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SUBCOMMITTEE ON POLYMER TERMINOLOGY

DEFINITIONS OF TERMS RELATING TO THE
STRUCTURE AND PROCESSING OF SOLS, GELS,
NETWORKS, AND INORGANIC–ORGANIC HYBRID
MATERIALS

(IUPAC Recommendations 2007)

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Definitions of terms relating to the structure and processing of sols, gels, networks, and inorganic–organic hybrid materials

(IUPAC Recommendations 2007)

Abstract: This document defines terms related to the structure and processing of inorganic, polymeric, and inorganic–organic hybrid materials from precursors, through gels to solid products. It is divided into four sections—precursors, gels, solids, and processes—and the terms have been restricted to those most commonly encountered.

For the sake of completeness and where they are already satisfactorily defined for the scope of this document, terms from other IUPAC publications have been used. Otherwise, the terms and their definitions have been assembled in consultation with experts in the relevant fields. The definitions are intended to assist the reader who is unfamiliar with sol-gel processing, ceramization, and related technologies and materials, and to serve as a guide to the use of standard terminology by those researching in these areas.

Keywords: sols; gels; inorganic–organic hybrids; sol-gel processing; ceramics; networks; IUPAC Inorganic Chemistry Division; IUPAC Polymer Division.

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1. INTRODUCTION

This document provides definitions of the terms most commonly used in relation to sol-gel processing and ceramization. It embraces all categories of materials and their processing. The definitions result from the efforts of a working party drawn from the membership of the IUPAC Polymer and Inorganic Chemistry Divisions.

As depicted in Fig. 1, the various terms relating both to materials and processing can be described within a grid that correlates type of material (precursor, gel, or solid) with class of material (inorganic, hybrid, or polymeric). Accordingly, the terms in this document are grouped first by type (the columns in Fig. 1) and then by type-to-type conversion, i.e., process (the rows in Fig. 1). Where it is necessary to indicate or differentiate between classes of material (inorganic, hybrid, and polymer), this has been done within the definition of the relevant term.
For ease of reference, the terms in each section, subsection, etc. are listed alphabetically and numbered sequentially. Cross-references to terms defined elsewhere in the document are denoted in italic typeface. If there are two terms in an entry on successive lines, the second is a synonym.

For the present document, the terms describing the structure and behavior of networks have been restricted to those that are commonly used, rely on clearly defined theoretical concepts, and are unambiguous in their meanings. This area of terminology will be dealt with in more detail in a later document.

2. PRECURSORS

2.1 **agglomerate** (except in polymer science)
Cluster of primary particles held together by physical interactions.

*Note 1:* A primary particle is the smallest discrete identifiable entity observable by a specified identification technique, e.g., transmission electron microscopy, scanning electron microscopy, etc.

*Note 2:* The particles that comprise agglomerates can usually be readily dispersed.

See the Note of 2.3.

2.2 **agglomerate** (in polymer science)
aggregate (in polymer science)
Cluster of molecules or particles that results from *agglomeration* [3].
See Definition 1.42 in [3].
2.3 aggregate (except in polymer science)
Cluster of primary particles interconnected by chemical bonds.

Note: Alternative definitions of aggregate and agglomerate are used in catalysis [2]. The distinction offered by these definitions is in conflict with the distinction understood in the wider context and with the concepts of aggregation and agglomeration. To avoid confusion, the definitions proposed here are recommended.

2.4 aggregate (in polymer science)
See agglomerate (in polymer science).

2.5 chemical functionality
Ability of functional groups present within a polymer or polymer network to participate in chemical reactions.

Note: The chemical functionality of a network formed by a sol-gel process from a precursor such as (RO)$_3$Si-CH=CH$_2$ is that of the vinyl group.

2.6 colloid
A short synonym for a colloidal system. (Gold Book online, 1972 entry.)

2.7 colloidal
State of subdivision, implying that the molecules or polymolecular particles dispersed in a medium have at least in one direction a dimension roughly between 1 nm and 1 µm, or that in a system discontinuities are found at distances of that order. (Gold Book online, 1972 entry.)

2.8 colloidal dispersion
System in which particles of colloidal size of any nature (e.g., solid, liquid, or gas) are dispersed in a continuous phase of a different composition (or state). (Gold Book online, 1972 entry.)

Note: The name dispersed phase for the particles should be used only if they have essentially the properties of a bulk phase of the same composition.

2.9 colloidal sol
See sol.

2.10 colloidal suspension
Suspension in which the size of the particles lies in the colloidal range. (Gold Book online, 1972 entry.)

Note: A colloidal suspension is colloidal dispersion of a solid in a liquid.

2.11 connectivity
Number of covalent bonds emanating from a constitutional unit of an oligomer molecule or a macromolecule.

Note: The definition within [2] is compatible with this definition but is too general to be readily understood in the present context.
2.12 **functionality** (of a monomer), $f$
Number of covalent bonds that a monomer molecule or monomeric unit (see Definition 1.8 in [1]) in a macromolecule or oligomer molecule can form with other reactants.

*Note 1:* There are no monofunctional monomers.

*Note 2:* If $f = 2$, a linear chain macromolecule or a macrocycle (see Definition 1.57 in [1]) can be formed.

*Note 3:* If $f > 2$, a branch point (see Definition 1.54 in [1]) can be formed leading to a branched macromolecule, a network, or a micronetwork.

*Note 4:* Ethene and ethylene glycol are examples of difunctional monomers, glycerol is an example of a trifunctional monomer, and divinylbenzene and pentaerythritol are examples of tetrafunctional monomers.

2.13 **pre-gel regime**
Stage of a network-forming polymerization or crosslinking process extending up to, but not beyond, the gel point.

*Note:* The pre-gel regime may be expressed as the length of time or the chemical conversion required to reach the gel point from the start of a polymerization or crosslinking process.

2.14 **pre-gel state**
State of a network-forming polymerization or crosslinking process in the pre-gel regime.

*Note:* In the pre-gel state, the sol fraction is equal to unity. All the molecules formed have finite (statistically definable) relative molecular masses.

2.15 **slip**
*Ceramic precursor* dispersed in a liquid.

2.16 **sol**
colloidal sol
Fluid colloidal system of two or more components. (Gold Book online, 1972 entry.)

*Note:* Examples of colloidal sols are protein sols, gold sols, emulsions, and surfactant solutions above their critical micelle concentrations.

2.16.1 **aerosol**
*Sol* in which the dispersed phase is a solid, a liquid, or a mixture of both and the continuous phase is a gas (usually air).

*Note 1:* Owing to their size, the particles of the dispersed phase have a comparatively small settling velocity and hence exhibit some degree of stability in the earth’s gravitational field.

*Note 2:* An aerosol can be characterized by its chemical composition, its radioactivity (if any), the particle size distribution, the electrical charge, and the optical properties.

Modified from [2], within which particles with equivalent diameters usually between 0.01 and 100 µm are specified. This extends beyond the size range specified for a colloidal system. To avoid confusion, the definition proposed here is recommended.

2.16.2 **particulate sol**
Sol in which the dispersed phase consists of solid particles.

2.16.3 **polymeric sol**
Sol in which the dispersed phase consists of particles having a polymeric structure.

2.16.4 **sonosol**
Sol produced by the action of ultrasonically induced cavitation.

2.17 **sol fraction**
Mass fraction of the dissolved or dispersed material resulting from a network-forming polymerization or crosslinking process that is constituted of molecules of finite (statistically definable) relative molecular masses.

See also **gel fraction**.

3. **GELS**

3.1 **gel**
Non-fluid colloidal network or polymer network that is expanded throughout its whole volume by a fluid.

*Note 1:* A gel has a finite, usually rather small, yield stress.

*Note 2:* A gel can contain
(i) a covalent polymer network, e.g., a network formed by crosslinking polymer chains or by nonlinear polymerization;
(ii) a polymer network formed through the physical aggregation of polymer chains, caused by hydrogen bonds, crystallization, helix formation, complexation, etc., that results in regions of local order acting as the network junction points. The resulting swollen network may be termed a thermoreversible gel if the regions of local order are thermally reversible;
(iii) a polymer network formed through glassy junction points, e.g., one based on block copolymers. If the junction points are thermally reversible glassy domains, the resulting swollen network may also be termed a thermoreversible gel;
(iv) lamellar structures including mesophases, e.g., soap gels, phospholipids, and clays;
(v) particulate disordered structures, e.g., a flocculent precipitate usually consisting of particles with large geometrical anisotropy, such as in $V_2O_5$ gels and globular or fibrillar protein gels.

Corrected from [2], where the definition is via the property identified in Note 1 (above) rather than of the structural characteristics that describe a gel.

3.1.1 **aerogel**
Gel comprised of a microporous solid in which the dispersed phase is a gas.

*Note:* Microporous silica, microporous glass, and zeolites are common examples of aerogels.

Corrected from [2], where the definition is a repetition of the incorrect definition of a gel followed by an inexplicit reference to the porosity of the structure.

3.1.2 alcogel
*Gel* in which the swelling agent consists predominantly of an alcohol or a mixture of alcohols.

3.1.3 aquagel
*Hydrogel* in which the network component is a *colloidal network*.

3.1.4 colloidal gel
*Gel* in which the network component comprises particles of colloidal dimensions. See also *colloidal network*.

3.1.5 gel microparticle
See *microgel*.

3.1.6 gel nanoparticle
See *nanogel*.

3.1.7 humming gel
See *ringing gel*.

3.1.8 hydrogel
*Gel* in which the swelling agent is water.

*Note 1:* The network component of a hydrogel is usually a *polymer network*.

*Note 2:* A hydrogel in which the network component is a *colloidal network* may be referred to as an *aquagel*.

3.1.9 microgel
gel microparticle
Particle of *gel* of any shape with an equivalent diameter of approximately 0.1 to 100 µm. Modified from [2]. The definition proposed here is recommended for its precision and because it distinguishes between a microgel and a *nanogel*.

3.1.10 nanogel
gel nanoparticle
Particle of *gel* of any shape with an equivalent diameter of approximately 1 to 100 nm.

3.1.11 neutralized gel
*Gel* containing acidic or basic groups that have been neutralized.

3.1.12 particulate gel
*Gel* in which the network component comprises solid particles.
3.1.13 polyelectrolyte gel
Polymer gel in which the polymer network contains ionic or ionizable groups in a significant fraction of its constitutional units.

3.1.14 polymer gel
Gel in which the network component is a polymer.

3.1.15 responsive gel
Gel that responds to external electrical, mechanical, thermal, light-induced, or chemical stimulation.

Note: The use of the term intelligent gel is discouraged.

3.1.16 rheopexic gel
rheotropic gel
Gel for which the time of solidification after discontinuation of a relatively high shear rate, is reduced by applying a small shear rate.

3.1.17 rheotropic gel
See rheopexic gel.

3.1.18 ringing gel
humming gel
Gel with energy dissipation in the acoustic frequency range.

Note: A ringing gel is often a hydrogel with a surfactant as a third component and has a composition within an isotropic, one phase region of its ternary phase diagram.

3.1.19 sonogel
Colloidal gel produced by the action of ultrasonically induced cavitation.

3.1.20 thermoreversible gel
Swollen network in which the junction points are thermally reversible. See also gel.

3.1.21 thixotropic gel
Gel which has a reduced viscosity on the application of a finite shear but which recovers its original viscosity when the shear is discontinued.

3.1.22 xerogel
Open network formed by the removal of all swelling agents from a gel.

Note: Examples of xerogels include silica gel and dried out, compact macromolecular structures such as gelatin or rubber.

Modified from [2]. The definition proposed here is recommended as being more explicit. See also swelling.
3.2 drying control chemical additive (DCCA)
Cosolvent included to facilitate the rapid drying of gels without cracking.

3.3 gel point
gelation point
Point of incipient network formation in a process forming a chemical or physical polymer network.

Note 1: In both network-forming polymerization and the crosslinking of polymer chains, the gel point is expressed as an extent of chemical reaction (cf. gel time).

Note 2: At the gel point, a solid (network) material spanning the entire system is formed. See also gel fraction.

Note 3: The gel point is often detected using rheological methods. Different methods can give different gel points because viscosity is tending to infinity at the gel point and a unique value cannot be measured directly.

3.4 gel temperature
See gelation temperature.

3.5 gel time
gelation time
Time interval from the start of a network-forming process to the gel point.

3.6 gelation point
See gel point.

3.7 gelation temperature
gel temperature
Temperature threshold for the formation of a thermoreversible gel.

Note 1: A thermoreversible gel is usually formed by cooling a polymer solution. In these cases, the gel temperature is a maximum temperature at which the presence of network is observed.

Note 2: Since gel temperatures depend on the method of determination, this should always be indicated.

3.8 gelation time
See gel time.

3.9 swelling agent
Fluid used to swell a gel, network, or solid.
See also swelling.
4. SOLIDS

4.1 Terms describing materials

4.1.1 ceramer
Chemically bonded hybrid material which is a crosslinked organic–inorganic polymer.

Note: Ceramers are usually prepared by sol-gel processing of oligomers or polymers with reactive silyloxy substituents.

4.1.2 ceramic
Rigid material that consists of an infinite three-dimensional network of sintered crystalline grains comprising metals bonded to carbon, nitrogen, or oxygen.

Note: The term ceramic generally applies to any class of inorganic, non-metallic product subjected to high temperature during manufacture or use.

4.1.3 ceramic precursor
preceramic, preceramic material
Material that is converted to a ceramic through pyrolysis.

Note: Examples include poly(dimethylsilanediyl), poly(carbasilane)s, poly(silazane)s, etc.

4.1.4 ceramic-reinforced polymer
Polymer composite consisting of a polymer continuous phase and disperse phase domains of microscopic ceramic particles.
See also Definition 3.2 in [3].

4.1.5 ceramic yield
Mass of ceramic expressed as a percentage of the mass of the ceramic precursor used in the ceramization process.

4.1.5.1 theoretical ceramic yield
Ceramic yield based on the stoichiometry of the ceramization process.

4.1.6 composite
Multicomponent material comprising multiple, different (non-gaseous) phase domains in which at least one type of phase domain is a continuous phase [3].

Note: A foamed substance, which is a multiphase material that consists of a gas dispersed in a liquid or solid, is not normally considered to be a composite.

4.1.7 creep
Time-dependent change of the dimensions of a material under a constant load.

4.1.8 elastomer
Polymer that displays rubber-like elasticity.
4.1.8.1 thermoplastic elastomer
Elastomer comprising a thermoreversible network.

4.1.9 fractal agglomerate
Agglomerate having the same fractal dimension as the constituent particles.

4.1.10 fractal dimension, \( d \)
mass fractal dimension, Hausdorff dimension
Parameter that provides a mathematical description of the fractal structure of a polymer network, an aggregated particulate sol, or of the particles that comprise them.

- **Note 1:** \( m \propto r^d \) in which \( m \) is the mass contained within a radius, \( r \), measured from any site or bond within a fractal structure.
- **Note 2:** For a Euclidean object of constant density, \( d = 3 \), but for a fractal object, \( d < 3 \), such that its density decreases as the object gets larger.
- **Note 3:** For the surface area of a fractal object, \( s \propto r^{d'} \) in which \( s \) is the surface area contained within a radius, \( r \), measured from any site or bond and \( d' \) is termed the surface fractal dimension.

4.1.11 gel fraction
Mass fraction of the network material resulting from a network-forming polymerization or crosslinking process.

- **Note:** The gel fraction comprises a single molecule spanning the entire volume of the material sample.

See also sol fraction.

4.1.12 green body
Object formed from a preceramic material prior to pyrolysis.

4.1.13 Hausdorff dimension
See fractal dimension.

4.1.14 hybrid material
Material composed of an intimate mixture of inorganic components, organic components, or both types of component.

- **Note:** The components usually interpenetrate on scales of less than 1 \( \mu \)m.

4.1.14.1 chemically bonded hybrid (material)
Hybrid material in which the different components are bonded to each other by covalent or partially covalent bonds.
4.1.14.2 clay hybrid
polymer-clay hybrid, polymer-clay composite
Organic–inorganic composite material in which one of the components is a clay, the particles of which are dispersed in a polymer.

4.1.14.3 hybrid polymer
Polymer or polymer network comprised of inorganic and organic components.

Note: Examples include inorganic–organic polymers and organic–inorganic polymers.

4.1.14.4 polymer-clay composite
See clay hybrid.

4.1.14.5 polymer-clay hybrid
See clay hybrid.

4.1.15 inorganic–organic polymer (IOP)
Polymer or polymer network with a skeletal structure comprising inorganic and organic units [4].

Note 1: Examples include poly(carbasilane)s, poly(phenylenesilandiyi)s, poly(phenylene-sulfide)s, etc.

Note 2: cf. 4.1.22.

4.1.15.1 inorganic polymer
Polymer or polymer network with a skeletal structure that does not include carbon atoms.

Note: Examples include polyphosphazenes, polysilicates, polysiloxanes, polysilanes, poly-silazanes, polygermanes, polysulfides, etc.

4.1.16 mass fractal dimension
See fractal dimension.

4.1.17 mixed ceramic
Ceramic material consisting of co-continuous interpenetrating networks of two or more metal carbides, nitrides, or oxides.

4.1.18 monolith
Shaped, fabricated, intractable article with a homogeneous microstructure which does not exhibit any structural components distinguishable by optical microscopy.

Note: The article is usually fabricated by cold pressing or hot pressing of a polymeric material, or by using a reactive processing technique such as reaction injection molding, crosslinking, sol-gel processing, sintering, etc.

4.1.19 multiphase copolymer
Copolymer comprising phase-separated microdomains.
See Definition 3.3 in [3].
4.1.20 **nanocomposite**

*Composite* in which at least one of the phase domains has at least one dimension of the order of nanometres.

Corrected from Definition 1.15 in [3], which refers to phases instead of phase domains.

4.1.21 **network**

Highly ramified structure in which essentially each constitutional unit is connected to each other constitutional unit and to the macroscopic phase boundary by many paths through the structure, the number of such paths increasing with the average number of intervening constitutional units; the paths must on average be coextensive with the structure.

*Note:* Usually, and in all systems that exhibit rubber elasticity, the number of distinct paths is very high, but, in most cases, some constitutional units exist that are connected by a single path only.

Modified from [2]. The definition proposed here is a generalization to cover both polymeric networks and networks comprised of particles.

4.1.21.1 **colloidal network**

Network comprising particles of colloidal dimensions.

4.1.21.2 **network polymer**

See *polymer network*.

4.1.21.3 **polymer network**

Polymer composed of one or more networks. (Gold Book online, 1996 entry.)

4.1.21.3.1 **bimodal network**

Bimodal polymer network

*Polymer network* comprising polymer chains having two significantly different molar-mass distributions between adjacent *junction points*.

4.1.21.3.2 **bimodal polymer network**

See *bimodal network*.

4.1.21.3.3 **covalent network**

Network in which the permanent paths through the structure are all formed by covalent bonds.

*Note:* Modification of the entry given as a note within the definition of network (in polymer chemistry) in [2].

4.1.21.3.4 **covalent polymer network**

See *covalent network*.
4.1.21.3.5 entanglement network

Polymer network with junction points or zones formed by physically entangled chains.
See also physical network and chain entanglement.

4.1.21.3.6 interpenetrating polymer network (IPN)

Polymer comprising two or more networks that are at least partially interlaced on a molecular scale but not covalently bonded to each other and cannot be separated unless chemical bonds are broken.

Note: A mixture of two or more preformed polymer networks is not an IPN.

4.1.21.3.6.1 sequential interpenetrating polymer network

Interpenetrating polymer network prepared by a process in which the second component network is formed following the formation of the first component network.

4.1.21.3.6.2 simultaneous interpenetrating polymer network

Interpenetrating polymer network prepared by a process in which the component networks are formed concurrently.

4.1.21.3.7 micronetwork

Polymer network that has dimensions of the order of 1 nm to 1 µm.
Modified from [2]. The definition proposed here is recommended as being more explicit.

4.1.21.3.8 model network

Polymer network synthesized using a reactant or reactants of known molar mass or masses and chemical structure.

Note 1: A model network can be prepared using a nonlinear polymerization or by crosslinking of existing polymer chains.

Note 2: A model network is not necessarily a perfect network. If a nonlinear polymerization is used to prepare the network, nonstoichiometric amounts of reactants or incomplete reaction can lead to network containing loose ends. If the crosslinking of existing polymer chains is used to prepare the network, then two loose ends per existing polymer chain result. In the absence of chain entanglements, loose ends can never be elastically active network chains.

Note 3: In addition to loose ends, model networks usually contain ring structures as network imperfections.

Note 4: Loose ends and ring structures reduce the concentration of elastically active network chains and result in the shear modulus and Young’s modulus of the rubbery networks being less than the values expected for a perfect network structure.

Note 5: Physical entanglements between network chains can lead to an increase in the concentration of elastically active network chains and, hence, increases in the shear modulus and the Young’s modulus above the values expected for a perfect network structure.

4.1.21.3.9 oxide network

Network comprising only metal–oxygen linkages.
4.1.21.3.10 perfect network
perfect polymer network
Polymer network composed of chains all of which are connected at both of their ends to different junction points.

Note: If a perfect network is in the rubbery state then, on macroscopic deformation of the network, all of its chains are elastically active and display rubber elasticity.

4.1.21.3.11 perfect polymer network
See perfect network.

4.1.21.3.12 physical network
Polymer network with junction points or zones formed by physically interacting chains which need not be permanent.

Note 1: The junction points or zones need not be permanent over the time scale of the observation or measurement.

Note 2: The interaction can be due to hydrogen bonds, \( \pi-\pi \) interactions, chain entanglements, etc.

Note 3: Modification of the entry given as a note within the definition of network (in polymer chemistry) in [2].

4.1.21.3.13 reversible network
Polymer network that forms or breaks up as the temperature is changed or under the action of a force.

Note: The junction points in a reversible network are usually small crystallites or glassy domains such as those formed within block copolymers.

4.1.21.3.13.1 thermoreversible network
Reversible network that forms or breaks up as the temperature is changed.

4.1.21.3.14 semi-interpenetrating polymer network (SIPN)
Polymer comprising one or more polymer networks and one or more linear or branched polymers characterized by the penetration on a molecular scale of at least one of the networks by at least some of the linear or branched macromolecules.

Note: An SIPN is distinguished from an IPN because the constituent linear or branched macromolecules can, in principle, be separated from the constituent polymer network(s) without breaking chemical bonds; it is a polymer blend.

4.1.21.3.14.1 sequential semi-interpenetrating polymer network
Semi-interpenetrating polymer network prepared by a process in which the linear or branched components are formed following the completion of the reactions that lead to the formation of the network(s) or vice versa.
4.1.21.3.14.2 simultaneous semi-interpenetrating polymer network
Semi-interpenetrating polymer network prepared by a process in which the networks and the linear or branched components are formed concurrently.

4.1.21.3.15 transient network
Network that exists only transiently.

Note: The network structure of a transient polymer network is based on transient junction points or crosslinks arising from interactions between polymer chains.

4.1.22 organic–inorganic polymer (OIP)
Polymer or polymer network with a skeletal structure comprised only of carbon but which has side groups that include inorganic components [4].

Note: cf. 4.1.15.

4.1.23 organically modified ceramic
Organically modified ceramic
Chemically bonded hybrid material which is a crosslinked inorganic–organic polymer.

Note 1: Organically modified ceramics are hybrid polymers with inorganic and organic moieties linked by stable covalent bonds and based on organically modified alkoxysilanes, functionalized organic polymers, or both.

Note 2: Though it is a commonly used acronym for organically modified ceramic, “Ormocer” is a registered trademark and as such its terminological use is strongly discouraged.

4.1.24 organically modified silica (silicate)
Silica modified by organic groups.

Note 1: Organically modified silicas can be obtained by sol-gel processing.

Note 2: An organically modified silica is of general structure \((RO)_{a}Si(B)_{b}(C)_{c}(D)_{d}\), where \((a + b + c + d) = 4\), R is any alkyl, aryl, or heteroaryl group and B, C, and D are generally organic groups.

Note 3: Though it is a commonly used acronym for organically modified silicate, “Ormosil” is a trademark and as such its terminological use is discouraged.

4.1.25 organomodified ceramic
See organically modified ceramic.

4.1.26 polymer alloy
Polymeric material, exhibiting macroscopically uniform physical properties throughout its whole volume, that comprises a compatible polymer blend, a miscible polymer blend, or a multiphase copolymer. See Definition 1.38 in [3].
4.1.27  polymer blend
Macroscopically homogeneous mixture of two or more different species of polymer. (Gold Book online, 1997 entry).

Note 1: In most cases, blends are homogeneous on scales larger than several times the wavelengths of visible light.

Note 2: In principle, the constituents of a blend are separable by physical means.

Note 3: No account is taken of the miscibility or immiscibility of the constituent macromolecules, i.e., no assumption is made regarding the number of phase domains present.

Note 4: The use of the term polymer alloy for a polymer blend is discouraged, as the former term includes multiphase copolymers but excludes incompatible polymer blends.

Note 5: The number of polymeric components that comprise a blend is often designated by an adjective, viz. binary, ternary, quaternary, etc.

4.1.27.1  compatible polymer blend
Immiscible polymer blend that exhibits macroscopically uniform physical properties.

Note: The macroscopically uniform properties are usually caused by sufficiently strong interactions between the component polymers.

4.1.27.2  homogeneous polymer blend
Miscible polymer blend
Polymer blend that is a single-phase structure.

Note 1: For a polymer blend to be miscible, it must obey the thermodynamic criteria of miscibility.

Note 2: Miscibility is sometimes assigned erroneously on the basis that a blend exhibits a single \( T_g \) or is optically clear.

Note 3: The miscible system can be thermodynamically stable or metastable.

Note 4: For components of chain structures that would be expected to be miscible, miscibility may not occur if molecular architecture is changed, e.g., by crosslinking.

Modified from Definition 1.3 in [3]. The definition proposed here is preferred because it emphasizes the requirement for homogeneity over miscibility.

4.1.27.3  miscible polymer blend
See homogeneous polymer blend.

4.1.28  polymer-derived ceramic (PDC)
Ceramic derived from a polymeric ceramic precursor.

4.1.29  preceramic
See ceramic precursor.
4.1.30 **preceramic material**
See *ceramic precursor*.

4.1.31 **sol-gel material**
Material formed through a *sol-gel process*.

4.1.31.1 **sol-gel coating**
Coating formed through a *sol-gel process*.

4.1.31.2 **sol-gel metal oxide**
Metal oxide formed through a *sol-gel process*.

4.1.31.3 **sol-gel silica**
Silica formed through a *sol-gel process*.

4.1.32 **surface fractal dimension**
See *fractal dimension*.

4.2 **Terms describing the molecular structure and behavior of networks**

4.2.1 **affine chain behavior**
Behavior of a *polymer network* in which the junction points deform uniformly with the macroscopic deformation of the *network*.

*Note:* In reality, affine chain behavior can apply only at small deformations.

4.2.2 **branch point**
Point on a polymer chain at which a branch is attached. (Definition 1.54 in [1] and Gold Book online, 1996 entry.)

*Note:* The Gold Book entry has notes which define an *f*-functional *branch point* and a *junction point*, both of which are explicitly defined in the present document.

4.2.2.1 **f-functional branch point**
Branch point from which *f* linear chains emanate.

*Note 1:* Examples are three-, four-, and five-functional, branch points.

*Note 2:* Alternatively, the terms trifunctional, tetrafunctional, pentafunctional, etc. may be used.

See also *functionality*.

4.2.3 **chain entanglement**
Interlocking of polymer chains in a polymer material forming a transient or permanent network junction over the time scale of the measurement.
4.2.3.1 bowtie entanglement

butterfly entanglement

*Chain entanglement* with topology similar to that of a bowtie.

4.2.3.2 butterfly entanglement

See *bowtie entanglement*.

4.2.4 crosslink

Small region in a macromolecule from which at least four chains emanate and which is formed by reactions involving sites or groups on existing macromolecules or by interactions between existing macromolecules. (Definition 1.59 in [1] and Gold Book online, 1996 entry.)

*Note 1*: The small region may be an atom, a group of atoms, a *branch point* or a number of *branch points* connected by bonds, groups of atoms or oligomeric chains.

*Note 2*: In the majority of cases, a crosslink is a covalent structure but the term is also used to describe a region of weaker chemical interaction, portions of crystallites, or even physical interactions and entanglements.

See also *crosslinking*.

4.2.4.1 permanent crosslink

*Crosslink* formed by covalent bonds, intermolecular or intramolecular interactions that are stable under the conditions of use of the material formed.

4.2.4.2 transient crosslink

*Crosslink* formed by intermolecular or intramolecular interactions that are unstable under the conditions of use of the material formed.

4.2.5 crosslink density

Number of *crosslinks* per unit volume in a *polymer network*. See also *junction-point density*.

4.2.6 crosslinking site

Site on a macromolecule or region in a polymer material that takes part in the formation of chemical or physical *crosslinks*.

4.2.7 elastically active network chain

Segment of a chain between two successive *crosslinks* in a *polymer network* that is long enough to show entropic elasticity.

4.2.8 interjunction molar mass

See *network-chain molar mass*.

4.2.9 junction point

*Branch point* in a polymer network.
4.2.9.1 thermoreversible junction point

Junction point in a polymer network that can be destroyed and formed reversibly by a change of temperature.

4.2.9.2 transient junction point

Junction point in a polymer network that exists only for a finite period of time.
See also crosslink, Note 2.

4.2.10 junction-point density

Number of junction points per unit volume in a polymer network.
See also crosslink density.

4.2.11 loose end

Polymer chain within a network which is connected by a junction point at one end only.
Modified from [2].

4.2.12 network-chain molar mass, $M_c$

Interjunction molar mass
Number-average molar mass of polymer chains between two adjacent crosslinks or junction points in a polymer network.
Units, kg mol$^{-1}$.

4.2.13 network defect

Elastically ineffective chains in a polymer network.

Note: A network defect is caused by a loose end or a cyclic structure.

4.2.14 phantom chain behavior

Hypothetical behavior in which chains can move freely through one another when a network is deformed.

5. PROCESSES

5.1 aerosol hydrolysis

Hydrolysis of the dispersed component of an aerosol.

5.2 agglomeration (except in polymer science)

Coagulation, flocculation
Process of contact and adhesion whereby dispersed particles are held together by weak physical interactions ultimately leading to phase separation by the formation of precipitates of larger than colloidal size.

Note: Agglomeration is a reversible process.

Modified from [2]. The definition proposed here is recommended for distinguishing agglomeration from aggregation.
5.3 agglomeration (in polymer science)
aggregation (in polymer science)
Process in which dispersed molecules or particles assemble rather than remain as isolated single molecules or particles.
See Definition 1.41 in [3].

5.4 aggregation (except in polymer science)
Process whereby dispersed molecules or particles form aggregates.

5.5 aggregation (in polymer science)
See agglomeration (in polymer science).

5.6 calcination
Heating to high temperatures in air or oxygen.

Note 1: The term is most likely to be applied to a step in the preparation of a catalyst.

Note 2: In sol-gel processing, the term applies to the heating of a polymer network containing metal compounds to convert it into an oxide network.

Modified from [2]. The definition proposed here is more explicit about the elevated temperatures that are required.

5.7 carbo-reduction
Process in which a metal oxide is reduced in the presence of carbon or a carbon-containing compound.

5.8 ceramization
Process in which a ceramic precursor is converted into a ceramic.

5.9 coagulation
See agglomeration.

5.10 colloidal processing
Sol-gel processing in which a network of precipitated colloidal particles is treated by a conventional processing technique, such as cold pressing, hot pressing, or sintering, in order to produce a ceramic article.

5.11 critical concentration
See sol-gel critical concentration.

5.12 crosslinking
Reaction involving sites or groups on existing macromolecules or an interaction between existing macromolecules that results in the formation of a small region in a macromolecule from which at least four chains emanate [6].

Note 1: The small region may be an atom, a group of atoms, or a number of branch points connected by bonds, groups of atoms, or oligomeric chains.
Note 2: A reaction of a reactive chain end of a linear macromolecule with an internal reactive site of another linear macromolecule results in the formation of a branch point, but is not regarded as a crosslinking reaction.

See also crosslink.

5.13 curing
Chemical process of converting a prepolymer or a polymer into a polymer of higher molar mass and then into a network.

Note 1: Curing is achieved by the induction of chemical reactions which might or might not require mixing with a chemical curing agent.

Note 2: Physical aging, crystallization, physical crosslinking, and postpolymerization reactions are sometimes referred to as “curing”. Use of the term “curing” to describe such processes is deprecated.

See also vulcanization and Definition 1.4 in [6].

5.13.1 EB curing
See electron beam curing.

5.13.2 electron beam curing
EB curing
Curing induced by electron beam irradiation.

5.13.3 photochemical curing
photocuring
Curing induced by photoirradiation.

5.13.4 photocuring
See photochemical curing.

5.13.5 thermal curing
Curing induced by heating.

5.14 deflocculation
See peptization.

5.15 densification
Removal of impurities and the elimination of pores from a xerogel to give a material of as near bulk density as possible.

5.16 exfoliation
Process by which the layers of a multilayered structure separate.
5.17 flocculation
See agglomeration.

5.18 gel aging
Time-dependent changes in the chemical or the physical structure and the properties of a gel.

Note 1: The aging of a polymer gel can involve polymerization, crystallization, formation of glassy phases, formation of branch points, junction points as well as chain scission and chemical changes to constitutional units of the network chains.

Note 2: The aging of an inorganic gel can involve syneresis, coarsening, ripening, and phase transformation.

5.19 gelation
Process of passing through the gel point to form a gel or network.

5.20 hipping
hot isostatic pressing
Isostatic pressing process carried out at elevated temperatures.

Note 1: The pressurizing fluid used in this process is usually a gas.

Note 2: The temperature is usually in excess of 600 °C.

5.21 hot isostatic pressing
See hipping.

5.22 hydrolysis ratio, \( r_w \)
Mole ratio of water to alkoxy groups used in sol-gel processing of metal alkoxides.

5.23 in situ composite formation
Process for preparing a polymer composite by (a) forming the filler or reinforcement in an existing polymer or (b) polymerizing monomers in the presence of dispersed filler.

5.24 intercalation reaction
insertion reaction
Reaction, generally reversible, that involves the penetration of a host material by guest species without causing a major structural modification of the host. (Gold Book online, 1994 entry).

Note 1: Intercalation can refer to the insertion of a guest species into a one-, two-, or three-dimensional host structure.

Note 2: The guest species is not distributed randomly but occupies positions predetermined by structure of the host material.

Note 3: Examples of intercalation reactions are the insertion of lithium into layered TiS\(_2\) \([\text{Li}_x\text{TiS}_2 (0 \leq x \leq 1)]\) and of potassium into the layers of graphite (C\(_8\)K).
5.25 **isostatic pressing**
Application of a hydrostatic pressure through a liquid to achieve densification followed by the production of a uniform compact *monolith* through *ceramization* of the densified liquid.

5.26 **net shaping**
Production of an object in, or as close as possible to, its final shape prior to ceramization.

5.27 **Ostwald ripening**
Dissolution of small crystals or *sol* particles and the redeposition of the dissolved species on the surfaces of larger crystals or sol particles.

*Note:* The process occurs because smaller particles have a higher surface energy, hence higher total Gibbs energy, than larger particles, giving rise to an apparent higher solubility.

Modified from [2]. The definition proposed here is recommended for its inclusion of sol particles.

5.28 **peptization**
*Deflocculation*
Reversal of *coagulation* or *flocculation*, i.e., the dispersion of *aggregates* to form a colloidally stable suspension or emulsion [2].

5.29 **precipitation**
Sedimentation of a solid material (a precipitate) from a liquid solution in which the material is present in amounts greater than its solubility in the liquid. (Gold Book online, 1990 entry.)

*Note:* When precipitation occurs in *sol-gel processing*, *sol* particles have aggregated to a size where gravitational forces cause them to sink or float. Generally, *aggregation* arises from a change in the sol that reduces the interparticle repulsion.

5.30 **pyrolysis**
Thermolysis, usually associated with exposure to a high temperature.

*Note 1:* The term generally refers to reaction in an inert environment.

*Note 2:* Pyrolysis is the commonly used term for a high-temperature treatment that converts a *ceramic precursor* to a *ceramic*.

Modified from [2]. The definition proposed here is more explicit about the elevated temperatures involved.

5.31 **reaction injection molding** (RIM)
Reactive polymer processing that produces polymer *monoliths* by low-pressure injection and mixing of low-viscosity precursors into molds.

*Note:* Reaction injection molding commonly uses two-component precursors that produce *polymer networks* after mixing.

See also reaction blending, Definition 1.19 in [6].

5.31.1 reinforced reaction injection molding (RRIM)

*Reaction injection molding* within which glass fibers are included to increase the strength of the molding.

5.32 reactive polymer processing

Process whereby a polymeric *monolith* is produced through an in situ polymerization or polymer modification reaction.

*Note 1:* The polymerization or modification reaction and the transformation of the resulting polymer into a shaped product is accomplished in the same processing equipment.

*Note 2:* This type of processing is commonly accomplished by extrusion or injection molding.

*Note 3:* *Reaction injection molding* and *reinforced reaction injection molding* are types of reactive polymer processing.

5.33 sedimentation (in chemistry)

Separation of a dispersed system under the action of a gravitational or centrifugal field according to the different densities of the components.

5.34 shrinkage

Decrease in volume of a *network*, *gel*, or solid associated with the exudation of a fluid.

5.35 sintering

Temperature-induced coalescence and *densification* of porous solid particles below the melting points of their major components.

*Note 1:* The term was originally coined for the process by which fly ash produced in combustion of fuels such as coal is baked at a very high temperature. The sintered material is used in the manufacture of cinder blocks and other ceramic products.

Modified from [2]. The definition proposed here is recommended as being more explicit.

5.36 slip casting

Procedure in *ceramic* processing whereby *slip* is contained in a porous plaster mold prior to *pyrolysis*.

5.37 sol-gel critical concentration

Critical concentration

Concentration of an added electrolyte above which a *particulate sol* undergoes *coagulation* instead of *gelation*.

5.38 sol-gel process

Process through which a *network* is formed from solution by a progressive change of liquid precursor(s) into a *sol*, to a *gel*, and in most cases finally to a dry *network*.

*Note:* An *inorganic polymer*, e.g., silica gel, or an organic–inorganic hybrid can be prepared by sol-gel processing.
5.39 **sol-gel transition**
Transition of a sol to a gel at the gel point.
Corrected from [2], within which the definition improperly attempts a redefinition of the terms sol and gel. The definition proposed here is recommended for its precision through cross-reference to the properly defined terms.

5.40 **supercritical drying of a gel**
Drying of a gel using a supercritical fluid.

*Note:* Since liquid and vapor are indistinguishable in a supercritical fluid, there is no capillary pressure to cause shrinkage and cracking of the pores formed in the gel.

5.41 **swelling**
Increase in volume of a gel or solid associated with the uptake of a liquid or gas. (Gold Book online, entry 1972.)

5.42 **syneresis**
Spontaneous shrinking of a gel with exudation of liquid. (Gold Book online, 1972 entry.)

*Note:* Bond formation or attraction between particles or network chains within a gel induces the contraction and thereby the exudation of liquid from the network.

5.42.1 **microsyneresis**
Syneresis in which the exudation of the liquid is from microscopic regions within a network.

5.43 **thermolysis**
Uncatalyzed cleavage of one or more covalent bonds resulting from exposure of a compound to a raised temperature, or a process in which such cleavage is an essential part. (Gold Book online, 1994 entry.) See also pyrolysis.

5.44 **uniaxial pressing**
Application of pressure in one direction during ceramization to achieve a uniform densification and the production of a compact monolith.

5.45 **viscous flow sintering**
See viscous sintering.

5.46 **viscous sintering**
Viscous flow sintering
Sintering process by which it is possible to densify gels to glasses and ceramics at elevated temperatures.

5.47 **vulcanization**
Chemical crosslinking of high molar-mass linear or branched polymers to give a polymer network.

*Note 1:* The polymer network formed often displays rubberlike elasticity. However, a high concentration of crosslinks can lead to rigid materials.
Note 2: A classic example of vulcanization is the crosslinking of \textit{cis}-polyisoprene through sulfur bridges in the thermal treatment of natural rubber with sulfur or a sulfur-containing compound.

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