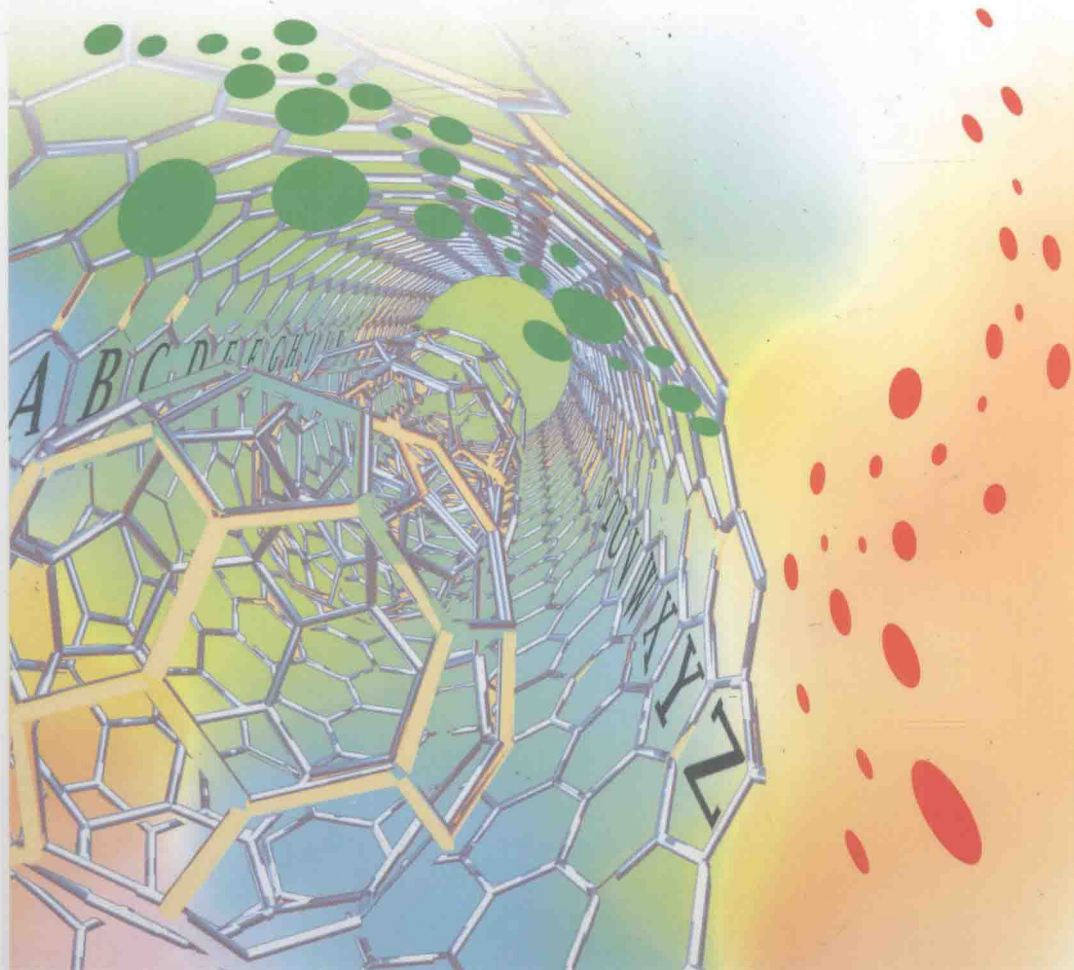


Laurier L. Schramm

 WILEY-VCH

Dictionary of Nanotechnology, Colloid and Interface Science



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About the Author

Dr. Laurier L. Schramm is President and CEO of the Saskatchewan Research Council (SRC), a leading Canadian provider of applied research, development, design, and technology demonstration. He previously served as Vice President, Energy of the Alberta Research Council, President and CEO of the Petroleum Recovery Institute, and as a senior scientist in industrial process research at Syncrude Canada Ltd. He has served on the Boards of Directors, or their equivalent, of numerous organizations engaged in research, development, and demonstration, and was most recently a member of the National Panel of Experts on Sustainable Energy Science & Technology (Canada).

Dr. Schramm has been a strong proponent and practitioner of university-industry collaboration and is an adjunct professor of chemical and petroleum engineering at the University of Calgary. He has over 30 years of R&D experience in colloid, interface, and petroleum science, and has received major national awards for his research. He holds 17 patents, over 300 other scientific publications and proprietary reports, and has given over 100 national and international scientific presentations. Many of his inventions have been adopted into commercial practice; and his work on the development of oil-tolerant foams for enhanced oil recovery was judged to be a Milestone of Canadian Chemistry in the 20th Century by the Canadian Society for Chemistry. In 2002 he was awarded Canada's Queen Elizabeth II Golden Jubilee Medal for his creative contributions to Canadian petroleum technology. This is his ninth book.

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Because there are so many different, specialized references to aspects of nanotechnology and colloid and interface systems, especially in industrial practice, some important terms will inevitably have been missed. I will greatly appreciate it if readers would take the trouble to inform me of any significant errors or omissions.

Saskatoon, SK, Canada
July 2008

Laurier L. Schramm

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Introduction and Historical Evolution

In the early 1800s Thomas Graham studied the diffusion, osmotic pressure, and dialysis properties of a number of substances, including a variety of solutes dissolved in water (see References [1–3]). He noticed that some substances diffused quite quickly through parchment paper and animal membranes and formed crystals when dried. Other substances diffused only very slowly, if at all, through the parchment or membranes and apparently did not form crystals when dried. Graham proposed that the former group of substances, which included simple salts, be termed “crystalloids”, and that the latter group, which included albumen and gums, be termed “colloids”. Although colloidal dispersions had certainly been studied long before this time, and the alchemists frequently worked with body fluids, which are colloidal dispersions, Graham is generally regarded as having founded the discipline of colloid science.

The test of crystal formation later turned out to be too restrictive, the distinction of crystalloids versus colloids was dropped, and the noun colloid was eventually replaced by the adjective colloidal, indicating a particular state of dispersed matter: matter for which at least one dimension falls within a specific range of distance values. The second property that distinguishes all colloidal dispersions is the extremely large area of the interface between the two phases compared with the mass of the dispersed phase. Table 1 in Appendix 1 illustrates the wide range of dispersions concerned. It follows that any chemical and physical phenomena that depend on the existence of an interface become very prominent in colloidal dispersions. Interface science thus underlies colloid science.¹⁾ In 1917 Wolfgang Ostwald, another founder of colloid science, wrote:

1) Here again we encounter evidence of a living language. Following Graham's identification of a new division of chemistry, colloid chemistry, the realization of the profound importance of the interface between the phases led subsequent chemists to refer to

the discipline as colloid and capillary chemistry (meaning colloid and interface chemistry). In view of the wide interdisciplinary nature, I prefer the term colloid and interface science.

“It is simply a fact that colloids constitute the most universal and the commonest of all the things we know. We need only to look at the sky, at the earth, or at ourselves to discover colloids or substances closely allied to them. We begin the day with a colloid practice – that of washing – and we may end it with one in a drink of colloid coffee or tea” [4].

Now, more than 200 years later, a vast lexicon is associated with the study of colloid and interface science because, in addition to the growth of the fundamental science itself, we recognize a great diversity of occurrences and properties of colloids and interfaces in industry and indeed in everyday life. Many other scientific disciplines become involved in the study and treatment of colloidal systems, each discipline bringing elements of its own special language. The most recent addition is the overlapping field of nanotechnology.

In 1959, physicist Richard Feynman gave the first known lecture on nanotechnology at the annual meeting of the American Physical Society [5], in which he proposed the idea that atomic manipulation could be used to build structures. The term nanotechnology itself appears to have been coined in Japan, in 1974, by Norio Taniguchi to describe processes at the nanometre scale. Significant interest, and work in, the area of nanotechnology grew particularly rapidly following the publication of the book *Engines of Creation* by Eric Drexler in 1986 [6]. An illustration of the new way of thinking that is represented by nanotechnology is given in this quote from B.C. Crandall:

“We are distinct from all previous generations in that we have *seen* our atoms – with scanning tunneling and atomic force microscopes. But more than simply admiring their regular beauty, we have begun to build minute structures. Each atom is a single brick; their electrons are the mortar. Atoms, the ultimate in material modularity, provide the stuff of this new technology” [7].

Now, just over 20 years later, the nanotechnology field has grown exponentially, leading to a plethora of new terms in the areas of nanoscience and nanotechnology. The “nano” regime, which spans the distance range from 1 to 100 nm, explicitly overlaps heavily with the size-range of colloid science and technology, which spans the range from 1 to 1,000 nm. As well, some authors distinguish between nanotechnology and microtechnology, the latter referring to species and phenomena in the micrometre scale. There has been an explosion of terms with the “nano” prefix and the number of possible “nano” terms is virtually unlimited, especially when material types are included (Table 2 in Appendix 1 provides an illustrative listing and Table 3 shows the prefix nano in relation to other decimal prefixes in science and technology). For example, there are a wide range of types of nanorods, nanotubes, nanowires, nanobelts, and nanoribbons in nanoscale electronic circuit elements alone. Accordingly some choices have had to be made regarding how many “nano” terms to include in this book.

Although it is true that some nanodispersions are simply colloidal dispersions under a new name, many other aspects of nanotechnology are genuinely new and distinct, such as carbon nanotubes and quantum dots. It has been suggested, but not

universally adopted, that the term nanotechnology be used to refer to the study of the nanoscale regime, and the term molecular nanotechnology be used to refer to the 'nano approach,' by which is meant the precise, controlled assembly of structures up from the molecular scale that are well-organized. This is in contrast to the classical "top down" approach of making things by cutting, bending, and otherwise shaping structures from larger starting pieces. In the dispersions area an analogy would be the use of colloidal ink dispersions in robocasting to build near-nanometre scale three-dimensional structures, as opposed to the formation of materials by subdividing bulk phases and then kinetically stabilizing their dispersions using emulsifiers and stabilizers.

This book provides brief explanations for the most important terms that may be encountered in a study of the fundamental principles, experimental investigations, and industrial applications of nanotechnology and colloid and interface science. Even this coverage represents only a personal selection of the terms that could have been included were there no constraints on the size of the book.

I have tried to include as many important terms as possible, and cross-references for the more important synonyms and abbreviations are also included. The difficulty of keeping abreast of the colloid and interface science vocabulary, in particular, has been worsened by the tendency for the language itself to change as the science has evolved since the 1800s, just as the meaning of the word colloid has changed. Many older terms that are either no longer in common use, or worse, that now have completely new meanings, are included as an aid to the reader of the older colloid and interface science literature and as a guide to the several meanings that many terms can have. As an emerging field, the meanings of terms in nanoscience and nanotechnology are still somewhat in flux, although some standardization is beginning to occur. As an indication of the continual evolution of the science, technology, and terminology of the "very small," this book also contains a modest number of terms from the emerging field of picotechnology.

Some basic knowledge of underlying fields such as chemistry, physics, geology, and chemical engineering is assumed. Many of the important named colloids and phenomena (such as Pickering emulsions), equations, and constants are included, although again this selection represents only some of the terms that could have been included. Finally, I have also included a selection of brief biographical introductions to more than 85 scientists and engineers whose names are associated with famous named phenomena, equations, and laws in nanotechnology and colloid and interface science. Students first become aware of the people that have laid the foundation for a scientific discipline as they encounter these eponyms. By adopting the "students' view" of famous names in the field, it will be seen that in some cases the scientists are very famous, and biographies are readily found. In other cases the scientists are not as well known, and in some cases their contribution to nanotechnology and colloid and interface science was otherwise slight. For those interested in this feature specifically, I have included an index of famous names in nanotechnology and colloid and interface science (Table 21 in the Appendix) for easy searching.

Specific literature citations are given when the sources for further information are particularly useful, unique, or difficult to find. For terms drawn from fundamental colloid and interface science, much reliance was placed on the recommendations of the IUPAC Commission on Colloid and Surface Chemistry [8]. Numerous other sources have been particularly helpful in colloid and interface science (textbook [9–14]) and its subdisciplines and related, specialized fields [15–31]. I recommend these sources as starting points for further information. Similarly, for terms emerging in nanotechnology, much reliance was placed on the recommendations of ASTM Committee E56 on Nanotechnology [32] and the British Standards Institution Vocabulary on Nanoparticles [33]. Other helpful sources include [34–38]. For the famous names entries, I have drawn on a number of general references [39–44] and have also included numerous specific references for those interested in additional information.

A

AAN	→ Average Agglomeration Number.
Ablation	The reduction of particles into smaller sizes due to erosion by other particles or the surrounding fluid. May also refer to the size reduction of liquid droplets due to erosion, as in the processing of an oil sand slurry in which the oil (bitumen) is very viscous.
Abrasion	The wearing down of a surface by erosion due to particles in the surrounding fluid.
Absolute Filtration Rating	The diameter of the largest spherical particle that will pass through a filter, under given test conditions, without deformation.
Absolute Viscosity	A term used to indicate viscosity measured by using a standard method, with the results traceable to fundamental units. Absolute viscosities are distinguished from relative measurements made with instruments that measure viscous drag in a fluid without known or uniform applied shear rates. → Viscosity, <i>see</i> Table 4.
Absorbance	In optics, a characteristic of a substance whose light absorption is being measured. The Beer–Lambert law gives the ratio of transmitted (I) to incident (I_0) light as $\log(I/I_0) = alc$, where a is the absorptivity, l is the optical path length, and c is the concentration of species in the optical path. The logarithmic term is called the “absorbance”.
Absorbate	A substance that becomes absorbed into another material, or absorbent. → Absorption.
Absorbent	The substrate into which a substance is absorbed. → Absorption.
Absorption	The increase in quantity (transfer) of one material into another or of material from one phase into another phase. Absorption may also denote the <i>process</i> of material accumulating inside another.

Acacia Gum	→ Gum.
Accumulation Aerosol	An aerosol in which the primary particles or droplets have aggregated and/or coalesced into larger species or aggregates, typically in the size range of 50 to 1,000 nm. → Aerosol and → Nucleation Aerosol.
Acheson, Edward (Goodrich) (1856–1931)	An American electrochemist and inventor known for his work in the electrical and electric lighting fields, and in abrasives. A contemporary of Thomas Edison, with whom he was at times a collaborator or a competitor, Acheson developed conducting carbon for Edison's electric light bulbs, and managed electric generating plants and lamp manufacturing factories in Europe and the United States. Acheson discovered silicon carbide, its practical application as an abrasive, and coined the name Carborundum. Acheson also developed pure graphite and colloidal graphite products and founded several companies for their manufacture. Two of Acheson's colloidal graphite products (suspensions in oil or water) were called Oildag and Aquadag. He was granted 70 patents on devices, techniques, and compositions of matter in the fields of mechanics, electricity, electrochemistry, and colloid chemistry.
Acicular Particle	A long, narrow particle, such as a "needle-shaped" particle. Example: pine needles.
Acid Number	→ Total Acid Number.
ACN	Alkane carbon number, → Equivalent Alkane Carbon Number.
Acoustophoretic Mobility	An analogue of the electrophoretic mobility that can be calculated from either of the electroacoustical methods of electrokinetic sonic amplitude or ultrasound vibration potential. → Electrokinetic Sonic Amplitude, → Ultrasound Vibration Potential, and see Reference [45].
Activated Adsorption	Chemisorption, that is, adsorption for which an activation energy barrier must be overcome, as opposed to unactivated adsorption, or physisorption, for which there is no activation energy barrier to be overcome. → Chemisorption, → Physisorption.
Activated Carbon	Carbonaceous material (such as coal) that has been treated, or activated, to increase the internal porosity and surface area. This treatment enhances its sorptive properties. Activated carbon is used for the removal of organic materials in water- and wastewater-treatment processes. Also termed "activated charcoal".
Activated Charcoal	→ Activated Carbon.
Activation Energy	The minimum potential energy that must be attained by a system for a reaction or process to take place at a significant rate. Catalysts

usually function by providing a mechanism for a reaction that has a lower activation energy than does the uncatalyzed reaction.

Activator	Any agent that may be used in froth flotation to enhance, selectively, the effectiveness of collectors for certain mineral components. Example: sphalerite (ZnS) can be treated with copper sulfate (the activator), which adsorbs and bridges to ethyl xanthate (a collector), which in turn allows the sphalerite to be floated. → Froth Flotation.
Active Site	In adsorption, the specific regions of an adsorbent onto which a substance may adsorb. In catalysis, the site responsible for a particular reaction.
Active Surface Area	→ Fuchs Surface Area.
Active Surfactant	The primary surfactant in a detergent formulation. → Detergent.
Adagulation	The deposition of small, usually colloidal-sized particles onto larger size particles. Also termed Slime Coating.
Adamson, Arthur W. (1919–2003)	An American physical and surface chemist known for his work in inorganic photochemistry (he has been called “the father of inorganic photochemistry”), surface chemistry and chemical education. He is particularly known to colloid and interface scientists for his textbooks on physical chemistry and surface and colloid chemistry, especially “Physical Chemistry of Surfaces,” which continued through six editions.
Adatom	An adsorbed atom.
Additive Electrolyte	→ Critical Coagulation Concentration.
Adhesion	(1) The attachment of one phase to another. → Work of Adhesion, → Adhesive. (2) The load causing failure of a joint, for example, of a glued joint between two materials. → Peel Test.
Adhesion Tension	An older term that referred to the wetting tension and/or the interfacial tension between solid and liquid phases. These usages have been discouraged to avoid confusion with the work of adhesion. <i>See also</i> Reference [4].
Adhesional Wetting	The process of wetting when a surface (usually solid), previously in contact with gas, becomes wetted by liquid. This term is sometimes used to describe wetting that includes the formation of an adhesional bond between the liquid and the phase it is wetting. → Wetting, → Spreading Wetting, → Immersional Wetting.
Adhesive	Any substance that enables or enhances mechanical adhesion, usually between solids. Example: glue.

Adjuvant	Chemicals that modify the effect of specific other chemicals while having few if any direct effects when they occur by themselves. Adjuvant surfactants increase the effects of biologically active compounds in agrochemical preparations. Their ability to perform this function is at least partly due to their ability to enhance wetting and spreading, which reduces the amount of active ingredient needed to be effective. Example: the use of nonionic surfactants in herbicide solutions sprayed on crops.
Admicelle	→ Hemimicelle.
Admicellar Catalysis	Catalysis occurring in the admicellar (internal) region of admicelles adsorbed onto some medium. → Hemimicelle.
Admicellar Chromatography	The chromatographic separation of compounds as they pass through a medium containing media bearing admicelles. → Hemimicelle.
Adsolubilization	A surface analog of micellar solubilization in which adsorbed surfactant bilayers (admicelles) absorb solutes from solution. Example: the partitioning of sparingly soluble organic molecules from water into admicelles. <i>See</i> Reference [46].
Adsorbate	A substance that becomes adsorbed at the interface or into the interfacial layer of another material, or adsorbent. → Adsorption.
Adsorbent	The substrate material onto which a substance is adsorbed. → Adsorption.
Adsorbent Surface	→ Adsorption Space.
Adsorptive Filtration	Filtration in which particles are attracted to and retained by filter elements due to electrostatic and/or dispersion forces.
Adsorption	The increase in quantity of a component at an interface or in an interfacial layer. In most usage it is positive, but it can be negative (depletion); in this sense negative adsorption is a different process from desorption. Adsorption may also denote the process of components accumulating at an interface.
Adsorption Capacity	The maximum amount of adsorbate that can be adsorbed by an adsorbent. The amount of adsorbed substance reached in a saturated solution, often where the solute is strongly adsorbed from a solution in which it has limited solubility.
Adsorption Complex	The combination of a (molecular) species that is adsorbed together with that portion of the adsorbent to which it is bound.
Adsorption Hysteresis	The phenomenon in which adsorption and desorption curves (isotherms) depart from each other.
Adsorption Isobar	→ Adsorption Isotherm.

Adsorption Isostere	The function relating the equilibrium pressure to the equilibrium temperature for a constant value of the amount (or surface excess amount) of substance adsorbed by a specified amount of adsorbent.
Adsorption Isotherm	The mathematical or experimental relationship between the equilibrium quantity of a material adsorbed and the composition of the bulk phase, at constant temperature. The adsorption isobar is the analogous relationship for constant pressure, and the adsorption isostere is the analogous relationship for constant volume. → Langmuir Isotherm, → Freundlich Isotherm, → Polanyi Isotherm, → Gibbs Isotherm, → Brunauer-Emmett-Teller Isotherm, → Characteristic Isotherm, → Frenkel-Halsey-Hill Isotherm, → Temkin Isotherm.
Adsorption Site	→ Active Site.
Adsorption Space	An interface is sometimes considered to comprise two regions, one containing a certain thickness of adsorbent; the other containing a certain thickness of the fluid phase. The former is termed the “surface layer of the adsorbent” (or adsorbent surface) and the latter is termed the “adsorption space”.
Adsorption Surface Area	A surface area determined by calculation from experimental adsorption data, using an adsorption isotherm model. For example, the BET surface area is that calculated using the BET adsorption isotherm method.
Adsorptive Material	Material that is present in one or both of the bulk phases bounding an interface and capable of becoming adsorbed.
Advancing Contact Angle	The dynamic contact angle that is measured when one phase is advancing, or increasing, its area of contact along an interface while in contact with a third, immiscible phase. It is essential to state through which phase the contact angle is measured. → Contact Angle.
Advection	The transport of material solely by mass motion. In meteorology, an example is the transfer of heat by horizontal motion of the air. For flow in porous media, advective flow is without dispersion and results in the step appearance of chemical species at the downstream end of a control volume through which the species were flowing. In this case, the Darcy velocity alone is needed to predict the “advective” time of appearance of chemical species downstream.
AEAPS	Auger electron appearance potential spectroscopy. → Appearance Potential Spectroscopy.
Aeolotropic	→ Anisotropic.