

# Colloid

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A **colloid**, in chemistry, is a mixture in which one substance of microscopically dispersed insoluble particles is suspended throughout another substance. Sometimes the dispersed substance alone is called the colloid;<sup>[1]</sup> the term **colloidal suspension** refers unambiguously to the overall mixture (although a narrower sense of the word *suspension* is distinguished from colloids by larger particle size). Unlike a solution, whose solute and solvent constitute only one phase, a colloid has a dispersed phase (the suspended particles) and a continuous phase (the medium of suspension). To qualify as a colloid, the mixture must be one that does not settle or would take a very long time to settle appreciably.

The dispersed-phase particles have a diameter between approximately 1 and 1000 nanometers.<sup>[2]</sup> Such particles are normally easily visible in an optical microscope, although at the smaller size range ( $r < 250$  nm), an ultramicroscope or an electron microscope may be required. Homogeneous mixtures with a dispersed phase in this size range may be called *colloidal aerosols*, *colloidal emulsions*, *colloidal foams*, *colloidal dispersions*, or *hydrosols*. The dispersed-phase particles or droplets are affected largely by the surface chemistry present in the colloid.

Some colloids are translucent because of the Tyndall effect, which is the scattering of light by particles in the colloid. Other colloids may be opaque or have a slight color.

Colloidal suspensions are the subject of interface and colloid science. This field of study was introduced in 1861 by Scottish scientist Thomas Graham.



Milk is an emulsified colloid of liquid butterfat globules dispersed within a water-based solution.

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## IUPAC definition

**Colloid:** Short synonym for *colloidal system*.<sup>[3][4]</sup>

**Colloidal:** State of subdivision such that the molecules or polymolecular particles dispersed in a medium have at least one dimension between approximately 1 nm and 1  $\mu\text{m}$ , or that in a system discontinuities are found at distances of that order.<sup>[3][4][5]</sup>

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## Classification

Because the size of the dispersed phase may be difficult to measure, and because colloids have the appearance of solutions, colloids are sometimes identified and characterized by their physico-chemical and transport properties. For example, if a colloid consists of a solid phase dispersed in a liquid, the solid particles will not diffuse through a membrane, whereas with a true solution the dissolved ions or molecules will diffuse through a membrane. Because of the size exclusion, the colloidal particles are unable to pass through the pores of an ultrafiltration membrane with a size smaller than their own dimension. The smaller the size of the pore of the ultrafiltration membrane, the lower the concentration of the dispersed colloidal particles remaining in the ultrafiltered liquid. The measured value of the concentration of a truly dissolved species will thus depend on the experimental conditions applied to separate it from the colloidal particles also dispersed in the liquid. This is particularly important for solubility studies of readily hydrolyzed species such as Al, Eu, Am, Cm, or organic matter complexing these species. Colloids can be classified as follows:

Medium/phase		Dispersed phase		
		Gas	Liquid	Solid
Dispersion medium	Gas	No such colliods are known Helium and Xenon are known to be immiscible under certain conditions. <sup>[6][7]</sup>	<b>Liquid aerosol</b> Examples: fog, clouds, mist, hair sprays	<b>Solid aerosol</b> Examples: smoke, ice cloud, atmospheric particulate matter
	Liquid	<b>Foam</b> Example: whipped cream, shaving cream	<b>Emulsion</b> Examples: milk, mayonnaise, hand cream; latex	<b>Sol</b> Examples: pigmented ink, blood
	Solid	<b>Solid foam</b> Examples: aerogel, styrofoam, pumice	<b>Gel</b> Examples: agar, gelatin, jelly	<b>Solid sol</b> Example: cranberry glass

Based on the nature of interaction between the dispersed phase and the dispersion medium, colloids can be classified as: **Hydrophilic colloids**: These are water-loving colloids. The colloid particles are attracted toward water. They are also called reversible sols. **Hydrophobic colloids**: These are opposite in nature to hydrophilic colloids. The colloid particles are repelled by water. They are also called irreversible sols.

In some cases, a colloid suspension can be considered a homogeneous mixture. This is because the distinction between "dissolved" and "particulate" matter can be sometimes a matter of approach, which affects whether or not it is homogeneous or heterogeneous.

## Hydrocolloids

A *hydrocolloid* is defined as a colloid system wherein the colloid particles are hydrophilic polymers dispersed in water. A hydrocolloid has colloid particles spread throughout water, and depending on the quantity of water available that can take place in different states, e.g., gel or sol (liquid). Hydrocolloids can be either irreversible (single-state) or reversible. For example, agar, a reversible hydrocolloid of seaweed extract, can exist in a gel and solid state, and alternate between states with the addition or elimination of heat.

Many hydrocolloids are derived from natural sources. For example, agar-agar and carrageenan are extracted from seaweed, gelatin is produced by hydrolysis of proteins of mammalian and fish origins, and pectin is extracted from citrus peel and apple pomace.

Gelatin desserts like jelly or Jell-O are made from gelatin powder, another effective hydrocolloid. Hydrocolloids are employed in food mainly to influence texture or viscosity (e.g., a sauce). Hydrocolloid-based medical dressings are used for skin and wound treatment.

Other main hydrocolloids are xanthan gum, gum arabic, guar gum, locust bean gum, cellulose derivatives as carboxymethyl cellulose, alginate and starch.

## Interaction between particles

The following forces play an important role in the interaction of colloid particles:<sup>[8][9][10]</sup>

- Excluded volume repulsion: This refers to the impossibility of any overlap between hard particles.
- Electrostatic interaction: Colloidal particles often carry an electrical charge and therefore attract or repel each other. The charge of both the continuous and the dispersed phase, as well as the mobility of the phases are factors affecting this interaction.
- van der Waals forces: This is due to interaction between two dipoles that are either permanent or induced. Even if the particles do not have a permanent dipole, fluctuations of the electron density gives rise to a temporary dipole in a particle. This temporary dipole induces a dipole in particles nearby. The temporary dipole and the induced dipoles are then attracted to each other. This is known as van der Waals force, and is always present (unless the refractive indexes of the dispersed and continuous phases are matched), is short-range, and is attractive.
- Entropic forces: According to the second law of thermodynamics, a system progresses to a state in which entropy is maximized. This can result in effective forces even between hard spheres.
- Steric forces between polymer-covered surfaces or in solutions containing non-adsorbing polymer can modulate interparticle forces, producing an additional steric repulsive force (which is predominantly entropic in origin) or an attractive depletion force between them. Such an effect is specifically searched for with tailor-made superplasticizers developed to increase the workability of concrete and to reduce its water content.

## Preparation

There are two principal ways of preparation of colloids:<sup>[11]</sup>

- Dispersion of large particles or droplets to the colloidal dimensions by milling, spraying, or application of shear (e.g., shaking, mixing, or high shear mixing).
- Condensation of small dissolved molecules into larger colloidal particles by precipitation, condensation, or redox reactions. Such processes are used in the preparation of colloidal silica or gold.

## Stabilization (peptization)

The stability of a colloidal system is defined by particles remaining suspended in solution at equilibrium.

Stability is hindered by aggregation and sedimentation phenomena, which are driven by the colloid's tendency to reduce surface energy. Reducing the interfacial tension will stabilize the colloidal system by reducing this driving force.

Aggregation is due to the sum of the interaction forces between particles.<sup>[12][13]</sup> If attractive forces (such as van der Waals forces) prevail over the repulsive ones (such as the electrostatic ones) particles aggregate in clusters.

Electrostatic stabilization and steric stabilization are the two main mechanisms for stabilization against aggregation.

- Electrostatic stabilization is based on the mutual repulsion of like electrical charges. In general, different phases have different charge affinities, so that an electrical double layer forms at any interface. Small particle sizes lead to enormous surface areas, and this effect is greatly amplified in colloids. In a stable colloid, mass of a dispersed phase is so low that its buoyancy or kinetic energy is too weak to overcome the electrostatic repulsion between charged layers of the dispersing phase.
- Steric stabilization consists in covering the particles in polymers which prevents the particle to get close in the range of attractive forces.

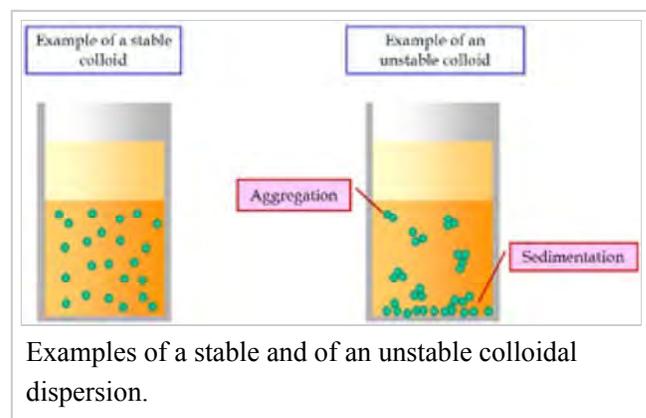
A combination of the two mechanisms is also possible (electrosteric stabilization). All the above-mentioned mechanisms for minimizing particle aggregation rely on the enhancement of the repulsive interaction forces.

Electrostatic and steric stabilization do not directly address the sedimentation/floating problem.

Particle sedimentation (and also floating, although this phenomenon is less common) arises from a difference in the density of the dispersed and of the continuous phase. The higher the difference in densities, the faster the particle settling.

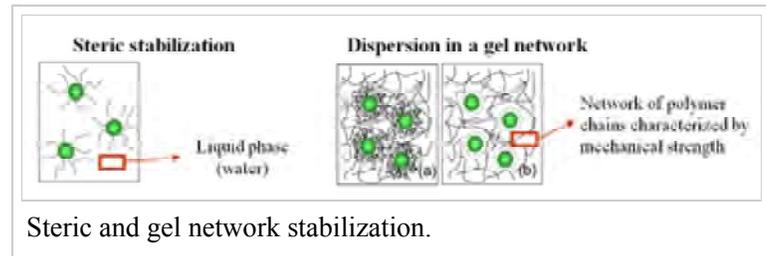
- The gel network stabilization represents the principal way to produce colloids stable to both aggregation and sedimentation.<sup>[14][15]</sup>

The method consists in adding to the colloidal suspension a polymer able to form a gel network and



characterized by shear thinning properties. Examples of such substances are xanthan and guar gum.

Particle settling is hindered by the stiffness of the polymeric matrix where particles are trapped.<sup>[14]</sup> In addition, the long polymeric chains can provide a steric or electrosteric stabilization to dispersed particles.



The rheological shear thinning properties find beneficial in the preparation of the suspensions and in their use, as the reduced viscosity at high shear rates facilitates deagglomeration, mixing and in general the flow of the suspensions.

## Destabilization

Unstable colloidal dispersions can form flocs as the particles aggregate due to interparticle attractions. In this way photonic glasses can be grown. This can be accomplished by a number of different methods:

- Removal of the electrostatic barrier that prevents aggregation of the particles. This can be accomplished by the addition of salt to a suspension or changing the pH of a suspension to effectively neutralize or "screen" the surface charge of the particles in suspension. This removes the repulsive forces that keep colloidal particles separate and allows for coagulation due to van der Waals forces.
- Addition of a charged polymer flocculant. Polymer flocculants can bridge individual colloidal particles by attractive electrostatic interactions. For example, negatively charged colloidal silica or clay particles can be flocculated by the addition of a positively charged polymer.
- Addition of non-adsorbed polymers called depletants that cause aggregation due to entropic effects.
- Physical deformation of the particle (e.g., stretching) may increase the van der Waals forces more than stabilization forces (such as electrostatic), resulting coagulation of colloids at certain orientations.

Unstable colloidal suspensions of low-volume fraction form clustered liquid suspensions, wherein individual clusters of particles fall to the bottom of the suspension (or float to the top if the particles are less dense than the suspending medium) once the clusters are of sufficient size for the Brownian forces that work to keep the particles in suspension to be overcome by gravitational forces. However, colloidal suspensions of higher-volume fraction form colloidal gels with viscoelastic properties. Viscoelastic colloidal gels, such as bentonite and toothpaste, flow like liquids under shear, but maintain their shape when shear is removed. It is for this reason that toothpaste can be squeezed from a toothpaste tube, but stays on the toothbrush after it is applied.

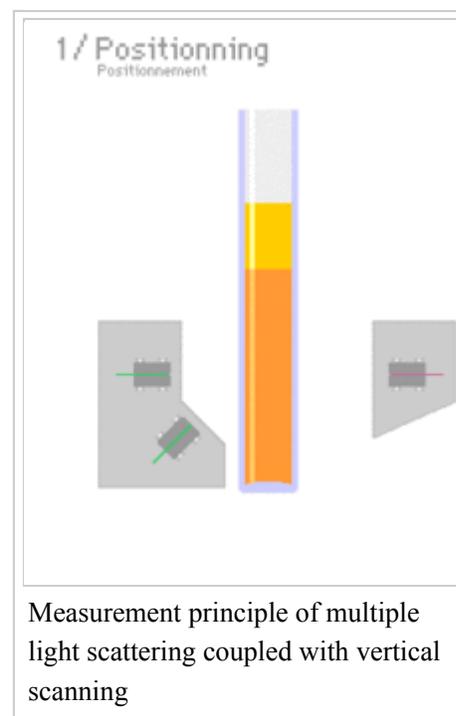
## Monitoring stability

Multiple light scattering coupled with vertical scanning is the most widely used technique to monitor the dispersion state of a product, hence identifying and quantifying destabilisation phenomena.<sup>[16][17][18][19]</sup> It works on concentrated dispersions without dilution. When light is sent through the sample, it is

backscattered by the particles / droplets. The backscattering intensity is directly proportional to the size and volume fraction of the dispersed phase. Therefore, local changes in concentration (e.g. Creaming and Sedimentation) and global changes in size (e.g. flocculation, coalescence) are detected and monitored.

### Accelerating methods for shelf life prediction

The kinetic process of destabilisation can be rather long (up to several months or even years for some products) and it is often required for the formulator to use further accelerating methods in order to reach reasonable development time for new product design. Thermal methods are the most commonly used and consists in increasing temperature to accelerate destabilisation (below critical temperatures of phase inversion or chemical degradation). Temperature affects not only the viscosity, but also interfacial tension in the case of non-ionic surfactants or more generally interactions forces inside the system. Storing a dispersion at high temperatures enables to simulate real life conditions for a product (e.g. tube of sunscreen cream in a car in the summer), but also to accelerate destabilisation processes up to 200 times. Mechanical acceleration including vibration, centrifugation and agitation are sometimes used. They subject the product to different forces that pushes the particles / droplets against one another, hence helping in the film drainage. However, some emulsions would never coalesce in normal gravity, while they do under artificial gravity.<sup>[20]</sup> Moreover, segregation of different populations of particles have been highlighted when using centrifugation and vibration.<sup>[21]</sup>



### As a model system for atoms

In physics, colloids are an interesting model system for atoms.<sup>[22]</sup> Micrometre-scale colloidal particles are large enough to be observed by optical techniques such as confocal microscopy. Many of the forces that govern the structure and behavior of matter, such as excluded volume interactions or electrostatic forces, govern the structure and behavior of colloidal suspensions. For example, the same techniques used to model ideal gases can be applied to model the behavior of a hard sphere colloidal suspension. In addition, phase transitions in colloidal suspensions can be studied in real time using optical techniques,<sup>[23]</sup> and are analogous to phase transitions in liquids. In many interesting cases optical fluidity is used to control colloid suspensions.<sup>[23][24]</sup>

### Crystals

A colloidal crystal is a highly ordered array of particles that can be formed over a very long range (typically on the order of a few millimeters to one centimeter) and that appear analogous to their atomic or molecular counterparts.<sup>[25]</sup> One of the finest natural examples of this ordering phenomenon can be found in precious opal, in which brilliant regions of pure spectral color result from close-packed

domains of amorphous colloidal spheres of silicon dioxide (or silica, SiO<sub>2</sub>).<sup>[26][27]</sup> These spherical particles precipitate in highly siliceous pools in Australia and elsewhere, and form these highly ordered arrays after years of sedimentation and compression under hydrostatic and gravitational forces. The periodic arrays of submicrometre spherical particles provide similar arrays of interstitial voids, which act as a natural diffraction grating for visible light waves, particularly when the interstitial spacing is of the same order of magnitude as the incident lightwave.<sup>[28][29]</sup>

Thus, it has been known for many years that, due to repulsive Coulombic interactions, electrically charged macromolecules in an aqueous environment can exhibit long-range crystal-like correlations with interparticle separation distances, often being considerably greater than the individual particle diameter. In all of these cases in nature, the same brilliant iridescence (or play of colors) can be attributed to the diffraction and constructive interference of visible lightwaves that satisfy Bragg's law, in a matter analogous to the scattering of X-rays in crystalline solids.

The large number of experiments exploring the physics and chemistry of these so-called "colloidal crystals" has emerged as a result of the relatively simple methods that have evolved in the last 20 years for preparing synthetic monodisperse colloids (both polymer and mineral) and, through various mechanisms, implementing and preserving their long-range order formation.

## In biology

In the early 20th century, before enzymology was well understood, colloids were thought to be the key to the operation of enzymes; i.e., the addition of small quantities of an enzyme to a quantity of water would, in some fashion yet to be specified, subtly alter the properties of the water so that it would break down the enzyme's specific substrate, such as a solution of ATPase breaking down ATP. Furthermore, life itself was explainable in terms of the aggregate properties of all the colloidal substances that make up an organism. As more detailed knowledge of biology and biochemistry developed, the colloidal theory was replaced by the macromolecular theory, which explains enzymes as a collection of identical huge molecules that act as very tiny machines, freely moving about between the water molecules of the solution and individually operating on the substrate, no more mysterious than a factory full of machinery. The properties of the water in the solution are not altered, other than the simple osmotic changes that would be caused by the presence of any solute. In humans, both the thyroid gland and the intermediate lobe (*pars intermedia*) of the pituitary gland contain colloid follicles.

## In the environment

Colloidal particles can also serve as transport vector<sup>[30]</sup> of diverse contaminants in the surface water (sea water, lakes, rivers, fresh water bodies) and in underground water circulating in fissured rocks<sup>[31]</sup> (e.g. limestone, sandstone, granite). Radionuclides and heavy metals easily sorb onto colloids suspended in water. Various types of colloids are recognised: inorganic colloids (e.g. clay particles, silicates, iron oxy-hydroxides), organic colloids (humic and fulvic substances). When heavy metals or radionuclides form their own pure colloids, the term "*Eigencolloid*" is used to designate pure phases, i.e. pure Tc(OH)<sub>4</sub>, U(OH)<sub>4</sub>, or Am(OH)<sub>3</sub>. Colloids have been suspected for the long-range transport of plutonium on the Nevada Nuclear Test Site. They have been the subject of detailed studies for many years. However, the

mobility of inorganic colloids is very low in compacted bentonites and in deep clay formations<sup>[32]</sup> because of the process of ultrafiltration occurring in dense clay membrane.<sup>[33]</sup> The question is less clear for small organic colloids often mixed in porewater with truly dissolved organic molecules.<sup>[34]</sup>

## Intravenous therapy

Colloid solutions used in intravenous therapy belong to a major group of volume expanders, and can be used for intravenous fluid replacement. Colloids preserve a high colloid osmotic pressure in the blood,<sup>[35]</sup> and therefore, they should theoretically preferentially increase the intravascular volume, whereas other types of volume expanders called crystalloids also increase the interstitial volume and intracellular volume. However, there is still controversy to the actual difference in efficacy by this difference,<sup>[35]</sup> and much of the research related to this use of colloids is based on fraudulent research by Joachim Boldt.<sup>[36]</sup> Another difference is that crystalloids generally are much cheaper than colloids.<sup>[35]</sup>

## References

- "Colloid". *Britannica Online Encyclopedia*. Retrieved 31 August 2009.
- Levine, Ira N. (2001). *Physical Chemistry* (5th ed.). Boston: McGraw-Hill. p. 955. ISBN 0-07-231808-2.
- Richard G. Jones; Edward S. Wilks; W. Val Metanomski; Jaroslav Kahovec; Michael Hess; Robert Stepto; Tatsuki Kitayama, eds. (2009). *Compendium of Polymer Terminology and Nomenclature (IUPAC Recommendations 2008)* (2nd ed.). RSC Publ. p. 464. ISBN 978-0-85404-491-7.
- Stepto, Robert F. T. (2009). "Dispersity in polymer science (IUPAC Recommendations 2009)" (PDF). *Pure and Applied Chemistry*. **81** (2): 351–353. doi:10.1351/PAC-REC-08-05-02.
- Slomkowski, Stanislaw; Alemán, José V.; Gilbert, Robert G.; Hess, Michael; Horie, Kazuyuki; Jones, Richard G.; Kubisa, Przemyslaw; Meisel, Ingrid; Mormann, Werner; Penczek, Stanislaw; Stepto, Robert F. T. (2011). "Terminology of polymers and polymerization processes in dispersed systems (IUPAC Recommendations 2011)" (PDF). *Pure and Applied Chemistry*. **83** (12). doi:10.1351/PAC-REC-10-06-03.
- de Swaan Arons, J.; Diepen, G. A. M. (2010). "Immiscibility of gases. The system He-Xe: (Short communication)". *Recueil des Travaux Chimiques des Pays-Bas*. **82** (8): 806–806. doi:10.1002/recl.19630820810. ISSN 0165-0513.
- de Swaan Arons, J.; Diepen, G. A. M. (1966). "Gas—Gas Equilibria". *J. Chem. Phys.* **44**: 2322. doi:10.1063/1.1727043.
- Belloni, Luc (2000). "Colloidal interactions". *J Phys: Cond Mat*. **12**: R549. doi:10.1088/0953-8984/12/46/201.
- Lekkerkerker, Henk N.W.; Tuinier, Remco (2011). *Colloids and the Depletion Interaction*. Heidelberg: Springer. doi:10.1007/978-94-007-1223-2. ISBN 9789400712225.
- van Anders, Greg; Klotsa, Daphne; Ahmed, N. Khalid; Engel, Michael; Glotzer, Sharon C. (2014). "Understanding shape entropy through local dense packing". *Proc Natl Acad Sci USA*. **111**: E4812–E4821. arXiv:1309.1187. doi:10.1073/pnas.1418159111.
- Kopeliovich, Dmitri. Preparation of colloids ([http://www.substech.com/dokuwiki/doku.php?id=preparation\\_of\\_colloids](http://www.substech.com/dokuwiki/doku.php?id=preparation_of_colloids)). substech.com
- Israelachvili, Jacob N. (1991). *Intermolecular and Surface Forces*. Academic Press. ISBN 978-0-12-391927-4.
- Menachem Elimelech; John Gregory; Xiadong Jia; Richard Williams (1998). *Particle deposition and aggregation: measurement, modelling and simulation*. Butterworth-Heinemann. ISBN 0-7506-7024-X.
- Comba, Silvia; Sethi (August 2009). "Stabilization of highly concentrated suspensions of iron nanoparticles using shear-thinning gels of xanthan gum". *Water Research*. **43** (15): 3717–3726. doi:10.1016/j.watres.2009.05.046. PMID 19577785.

15. Cantrell, K.J.; Kaplan, D.I.; Gilmore, T.J. (1997). "Injection of colloidal Fe-0 particles in sand with shear-thinning fluids". *Journal of Environmental Engineering-Asce*. **123** (8): 786–791. doi:10.1061/(ASCE)0733-9372(1997)123:8(786).
16. Roland, I; Piel, G; Delattre, L; Evrard, B (2003). "Systematic characterization of oil-in-water emulsions for formulation design". *International Journal of Pharmaceutics*. **263** (1–2): 85–94. doi:10.1016/S0378-5173(03)00364-8. PMID 12954183.
17. Lemarchand, Caroline; Couvreur, Patrick; Besnard, Madeleine; Costantini, Dominique; Gref, Ruxandra (2003). "Novel polyester-polysaccharide nanoparticles". *Pharmaceutical Research*. **20** (8): 1284–92. doi:10.1023/A:1025017502379. PMID 12948027.
18. Mengual, O (1999). "Characterisation of instability of concentrated dispersions by a new optical analyser: the TURBISCAN MA 1000". *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. **152**: 111–123. doi:10.1016/S0927-7757(98)00680-3.
19. Bru, P.; et al. (2004). T. Provder; J. Texter, eds. *Particle sizing and characterisation*.
20. Salager, J-L (2000). Françoise Nielloud; Gilberte Marti-Mestres, eds. *Pharmaceutical emulsions and suspensions*. CRC press. p. 89. ISBN 0-8247-0304-9.
21. Snabre, Patrick; Pouligny, Bernard (2008). "Size Segregation in a Fluid-like or Gel-like Suspension Settling under Gravity or in a Centrifuge". *Langmuir*. **24** (23): 13338–47. doi:10.1021/la802459u. PMID 18986182.
22. Manoharan, Vinothan N. (2015). "Colloidal matter: Packing, geometry, and entropy". *Science*. **349**: 1253751. doi:10.1126/science.1253751.
23. Greenfield, Elad; Nemirovsky, Jonathan; El-Ganainy, Ramy; Christodoulides, Demetri N; Segev, Mordechai (2013). "Shockwave based nonlinear optical manipulation in densely scattering opaque suspensions". *Optics Express*. **21** (20): 23785–23802. Bibcode:2013OExpr..2123785G. doi:10.1364/OE.21.023785. PMID 24104290.
24. Greenfield, Elad; Rotschild, Carmel; Szameit, Alexander; Nemirovsky, Jonathan; El-Ganainy, Ramy; Christodoulides, Demetrios N; Saraf, Meirav; Lifshitz, Efrat; Segev, Mordechai (2011). "Light-induced self-synchronizing flow patterns" (PDF). *New Journal of Physics*. **13** (5): 053021. Bibcode:2011NJPh...13e3021G. doi:10.1088/1367-2630/13/5/053021.
25. Pieranski, P. (1983). "Colloidal Crystals". *Contemporary Physics*. **24**: 25–73. Bibcode:1983ConPh..24...25P. doi:10.1080/00107518308227471.
26. Sanders, J.V.; Sanders, J. V.; Segnit, E. R. (1964). "Structure of Opal". *Nature*. **204** (4962): 1151. Bibcode:1964Natur.204..990J. doi:10.1038/204990a0.
27. Darragh, P.J.; et al. (1976). "Opals". *Scientific American*. **234** (4): 84–95. doi:10.1038/scientificamerican0476-84.
28. Luck, Werner; Klier, Manfred; Wesslau, Hermann (1963). "Über Bragg-Reflexe mit sichtbarem Licht an monodispersen Kunststofflatices. II". *Berichte der Bunsengesellschaft für physikalische Chemie*. **67** (1): 84–85. doi:10.1002/bbpc.19630670114.
29. Hiltner, P.A.; Krieger, I.M. (1969). "Diffraction of light by ordered suspensions". *J. Phys. Chem*. **73** (7): 2306. doi:10.1021/j100727a049.
30. Frimmel, Fritz H.; Frank von der Kammer; Hans-Curt Flemming (2007). *Colloidal transport in porous media* (1 ed.). Springer. p. 292. ISBN 3-540-71338-7.
31. Alonso, U.; T. Missana; A. Patelli; V. Rigato (2007). "Bentonite colloid diffusion through the host rock of a deep geological repository". *Physics and Chemistry of the Earth, Parts A/B/C*. **32** (1–7): 469–476. Bibcode:2007PCE....32..469A. doi:10.1016/j.pce.2006.04.021. ISSN 1474-7065.
32. Voegelin, A.; Kretzschmar, R. (December 2002). *Stability and mobility of colloids in Opalinus Clay*. (PDF). Nagra Technical Report 02-14. Institute of Terrestrial Ecology, ETH Zürich. p. 47. ISSN 1015-2636.
33. "Diffusion of colloids in compacted bentonite". Retrieved 12 February 2009.
34. Wold, Susanna; Trygve Eriksen (2007). "Diffusion of humic colloids in compacted bentonite". *Physics and Chemistry of the Earth, Parts A/B/C*. **32** (1–7): 477–484. Bibcode:2007PCE....32..477W. doi:10.1016/j.pce.2006.05.002. ISSN 1474-7065.
35. Martin, Gregory S. (19 April 2005). "An Update on Intravenous Fluids". *Medscape*. Medscape Infectious Diseases. Retrieved 6 July 2016.
36. Blake, Heidi (3 March 2011). "Millions of surgery patients at risk in drug research fraud scandal". *The Telegraph*. Archived from the original on 4 November 2011. Retrieved 4 November 2011.

## Further reading

- Lyklema, J. *Fundamentals of Interface and Colloid Science*, Vol. 2, p. 3208, 1995
- Hunter, R.J. *Foundations of Colloid Science*, Oxford University Press, 1989
- Dukhin, S.S. & Derjaguin, B.V. *Electrokinetic Phenomena*, J. Wiley and Sons, 1974
- Russel, W.B., Saville, D.A. and Schowalter, W.R. *Colloidal Dispersions*, Cambridge, 1989 Cambridge University Press
- Kruyt, H.R. *Colloid Science*, Volume 1, Irreversible systems, Elsevier, 1959
- Dukhin, A.S. and Goetz, P.J. *Ultrasound for characterizing colloids*, Elsevier, 2002
- Rodil, Ma. Lourdes C., *Chemistry The Central Science*, 7th Ed. ISBN 0-13-533480-2
- Pieranski, P., *Colloidal Crystals*, *Contemp. Phys.*, Vol. 24, p. 25 (1983)
- Sanders, J.V., *Structure of Opal*, *Nature*, Vol. 204, p. 1151, (1964);
- Darragh, P.J., et al., *Scientific American*, Vol. 234, p. 84, (1976)
- Luck, W. et al., *Ber. Bunsenges Phys. Chem.*, Vol. 67, p. 84 (1963);
- Hiltner, P.A. and Krieger, I.M., *Diffraction of Light by Ordered Suspensions*, *J. Phys. Chem.*, Vol. 73, p. 2306 (1969)
- Arora, A.K., Tata, B.V.R., Eds. *Ordering & Phase Transitions in Charged Colloids* Wiley, New York (1996)
- Sood, A.K. in *Solid State Physics*, Eds. Ehrenreich, H., Turnbull, D., Vol. 45, p. 1 (1991)
- Murray, C.A. and Grier, D.G., *Colloidal Crystals*, *Amer. Scientist*, Vol. 83, p. 238 (1995);
- Video Microscopy of Monodisperse Colloidal Systems*, *Annu. Rev. Phys. Chem.*, Vol. 47, p. 421 (1996)
- Tanaka, 1992, *Phase Transition of Gel*

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