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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)

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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.

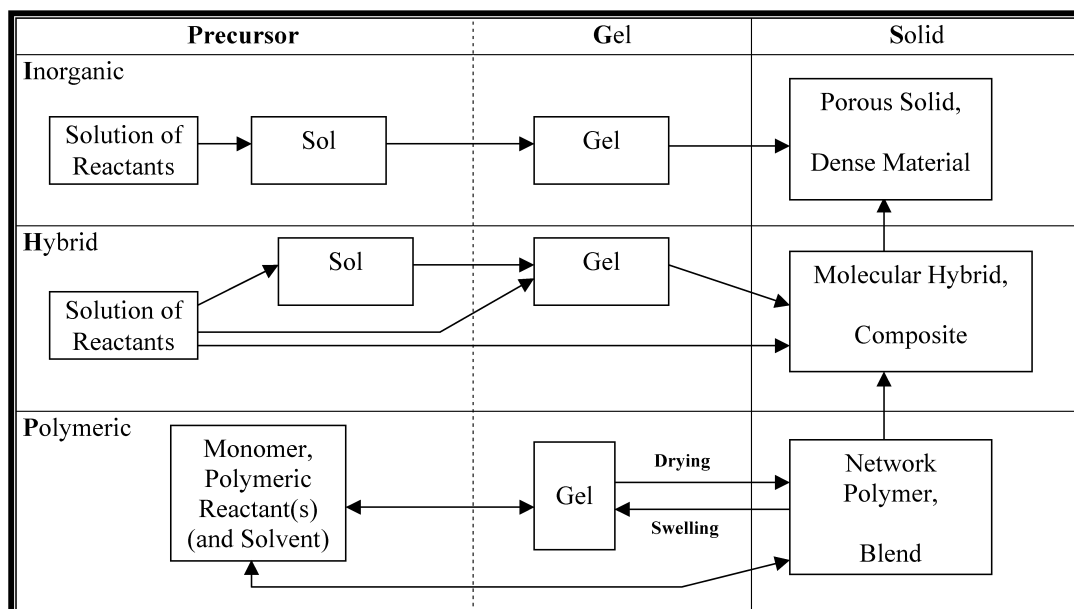


Fig. 1 Block diagram depicting the categories of materials and processes addressed by the terms within this document.

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 $(\text{RO})_3\text{Si}-\text{CH}=\text{CH}_2$ 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 μm .

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(phenylenesilanediy)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, polysilazanes, 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

network polymer

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, π - π 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

organommodified 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 $(\text{RO})_a\text{Si}(\text{B})_b(\text{C})_c(\text{D})_d$, 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 organommodified 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 [Li_xTiS_2 ($0 \leq x \leq 1$)] and of potassium into the layers of graphite (C_8K).

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 microsineresis

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 *cis*-polyisoprene through sulfide bridges in the thermal treatment of natural rubber with sulfur or a sulfur-containing compound.

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