headspace to a sorbent or cryogenic trap for collection.

**Note 2:** A typical apparatus for purge-and-trap is shown in Figure 3.

![Purge & Trap Accessory](image)

**Figure 3** Typical apparatus for dynamic headspace analysis (purge-and-trap).

2.8 **extractive distillation**

Separation of close-boiling liquids by fractional distillation in the presence of a *solvent* or salt that selectively interacts more strongly with one or more components of the mixture lowering their relative vapour pressure.

2.9 **flash desorption**

*Thermal desorption* where the temperature is rapidly increased to transfer condensed or sorbed compounds to the gas phase.
2.10 foam fractionation

Extraction method for the isolation of surface active compounds by their preferential adsorption at a gas-liquid (bubble) interface formed by passage of an inert gas through (typically) an aqueous solution.

2.11 headspace

The volume of vapours or gas above a sample in a closed container.

2.12 impinger

Simple glass bubbling chamber for vacuum-sampling of volatile analytes by passage through an extraction solution, the purpose of which is to capture and concentrate target analytes.

Note: Isolation by reaction with the extraction solution is common. Selectivity depends on the chemical specificity of the extraction solution.

2.13 multiple headspace extraction

Static headspace analysis procedure employing stepwise extraction at equal time intervals.

Note 1: At equilibrium the headspace is sampled and the remainder (or most of it) exhausted and replaced by fresh gas phase. The process is repeated and the original sample concentration estimated from the peak areas for two consecutive extractions.

\[ A_T = \frac{A_1^2}{A_1 - A_2} \]

where \( A_T \) = estimated sum of all partial peak areas corresponding to exhaustive extraction, \( A_1 \) the peak area obtained from the first headspace fraction and \( A_2 \) the peak area obtained in the second (consecutive) headspace fraction.

Note 2: External calibration is required to convert peak areas into sample concentration.

2.14 partition constant (headspace methods)

Ratio of the concentration of analyte in the sample to the concentration of analyte in the gas phase (headspace) at equilibrium.

Note: The partition constant is a fundamental parameter that expresses the mass distribution in the two phase system.
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\[ K = \frac{C_S}{C_G} = \left(\frac{w_S}{w_G}\right)\beta \]

\(C_S\) = analyte concentration in the sample, \(C_G\) = analyte concentration in the gas phase, \(w_S\) and \(w_G\) are the mass of analyte in each phase, and \(\beta\) the phase ratio.

### 2.15 phase ratio (headspace methods)

Ratio of the headspace volume to the condensed phase volume in a closed container.

Note: \[ \beta = \frac{V_G}{V_S} \]

\(\beta\) = phase ratio, \(V_G\) = the volume of gas phase above the sample (headspace), and \(V_S\) = volume occupied by the sample. \(V_G + V_S\) = total volume of the sample container.

### 2.16 simultaneous steam distillation-solvent extraction

A sample dispersed in an aqueous solution and a water immiscible organic solvent (extraction phase) are simultaneously heated in separate flasks and their vapours co-condensed and separated into two streams where water is returned to the sample flask and the extraction phase to the organic solvent flask.

Note: A typical apparatus for simultaneous steam distillation-solvent extraction is shown in Figure 4 [16].

Reference: [16].
Figure 4  Apparatus for simultaneous steam distillation-solvent extraction. A = aqueous sample suspension or solution; B = immiscible organic solvent and receiving flask for extracted compounds; C = bowl for phase separation; D, E, F, and G are solvent or vapor transfer arms; and H = entry port for additional solvent or alternative sample introduction position for continuous liquid-liquid extraction.

2.17 sorbent trap

Tube filled with porous sorbent typically used to extract analytes from the gas phase.

Note: The performance of a sorbent tube depends on the sorbent type, temperature, gas flow rate and desorption time.

2.18 static headspace analysis

Indirect method of analysis, in which a small aliquot of the vapour phase in contact with a sample is withdrawn for analysis.

Note 1: At equilibrium the analyte concentration in the gas phase is related to the sample concentration by a partition constant.

Note 2: The sample is enclosed in a thermostatted vessel.

2.19 sublation

Flotation process in which an analyte is adsorbed on the surface of gas bubbles moving through a solution and collected in an upper layer of immiscible solvent or in a sorbent trap.

Note 1: A typical apparatus for sublation is shown in Figure 5 [17].

Note 2: Since there is no liquid-phase mixing in the bulk of the system recoveries can approach 100%.

Adapted from reference: [4, 17].
Figure 5  Typical apparatus for extraction based on sublation. Identification: (1) nitrogen gas supply; (2) rotameter; (3) floatation cell; and (4) sintered glass disc [5].

2.20 thermal desorption

See flash desorption.

2.21 thermal extraction

Release of volatile compounds from a sample by heat.

Note: The volatile compounds are typically transported by a gas stream to a sorbent tube or cryogenic trap for collection.

3 Classical Liquid-Liquid Extraction

3.1 back extraction

stripping

Process of removing analytes from an extract by their distribution to a different phase.

Note: As normally used back extraction refers to the main compounds present or target analytes. It is an operation commonly employed in liquid-liquid extraction to enhance selectivity.

Adapted from reference: [5].
3.2 biphasic system (liquid-liquid distribution)

Equilibrium system containing two or more liquids with a single liquid-liquid interface.

3.3 chelation solvent extraction

*Extraction* method wherein charged analytes are extracted from an aqueous phase into an organic phase assisted by a chelating agent.

Note 1: The chelating agent also substitutes the water molecules in the coordination sphere of the metal ions. Consequently, the resultant metal chelates have a hydrophobic character which facilitates their transfer to the organic phase.

Note 2: The analytes are usually metal ions.

Reference: [18].

3.4 cloud point extraction

*Coacervative extraction* at a temperature above the cloud point temperature.

3.5 coacervative extraction

*Extraction* by a surfactant-rich, water-immiscible phase formed by adding a dehydrating agent to a colloidal solution of the sample and a surfactant above its critical micelle concentration.

Note 1: In cloud point extraction a small volume “surfactant-rich” phase enriched in sample components of moderate water solubility and a bulk aqueous phase with dissolved surfactant and highly water soluble compounds are formed [19].

Reference: [19].

3.6 continuous liquid-liquid extraction

*Extraction* in which a water-immiscible extraction solvent is continuously percolated through an aqueous solution and returned to the extraction solvent reservoir.

Note 1: Typically, a fixed volume of extraction solvent is recycled through the aqueous sample solution by distillation, condensation, and dripped into the sample solution. A siphon mechanism allows continuous recovery of the extraction solvent based on its relative density.

Note 2: A typical apparatus is shown in Figure 6.
Note 3: Continuous liquid-liquid extraction techniques are used when the sample volume is large, the distribution constant is small, or the rate of extraction is slow.

Figure 6 Apparatus for continuous liquid-liquid extraction with a lighter-than-water extraction solvent (left) and heavy-than-water extraction solvent (right).

3.7 countercurrent chromatography, (CCC)

Type of liquid-liquid chromatography using a support-free liquid stationary phase held in place by centrifugal forces while the other phase (the mobile phase) moves through it in a definite direction.

Note 1: Countercurrent chromatography is a continuous dynamic process under steady state conditions in which equilibrium may occur but is not essential [20-22].

Note 2: Countercurrent chromatography differs from countercurrent distribution (CCD) in that CCD is a discontinuous process based on the attainment of equilibrium prior to phase transfer in a multi-stage apparatus.

Note 3: There are two general approaches used to stabilize the liquid stationary phase based on hydrostatic or hydrodynamic system designs. Hydrostatic systems (known as centrifugal partition chromatography) employ a cascade of geometric volumes with connecting tubes, formed into a pattern, and rotated around a single axis providing a constant centrifugal force field. Hydrodynamic system designs (known as coil-planet centrifuges or high-speed countercurrent chromatography) employ a single flexible tube (column) wound around a former with a main axis of rotation and a secondary axis with
planetary rotation generating a variable centrifugal force field. The variable force field produces mixing and settling zones throughout the column length.

Reference: [20-22].

3.8 countercurrent extraction

*Extraction* in which both phases are continuously added (or changed) and flow (or move) in opposite directions as the extraction progresses.

Note 1: The phases are either immiscible or are separated by a membrane.

Adapted from reference: [5].

3.9 crosscurrent extraction

*Extraction* comprising a cascading series of states where the *raffinate* is brought into a subsequent stage and contacted with fresh solvent.

Adapted from reference: [5].

3.10 differential contactor

Type of continuous multistage *extraction* equipment in which there is only one interface at which phase separation by settling occurs.

Adapted from reference: [5].

3.11 distribution

Apportionment of a solute between two phases.

Note 1: The term partition or *extraction* may also be used in this sense where appropriate.

Reference: [5].

3.12 distribution constant, $K_D$

*partition ratio*

deprecated: distribution coefficient , distribution ratio, partition constant, extraction constant

Ratio of the concentration of a substance in a single defined form, A, in liquid phase 1 to its concentration in the same form in a second phase (liquid phase 2) at equilibrium.
\[ K_D = \frac{[A]_1}{[A]_2} \]

Note 1: If the equation relates to an organic-aqueous biphasic system the organic phase concentration is by convention the numerator and the aqueous phase concentration the denominator.

Note 2: In the case of non-ideal mixtures, concentrations should be replaced by activities. The distribution constant (partition ratio) is constant only if the activity coefficients are constant, which is not true in concentrated solutions.

Note 3: The use of the inverse ratio (aqueous/organic) may be appropriate in certain cases, e.g. where the organic phase forms the feed but its use in such cases should be clearly specified. The ratio of the concentration in the denser phase to the less dense phase is not recommended, as it can be ambiguous.

3.13 **distribution ratio, \( D \)**

Ratio of the total concentration of an analyte in the *extraction phase* regardless of its chemical form to its total concentration in a second phase.

Note: \( D \) is dependent on the experimental conditions (pH, presence of complexing agents, etc.) and does not necessarily imply that equilibrium has been achieved.

3.14 **feed**

Solution or gas containing analyte introduced into an extraction.

Note: If feed is used without qualification, the term may be taken to designate the initial liquid phase containing the main solute to be transferred or sample solution in a batch process.

3.15 **liquid-ion exchange**

A term used to describe the *liquid-liquid distribution* process for ions in which the transfer of ionic species from the *extractant* to the aqueous phase is accompanied by exchange of ions from the aqueous phase.

3.16 **liquid-liquid distribution**

- liquid-liquid extraction
- liquid-liquid partition

Process of transferring a dissolved substance from one liquid phase to another (immiscible or partially miscible) liquid phase in contact with it.
Note: Although extraction, partition and distribution are not synonymous, extraction may replace distribution where appropriate. Liquid-liquid extraction may be used in place of liquid-liquid distribution when the emphasis is on the analyte(s) being distributed (or extracted).

3.17 multistage countercurrent distribution

Multistage countercurrent separation based on a discontinuous, differential migration process employing a stepwise extraction.

3.18 Craig countercurrent distribution apparatus

Apparatus for *extraction* based on a *multistage countercurrent distribution*.

Note: The Craig countercurrent distribution (CCD) apparatus consists of a battery of glass vessels designed to allow mixing, settling and transfer of extracted phase (sample) and addition of fresh solvent (extractant) in a repetitive fashion. Movement about the horizontal axis provides gentle mixing of the phases, settling, and decanting of the upper phase, respectively. The extraction process is slow but is fully automated.

3.19 partition constant, $K_D$

deprecate: partition coefficient

Ratio of the activity of a species A in the extract $a_{A1}$ to the activity in a second phase with which it is in equilibrium $a_{A2}$.

$$K_D^*(A) = a_{A1}/a_{A2}$$

Note: The value of $K_D^*$ depends on the choice of standard states and on the temperature (and since liquids are weakly compressible, on pressure at high pressures).

3.20 phase ratio (liquid-liquid distribution)

Ratio of the volume of the *extraction phase* and sample solution.

3.21 raffinate

Phase left from the *feed* after being contacted by the extracting phase.

Adapted from reference: [5].
3.22 salting in

Addition of an electrolyte to an aqueous phase to decrease the distribution ratio of the analytes.

Related term: salting out.

3.23 salting out

Addition of an electrolyte to an aqueous phase to increase the distribution ratio of the analyte.

Note: The term is also used for the addition of electrolytes to reduce the mutual partial miscibility of two liquids.

Related term: salting in.

3.24 solvent (liquid-liquid distribution)

Immiscible fluid added to a process for the purpose of extracting material from the feed.

3.25 stage (liquid-liquid distribution)

The physically distinct part of an extraction process in which transfer of solute(s) occurs, followed by phase separation.

3.26 stagewise contactor

Type of continuous multi-stage liquid-liquid extraction equipment in which each stage has a physically distinct cycle of interphase contact and separation.

Note: There are the same number of phase separation interfaces as there are stages.

Adapted from reference: [5].

3.27 steady state (liquid-liquid distribution)

The state of a continuous process when it is operating in such a way that the concentration of solutes in exit streams remains constant with respect to time for a constant feed concentration, even when the two phases are not necessarily in thermodynamic equilibrium in any part of the process.
3.28 two-phase aqueous partition

Distribution in a biphasic system formed by two aqueous solutions containing structurally incompatible components (two polymers or a polymer and a salt) above a critical concentration.

Reference: [23].

4 Liquid-phase microextraction

4.1 acceptor phase
acceptor solution

Collection solvent for the target analytes in liquid-phase microextraction.

Note: This term can be used for all configurations of liquid-phase microextraction.

4.2 artificial liquid membrane
See supported liquid membrane.

4.3 calibrant in extraction phase

Internal standard that is incorporated in the extraction phase for calibration [VIM 2.39 [1]] in microextraction.

4.4 dispersing solvent

Solvent used to disperse the extraction solvent as fine particles throughout the sample solution in dispersive liquid-liquid microextraction.

Note: The dispersion solvent is typically a polar organic solvent miscible with water.

4.5 dispersive liquid-liquid microextraction, (DLLME)

Extraction of analyte(s) from a homogenous aqueous solution by fine particles of extraction phase dispersed throughout the solution.

Note 1: The extraction phase is formed by a mixture of extraction and dispersion solvents injected into the sample solution.

Note 2: The extraction phase can be formed by ion exchange when an ionic liquid is used as the extraction solvent.
Note 3: The extraction phase is sedimented by centrifugation and collected for analysis.

Reference: [24].

4.6 distribution constant calibration

*Calibration* [VIM 2.39 [1]] for *microextraction* when close to equilibrium conditions using a known *distribution constant* for the analyte.

4.7 donor phase

In *extraction*, the sample or sample solution.

4.8 electromembrane extraction, (EME)

*Hollow-fibre liquid-phase microextraction* in which the *extraction* is driven by an electrical potential sustained between the sample solution and the *acceptor phase*.

Note 1: A typical experimental arrangement is shown in Figure 7.

Note 2: Electromembrane extraction is typically performed in three-phase mode (aqueous → organic → aqueous).

Note 3: The sample is agitated or stirred during extraction.

Reference: [25].

![Figure 7](image_url) Typical experimental arrangement for electromembrane extraction.
4.9 hollow fibre

Narrow cylindrical tube prepared from a porous polymer.

Note: The internal diameter of the tube is typically 0.5-1.5 mm with walls 100 to 300 µm thick. Fibres are typically prepared from porous poly(propylene), although other materials can be used.

4.10 hollow-fibre liquid-phase microextraction, (HF-LPME)

Liquid-phase microextraction of analytes from a liquid (or gaseous) sample by a supported liquid membrane in the form of a porous hollow fibre with solvent-filled pores. The analytes are transferred to an acceptor phase contained in the lumen of the hollow fibre.

Note 1: A typical experimental arrangement is shown in Figure 8.

Note 2: The supported liquid membrane is generally an organic solvent immiscible with water and the sample an aqueous solution.

Note 3: The acceptor phase can be aqueous, which provides a three-phase extraction system (aqueous → organic → aqueous), or an organic solvent, providing a two-phase extraction system (aqueous → organic).

Note 4: The sample is agitated or stirred during extraction.

Reference: [26].

![Figure 8](image.png)

Figure 8 Typical experimental arrangement for hollow-fiber liquid-phase microextraction.
4.11 liquid-phase microextraction

Microextraction technique using a liquid as the extraction phase.

4.12 multiwell filter plate

Multiwell plate with porous polymeric filters at the base of each well.

Note: A multiwell filter plate can contain 96, 256, 384 or even 1536 individual porous filters used to prepare supported liquid membranes for parallel artificial liquid membrane extraction (PALME).

4.13 multiwell sample plate

Plate with multiple wells for individual samples.

4.14 parallel artificial liquid membrane extraction, (PALME)

Extraction of analytes from aqueous samples in a multiwell filter plate by migration through the solvent-filled filter pores into an acceptor phase located in each filter well.

Note 1: The solvent-filled filter pores function as a supported liquid membrane typically based on an organic solvent immiscible with water.

Note 2: PALME is usually performed in the three-phase mode (aqueous → organic → aqueous).

Reference: [27].

4.15 single-drop microextraction, (SDME)

Extraction of analytes from a liquid (or gaseous) sample by a single drop of extraction solvent.

Note 1: The extraction solvent drop with a volume typically less than 50 µl is normally suspended from the tip of a micro-syringe needle as shown in Figure 9.

Note 2: Typically, the sample is aqueous and the acceptor phase is an organic solvent, resulting in a two-phase extraction system (aqueous → organic). SDME can also be operated in three-phase mode (aqueous → organic → aqueous), or in the headspace mode (gas → organic or gas → aqueous).

Note 3: The sample is stirred or agitated during extraction. After extraction, the drop of acceptor phase is collected for the final analytical measurement.
4.16 **solidified floating organic drop**

Droplet of organic solvent recovered from the surface of the sample solution by solidification induced by cooling.

4.17 **solidified floating organic drop microextraction, (SFODME)**

*Extraction* employing a solidified floating organic drop [29].

Note: The extraction solvent has a melting point near room temperature to facilitate collection after solidification induced by cooling. The solidified solvent is then melted and analysed.

Reference: [29].

5 **Liquid (fluid)-solid phase extraction**

5.1 **microwave-assisted extraction, (MAE)**

*Leaching* using microwave energy to heat the solvent in contact with the sample.

Note 1: Microwaves are electromagnetic radiation of 300-300,000 MHz. They heat the extraction solution by their interaction with dielectric compounds (solvent or sample). Microwave heating is more efficient and rapid than convection and conduction and enhances the migration rate of compounds into the extraction solvent. Microwave-assisted extraction may be performed in a closed vessel with control of temperature and pressure or in an open vessel at atmospheric pressure [30].
5.2 pressurized hot-water extraction
subcritical water extraction

*Extraction* by water below its critical point (374.15°C and 22.064 MPa).

Note 1: The solvation properties of water become closer to organic solvents at elevated temperatures.

Note 2: Instrument requirements are similar to *pressurized-liquid extraction*.

Reference: [31].

5.3 pressurized-liquid extraction

*Leaching* performed at elevated temperature and pressure.

Note 1: A typical apparatus is shown in Figure 10.

Note 2: The sample in the form of a fine powder or liquid supported on an inert solid is packed into an extraction vessel and inserted in a closed flow-through system. The temperature, pressure, solvent type, and static and/or dynamic extraction time are varied to optimize the extraction performance.

Reference: [32].

Figure 10 Schematic diagram of a typical apparatus for pressurized liquid extraction.
5.4 Soxhlet extraction

Leaching with fresh solvent cycled several times through a fine solid sample contained in a porous thimble.

Note 1: A typical apparatus for classical Soxhlet extraction is shown in Figure 11.

Note 2: The extraction solvent is cycled in a continuous-discrete process by distillation, condensation and siphoning. Extracted material accumulates in the distillation flask.

Reference: [33].

![Figure 11](image)

Figure 11 Typical apparatus for classical Soxhlet extraction.

5.5 supercritical fluid extraction, (SFE)

Use of a supercritical fluid to extract analytes from a solid or supported liquid sample.

Note 1: The powdered sample, or supported liquid, is packed into a vessel and inserted into a closed flow-through system. The extracted material is typically recovered by reducing the pressure of the extraction fluid allowing it to evaporate [32].

Note 2: The most common supercritical fluid for extraction is carbon dioxide (critical point $= 39.9^\circ$C and 73.8 bar). Its extraction properties are varied by changing
its density (temperature and pressure) or by addition of polar organic solvents [35].

References: [32, 35].

5.6 QuEChERS (Quick, Easy, Cheap, Effective, Rugged and Safe) extraction

Streamlined multiresidue method for extraction and clean-up of analytes in complex matrices.

Note 1: Often used for samples containing pesticide residues

Note 2: The general procedure includes micro-scale extraction with acetonitrile, salt-assisted phase separation, and sample clean up using dispersive solid-phase extraction.

Note 3: There are several procedural variations of the general method for application to particular compounds or sample matrices [36].

Reference: [36].

5.7 ultrasound-assisted extraction, (UAE)

Extraction in which ultrasound energy is used to increase the extraction rate by enhancing the contact area between the sample and solvent.

Note 1: Ultrasound energy is applied to samples in a vessel immersed in a water bath or applied more directly using devices, such as horns, probes, or sono-reactors.

Note 2: Ultrasound energy causes cavitation in solvents, which generates numerous tiny bubbles in liquids and mechanical erosion of solids, including particle rupture. It promotes digestion and slurry formation with solids and homogenization and emulsification with liquids.

Reference: [37].

6 Digestion Methods

6.1 acid digestion

Process in which the sample (analyte and matrix) is dissolved by an acid.

Note 1: Acid digestion can also be used to remove a matrix constituent by selective volatilization, e.g., silicon by the use of hydrofluoric acid.
Note 2: Acid digestion can be performed in closed or open vessels.

Related term: bomb acid digestion.

Reference: [38].

6.2 ashing (chemical analysis)

Dry or wet matrix decomposition as a method of preconcentration of trace elements.

Related term: charring.

Reference: [39].

6.3 bomb acid digestion

Type of closed-vessel acid digestion.

Note: Materials which are not fully dissolved by acid-digestion at atmospheric pressure may require a more vigorous treatment in a pressure vessel lined with polytetrafluoroethylene (PTFE) glass, silica or vitreous (glassy) carbon or in sealed silica tubes; this treatment is called bomb digestion. The test sample and acids are heated in a closed vessel so that the digestion is carried out at higher temperature and pressure.

Related term: bomb acid digestion.

Reference: [38].

6.4 charring

Pyrolysis of samples containing organic matter.

Reference: [40].

6.5 closed-vessel acid digestion

Type of acid digestion performed in a closed vessel at elevated pressure.

Note: The increased rate of decomposition and retention of volatile trace elements is an advantage over open-vessel acid digestion [38].

Reference: [38].
6.6 digestion (sample preparation)

Sample dissolution with simultaneous matrix simplification.

6.7 enzymatic decomposition

Decomposition of organic materials by the actions of an enzyme whereby high molecular mass compounds are converted into lower molecular mass species.

Reference: [38].

6.8 fusion

Chemical process by which a sample is transformed into a glass.

Note: Fusion is commonly employed in XRF analysis. It typically consists of four steps: (1) mixing the sample with a fusion reagent and occasionally with an oxidant, in a crucible; (2) heating the crucible to a temperature where the fusion reagent melts; (3) agitation the crucible until the sample has dissolved; and (4) pouring the molten glass into a hot mould to form a flat glass disk of a given diameter after cooling, ready for measurement in the spectrometer [41]. Alternatively, the molten glass can be poured into a swirling warm acid solvent near ambient temperature for dissolution.

Reference: [41].

6.9 microwave acid digestion

Type of bomb acid digestion with microwave radiation used for sample heating.

6.10 open-vessel acid digestion

Type of acid digestion performed at ambient pressure wherein the digestion temperature is limited by the boiling point of the acid.

6.11 oxygen-flask combustion

Type of ashing in which the sample is burned in a closed flask containing oxygen and an absorbing solution which is subsequently analysed.

Reference: [38].
6.12 partial digestion

Digestion in which only a part of the sample, or some of the analytes present, are brought into solution.

Note: Partial digestion may be preferred over total decomposition if the relative analyte concentrations in the samples provides sufficient information (e.g. materials for geochemical exploration).

Reference: [38].

6.13 UV photochemical digestion

Formation of free metal ions in aqueous solution by oxidation under the influence of UV-light and possibly an oxidizing agent (e.g., hydrogen peroxide or peroxodisulfate) in order to break down dissolved organic matter and metal complexes.

Note: Typically samples are sea water, waste water, drinking water or fresh water.

Reference: [38].

7 Solid-Phase Extraction

7.1 cartridge

Short disposable column containing a bed of porous particles immobilized between two porous frits.

Note: The particles are sized to allow sample processing by gravity, gentle suction or low pressure.

Reference: [42, 43].

7.2 conditioning solvent

Small volume of solvent used to prepare the sorbent for efficient sample processing.

Note: Principal roles include removal of contaminants from the sorbent bed, creating the conditions for a stable flow of the sample solution during sampling, and to facilitate wetting of hydrophobic sorbent surfaces before applying aqueous samples.

7.3 elution solvent

Small volume of strong solvent used to displace target analytes from the sorbent bed.
7.4 **foamed polyurethane sorbent**

Sorbent consisting of spherical, micron-sized, agglomerated particles bound together in a rigid and highly porous structure used for the extraction of semi-volatile organic compounds from air in high-volume samplers.

Note 1: Their main attribute is their favourable aerodynamic properties, which permit sampling at high flow rates.

Note 2: Foamed polyurethane sorbents have a minor use for extracting compounds from water.

7.5 **immunosorbents**

Porous material with surface bound monoclonal or polyclonal antibodies capable of selective extraction of target analytes by formation of reversible antibody-antigen (compound) binding complexes.

Note 1: A high level of selectivity is possible due to the specificity of antibody-antigen spatial fitting and interactions.

Note 2: The porous support is chosen to minimize nonspecific matrix interactions to facilitate processing complex biological, environmental and food samples without additional clean up.

7.6 **inorganic oxide adsorbent**

*Adsorbent* with site-specific polar and ion exchange functional groups that extract analytes from a gas or liquid phase by their complementary interactions with the surface.

Note 1: Typical inorganic oxide adsorbents include silica gel, alumina, magnesium silicate (Florisil) and zirconia.

Note 2: Compounds with hydrogen-bonding or ionic functional groups are extracted efficiently, neutral dipolar compounds are extracted to a lesser extent, and weakly polarizable compounds to a limited extent.

7.7 **ion-exchange sorbent**

Porous material containing fixed ionic sites with a complementary charge to that of the target analyte.

Note 1: Ionic or ionizable compounds are extracted almost exclusively from water by electrostatic interactions with ion-exchange sorbents.
Note 2: Ion-exchange sorbents are usually classified as weak or strong depending on the identity of the ionic group and whether its charge is independent of the sample pH (strong ion-exchanger) or can be varied by changing the sample pH (weak ion-exchanger).

7.8 low-specificity sorbents

Sorbent with non-selective surface function groups that extract analytes, almost exclusively from an aqueous solution, in which the driving force for extraction is the reorganization of the water structure to minimize disruption by organic contaminants.

Note 1: From the gas phase compounds are extracted by non-polar and weakly polar interactions with high surface area sorbents.

Note 2: Typical low-specificity sorbents are chemically-bonded porous silica, hydrophobic macroporous polymers, and various forms of carbon.

Note 3: Low-specificity sorbents have surfaces with a low concentration of polar functional groups and retain compounds mainly through non-selective dispersion interactions.

7.9 magnetic nanoparticle sorbent

Sorbent consisting of nanometre-sized, spherical particles with a magnetic or magnetisable core surrounded by a sorbent shell.

Note: Magnetic nanoparticles have a high surface area-to-volume ratio and a low mass. They are easily dispersed in solution. A magnet facilitates recovery of the nanoparticles from the sample solution or suspension.

Reference: [44].

7.10 matrix-solid phase dispersion, (MSPD)

Extraction in which samples are blended with an abrasive solid sorbent forming a free flowing powder from which target analytes are recovered by solvent elution.

Note 1: A typical workflow scheme for matrix-solid-phase dispersion is shown in Figure 12. [45]

Note 2: For additional sample clean-up the sorbent/sample mixture is deposited at the head of a solid-phase extraction cartridge containing a suitable sorbent to retard the elution of matrix components.

Reference: [45].
7.11 microextraction by packed sorbent, (MEPS)

Solid-phase extraction using a syringe with a short sorbent bed located between the plunger and the needle.

Note 1: Typically based on a 100- or 250-µl volume syringe with a packed bed containing 1-2 mg of sorbent.

Note 2: The MEPS syringe facilitates low-dead volume sample processing by vertical movement of the plunger.

Reference: [46].

7.12 mixed-mode sorbent

Porous material with surface co-bonded ion exchange and alkyl functional groups.

Note: The dual extraction mechanism allows fractionation of mixtures into a neutral and acidic fraction, and a basic fraction, by a stepwise change in pH of the eluting solvent.

7.13 molecularly imprinted polymer sorbent, (MIPS)

Porous polymer sorbent with synthetic recognition sites with a high specificity for the sorption of a targeted compound or group of structurally-related compounds.
Note: The imprint is obtained by the co-polymerization of functional and crosslinking monomers in the presence of a template molecule (the analyte) and a porogen. The resultant imprint possesses a steric (size and shape) and chemical (spatial arrangement of complementary functional groups) memory of the template molecule that enable the sorbent to selectively rebind the template molecule from a complex matrix.

7.14 multiwell extraction plate

Regular array of wells in a single moulded body with a short sorbent bed or disc embedded at the base of each well.

Note 1: The design of a typical multiwall extraction plate is shown in Figure 13.

Note 2: Multiwell plates typically contain 24, 96, or 384 wells with volumes varying from about 0.1 to 10 ml. They are used for parallel sample processing in high throughput applications.

Reference: [47].

![Figure 13 Multiwell extraction plate.](image)

7.15 needle trap

Gas-tight syringe with a sorbent-filled needle.

Note: Vertical movement of the plunger allows bidirectional flow of sample through the sorbent bed (active sampling). Alternatively, sampling can occur by diffusion of analytes into the syringe needle (passive sampling).
Reference: [48].

7.16 particle-embedded glass fibre disc

Suspension of micron-sized sorbent particles woven into a glass fibre matrix.

Note: Small discs are self-supporting while larger discs require external support.

7.17 particle-loaded membrane disc

Suspension of micron-sized sorbent particles distributed throughout a web of poly(tetrafluoroethylene) microfibrils formed into a thin disc of various diameters.

Note: For general use the flexible discs are supported on a sintered glass disc in a filtration apparatus using suction to generate the desired flow through the membrane.

7.18 restricted-access sorbent

Porous material with a biocompatible outer surface and a retentive interior surface.

Note 1: Access to the retentive interior surface is restricted for macromolecules by a physical or chemical diffusion barrier that facilitates elution of macromolecules and extraction of low-mass compounds.

Note 2: The restricted access barrier can be accomplished by size exclusion, differential partitioning, or other phenomenon.

7.19 rinse solvent

Weak solvent used to displace matrix components from a sorbent without displacing the target analyte(s).

Note: An optional step, intermediate between sample application and elution.

7.20 solid-phase extraction

Extraction of analytes from a gas, liquid or fluid by transfer to a solid sorbent.

Note: Typical uses of solid-phase extraction include isolation, concentration, solvent exchange and matrix simplification.
7.21 solvent desorption

Use of a solvent, typically combined with agitation, to remove target analytes from a sorbent.

7.22 sorbent-containing pipette tip

A disposable pipette tip with a small packed bed, disc, or monolithic plug of sorbent at its narrow end.

Note 1: A typical design of sorbent-containing pipette device for high throughput sample processing is shown in Figure 14.

Note 2: A micropipettor is used to control sample processing steps. This arrangement facilitates the use of bidirectional flow (the cycling of sample and solvents across the sorbent bed in either direction) for sample processing.

Reference: [49].

Figure 14 Sorbent containing pipette tips in an array for use with a multiwall sample plate.

7.23 sorptive-tape extraction

Extraction from the surface of a solid by sorbent or polymer film in the form of a tape in direct contact with, or in the headspace above, the sample.

Note: The tape is typically a suitably-sized sheet of poly(dimethylsiloxane) polymer, or a piece of particle-loaded membrane, with a large surface area-to-volume ratio.
7.24 stir bar sorptive extraction

*Extraction* of compounds from solution by sorbent coated magnetic stir bar by rapid stirring (direct immersion) or by exposure to the headspace above a sample (*headspace extraction*).

**Note 1:** Related devices for simultaneous stirring and sampling include rotating disc, stir rod, and stir membrane devices [50].

**Note 2:** Rapid stirring accelerates mass transfer overcoming some of the limitations of diffusion controlled mass transfer in sessile solutions.

Reference: [50].

7.25 surface-bound macrocyclic sorbent

Porous material with surface bound macrocyclic ligands designed for the extraction of metal ions and some anions from aqueous solution.

**Note 1:** The selectivity of the extraction process depends on the stability of the host-guest complex, which can be optimized for individual ions by the choice of the macrocyclic cavity and the type of donor atoms.

**Note 2:** Extracted ions are recovered by elution with a solution of complexing agent with a higher binding constant than the surface-bound macrocyclic ligand.

7.26 surface-bound phenylboronic acid sorbent

Porous material with surface-bound phenylboronic acid groups for the selective extraction of bifunctional compounds by reversible formation of 5- or 6-membered covalent cyclic boronic acid complexes.

**Note:** Extraction occurs at a basic pH for compounds with hydrogen-donating functional groups on neighbouring carbon atoms (1,2- and 1,3-) and are released by elution with an acidic aqueous-organic solvent solution.

8 Solid-Phase Microextraction Techniques

8.1 biocompatible solid-phase microextraction

*Extraction* by a matrix-compatible immersion solid-phase *microextraction* device where the extraction phase and support are chosen to eliminate matrix interferences.
8.2 blade configuration

Solid-phase microextraction device where the extraction phase (sorbent) is dispersed in the form of a thin coating on the surface of a blade.

Note: This technique is typically used as a 96-blade brush in conjunction with a multiwell sample plate.

8.3 coated stirrer system

Device where the extraction phase is dispersed on the surface of a stir bar.

Related term: stir bar sorptive extraction.

8.4 coated vessel format

Sample vessel with sorbent-coated walls.

8.5 cold fibre solid-phase microextraction

Solid-phase microextraction in the fibre format with a sorbent temperature maintained below that of the sample matrix during extraction.

8.6 fibre format

Extraction phase in the form of a thin layer supported on a fibre made of inert material, such as fused silica, stainless steel or nickel-titanium alloy.

8.7 headspace solid-phase microextraction

Solid-phase microextraction where the extraction phase is placed in the headspace above the sample.

8.8 immersion solid-phase microextraction

Solid-phase microextraction where the extraction phase is immersed directly into the sample.

8.9 in-needle capillary adsorption trap, (INCAT )

In-tube format device with a sorbent-coated capillary placed inside a needle.
8.10 in-tube solid-phase microextraction

Non-exhaustive *extraction* in which a coated open tubular or packed capillary tube is the sorbent phase in a flow system.

Reference: [51].

8.11 matrix-compatible solid-phase microextraction

*Immersion solid-phase microextraction* where the *extraction phase* is designed to prevent sorption of particles or macromolecules present in the sample matrix.

8.12 membrane-protected solid-phase microextraction

Matrix compatible device where a thin coating of restricted access material or a membrane is placed over the *extraction phase* minimizing the *adsorption* of matrix components, such as macromolecules or particles, present in the sample matrix.

8.13 particle format

*Extraction phase* in the form of sorbent particles.

Note: Particles are typically of a nanometre size and applied in the *dispersion mode of extraction*.

8.14 rotating disk sorptive extraction, (RDSE)

*Sorbent-coated* disc consisting of a PTFE base with an integrated magnet and a sorbent film attached to one side.

Note: Facilitates more rapid stirring than conventional sorbent-coated stir bars (see *stir bar sorptive extraction*) without deterioration of the sorbent coating, because it is not in contact with the vessel wall.

8.15 solid-phase dynamic extraction, (SPDE)

*Extraction* by an in-tube format device where the needle is internally coated with a sorbent.

8.16 Solid-phase microextraction, (SPME)

*Microextraction* where the *extraction phase* is a solid or liquid sorbent.
8.17 thin film format

*Solid-phase microextraction* where the *sorbent* is in the form of a thin film on a support or self supported *membrane*.

9 Membrane Extraction

9.1 dialysate
permeate (dialysis)

Stream containing permeated analytes that leave a *dialysis* module.

9.2 dialysis

Process of separation of low molecular weight analytes from a matrix by a membrane permeable to all components of the system except the high molecular weight components, and allowing the exchange of the components of small molar mass to proceed in a continuous fashion.

9.3 downstream

Side of a *membrane* from which penetrants exit into the permeate.

Adapted from reference: [52].

9.4 electrodialysis

*Dialysis* in which ions are separated by an electrical potential across a *membrane*.

Note: The membrane is permeable to ions but not neutral compounds.

9.5 liquid membrane

Liquid phase in either a supported or unsupported form that serves as a *membrane* between two phases.

9.6 membrane

Structure having lateral dimensions much greater than its thickness, through which transfer may occur by a variety of driving forces.

Reference: [52].
9.7 membrane extraction

Separation of analytes from a sample by selective mass transfer (*permeation*) through a *membrane*.

9.8 membrane extraction with sorbent interface

Membrane extraction with simultaneous *sorbent* extraction of separated analytes.

9.9 microdialysis

*Dialysis* by a short length of *hollow-fibre membrane* used for sampling.

Note: Microdialysis is performed mostly in a living biological system.

9.10 microporous filtration

Separation process whereby particles are removed from a sample by application of hydraulic pressure, which forces only particle-free matrix to flow through a suitable *membrane*.

Note: Typically the membrane has a pore size down to 0.1µm.

9.11 non-porous membrane

*Membrane* in which transfer occurs through the membrane material.

Related term: *porous membrane*.

9.12 perfusate

Stream of *extraction phase* entering a *dialysis* module.

Note: Perfusate is also used to describe the stripping phase in *dialysis*.

9.13 permeate

Stream containing material that has passed through a *membrane*.

Adapted from reference: [52].

9.14 permeation

Selective mass transfer through a *membrane*.
9.15 pervaporation

Membrane-based process in which the feed stream and retentate stream are both liquid phases with the analytes emerging at the downstream face of the membrane as a vapour.

Adapted from reference: [52].

9.16 porous membrane

Membrane in which transfer occurs through its porous structure.

Related term: non-porous membrane.

9.17 retentate stream

Sample left over in membrane separations after initial contact with the membrane.

9.18 reverse osmosis

Liquid-phase separation in which pressure applied transmembrane pressure causes selective movement of solvent against its osmotic pressure difference.

Reference: [52].

9.19 semipermeable membrane device, (SPMD)

Enclosed membrane filled with extraction phase.

9.20 stream

The sample in membrane separations prior to contact with the membrane.

9.21 stripping phase:

Extraction phase in a membrane separation.

Adapted from reference: [52].

9.22 supported liquid membrane, (SLM)

Porous membrane with solvent-filled pores immobilized by capillary forces.

Note 1: Porous polymeric hollow fibres and filter disks are typically used as support formats for microextraction techniques.
Note 2: Water immiscible organic solvents are typically employed in the preparation of supported liquid membranes.

9.23 ultrafiltration

Separation whereby a solution containing a solute of molecular size significantly greater than that of the solvent molecule is removed from the solvent by the application of hydraulic pressure, which forces only the solvent to flow through a suitable membrane.

Note: The membrane usually has a pore size in the range 0.001–0.1 μm.

Reference: [53].

9.24 upstream (in membrane processes)

The side of a membrane into which penetrants enter from the feed stream.

Reference: [52].

10 Automated and High-Throughput Extraction Methods—Advanced Flow Methodology

10.1 automated extraction

Extraction with regulated feedback according to a manually selected set of conditions without human intervention.

10.2 automatic extraction

Extraction according to a manually selected set of conditions without human intervention.

10.3 bead injection

Fully renewable (disposable) packed sorbent bed for solid-phase extraction in a flow manifold or mesofluidic platform using programmable flow.

Note: A typical workflow for bead injection in a flow manifold is shown in Figure 15.

Reference: [54].
Figure 15 Bead-Injection protocols for automated μSPE with sorbent renewal for each assay (Reproduced from www.flowinjectiontutorial.com with the author’s permission (Prof. Ruzicka))

10.4 bioaccessibility

Soluble fraction of an analyte extracted with a defined set of operational conditions.

10.5 dynamic bioaccessibility

*Bioaccessibility* determined in a flow-through apparatus by leaching analytes from a solid or semisolid matrix.

10.6 flow injection analysis, (FIA)

Analysis of sample by rapid injection into a continuous stream of liquid for extraction, separation or modification by reaction.

Note: The three cornerstones of FIA are: (i) injection of well-defined sample volumes at the low microliter level; (ii) controllable dispersion and (iii) precise timing.

Reference: [3], [55].

10.7 flow-through extraction

*Extraction* by flow of sample across the *extraction phase*, or vice versa, to enhance the sampling rate.
Note: The forced flow of matrix or extraction phase is controlled by an external device.

10.8 **in-line cloud point extraction**

Cloud point extraction using a flow system integrating the merging of sample and surfactant streams in a single-phase liquid extraction protocol.

Note: The micellar phase is typically isolated by solid-phase extraction for quantification of extracted analytes.

Reference: [56].

10.9 **in-line dispersive liquid-phase microextraction**

*Microextraction* by a flow system integrating the merging of sample with extraction solvent and disperser to generate fine droplets of the organic phase for in-line liquid-phase microextraction.

Note: The droplets are typically isolated from the *extraction phase* by solid-phase extraction for quantification of target analytes.

Reference: [57], [58].

10.10 **in-line dynamic leaching**

*Leaching* of analytes by forced flow or aspiration of solvent through solid samples contained in columns.

Related term: *bioaccessibility*.

Reference: [59].

10.11 **in-line extraction chromatography**

Application of *in-line solid-phase extraction* employing selective interactions between a bead-immobilized complexing ligand and metal ions (mainly radionuclides).

Reference: [60].

10.12 **in-line hollow-fiber liquid-phase microextraction**

Integration of a single or bundle of hollow fibers impregnated with organic solvent in a flow-through extraction chamber for 2- or 3-phase *liquid-phase microextraction*. 
Reference: [61].

10.13 **in-line microaffinity chromatography**

Application of *in-line solid-phase extraction* employing selective interaction between bead-immobilized affinity ligands and biopolymers.

Reference: [62].

10.14 **in-line micro-solid-phase extraction, (µSPE)**

Automatic *solid-phase extraction* using a short packed or monolithic column as a permanent component of a flow system.

Reference: [63].

10.15 **in-line wetting-film extraction**

*Liquid phase microextraction* in a flow system employing dynamic coating of the inner wall of a hydrophobic (capillary) tube with organic solvent to generate a (pseudo-) stationary film of *extraction phase*.

Reference: [56].

10.16 **in-syringe liquid-phase microextraction**

Batch-type *liquid phase microextraction* in which the syringe barrel of a *sequential injection system* is used as an extractor for liquid-phase microextraction and phase separation.

Reference: [64].

10.17 **lab-at-valve liquid-phase microextraction**

Automatic batch-type liquid-phase *microextraction* in a sequential injection system using an external extraction container (e.g., pipette tip) connected to a multiposition rotary valve.

Reference: [65].

10.18 **lab-on-a-chip**

Microfluidic platform containing engraved microconduits for fluid handling based on pressure-driven or electroosmotic flow in which (bio)chemical processes are monitored in near real-time.
Reference: [66].

10.19 **lab-on-a-valve**

Mesofluidic platform containing engraved microconduits for fluid handling based on pressure-driven flow in which (bio)chemical processes are monitored in near real-time.

Reference: [55, 67].

10.20 **programmable flow**

Multi-bidirectional flow (including stopped flow) controlled by a high precision micro-syringe pump.

Reference: [68].

10.21 **mechanized extraction**

*Extraction* using a device with at least one mobile part that replaces or supplements human effort in any (or all) steps of the process.

10.22 **mesofluidic devices**

Integrated flow platforms with channel widths from 10 μm to 2 mm.

Note: *Lab-on-a-valve* platforms belong to the group of mesofluidic devices.

Reference: [68].

10.23 **microflow injection analysis, (µFIA)**

Miniaturized types of *flow injection analysis* using integrated (chip) platforms.

10.24 **microfluidic device**

Integrated flow platform with channel widths from 100 nm to 10 μm.

Reference: [69].

10.25 **multicommutation flow analysis**

Continuous-flow system with a set of microsolenoid valves for injecting low-microliter sample and/or reagent plugs for further processing downstream.
**10.26 segmented flow analysis**

Continuous-flow pumping system attaining steady-state extraction/reaction conditions facilitated by injection of air bubbles. This might be extended to immiscible liquids injected as droplets in the flow system.

Related term: *segmented flow extraction*.

**10.27 segmented flow extraction**

*Extraction* by insertion of the sample solution as equal-size droplets (segments) in a flowing stream of immiscible extraction phase.

Note 1: The characteristic components of the system are the segmenter (creates the droplets in the solvent stream); the extraction coil (Provides sufficient time for transfer of target analytes to the extraction solvent); and the phase separator (reconstitutes the sample solution and extraction solvent into two separate streams).

Note 2: A typical apparatus for segmented flow extraction is shown in Figure 16.

Reference: [70].

![Figure 16](image.png)

Figure 16 Typical segmented flow extraction manifold. C: carrier or liquid phase for sample; R: reagent (optional); P: propulsion unit; S: sample; IV: injection valve; MC: mixing coil; DB: displacement bottle (functions as a constant volume pump); ORG: organic solvent; SG: segmenter; EC: extraction coil; PS: phase separator; D: detector (optional); RC: restriction coil; and W: waste.

**10.28 sequential injection analysis**

Mesofludic approach to fluid manipulation via computer-controlled programmable flow through a multi-position rotary valve.

Reference: [69].
10.29 solid-phase optosensing

Continuous optical interrogation of a packed-sorbent bed in a flow system during the sorptive process.

Note: Detection is performed before analyte elution and sorbent regeneration.

Reference: [71].

MEMBERSHIP OF SPONSORING BODY

Membership of the Committee of the Chemistry and Analytical Chemistry Division during the preparation of this report (2014-2015) was as follows:


REFERENCES


[54] J. Qiao, X. Hou, P. Roos, M. Miró. Rapid determination of plutonium isotopes in environmental samples using sequential injection and extraction chromatography and


