HISTORICAL NOTE

Classics and Classicists of Colloid and Interface Science

III. The(Theodor) Svedberg

The(Theodor) Svedberg’s (1884–1971) invention of the ultracentrifuge and its application to the study of proteins from the mid-1920s has secured his niche as a principal founder of molecular biology and biophysical chemistry. Other modern instrumental techniques, such as X-ray diffraction and moving boundary electrophoresis, were first applied to the study of protein structure only from the mid-1930s. Actually Svedberg also initiated the work on moving boundary electrophoresis, for which his student Arne Tiselius won the 1948 Nobel Prize.

It surprises many to learn that the 1926 Nobel Prize in Chemistry was awarded to Svedberg, then in mid-career, for his work in colloid chemistry, most particularly for studies of Brownian motion. Indeed his first results on the ultracentrifugation of proteins were only published in 1926. The first optical centrifuge, not yet an ultracentrifuge, was built in 1923 while Svedberg was a visitor at the University of Wisconsin, in collaboration with graduate student J. B. Nichols, in order to study gold hydrosols.

Svedberg (1), the only child of Elias Svedberg, a civil engineer, and Augusta Alstermark, was born near Gavle, Sweden, on August 30, 1884. Even though he had already demonstrated great talents during his school years, his success at the University of Uppsala was amazing. He arrived in January 1904, passed the various courses and examinations for the Fil. kand. degree in record time, and plunged directly into research in the new colloid chemistry in September 1905.

Although he had earlier displayed strong interests in biology, Svedberg avoided a trend that was fashionable in colloid chemistry—diffuse speculations about colloids as models of living systems. Rather, he tackled the practical problem of preparing stable colloids reproducibly in order to permit quantitative studies of the relation between particle size and other physical properties. He published his first paper in December 1905 in which he refined Georg Bredig’s electric arc technique for the preparation of gold and platinum hydrosols by introducing alternating current discharges and performing the experiments in various organic solvents (2). He next assembled an ultramicroscope according to the design of Zsigmondy and Siedentopf.

His doctoral dissertation was submitted in 1907. There does not appear to be any indication of collaboration with a member of the faculty. Brownian motion is certainly the most dramatic aspect of colloidal behavior made apparent by the ultramicroscope, so it is no wonder that a study of Brownian motion comprised a major portion of his dissertation. He also studied the effect of particle size upon optical absorption, the effect of both temperature and added electrolyte upon the coagulation of hydrosols, as well as the electrical synthesis of sols.

His Brownian motion work displayed great imagination. Following an erroneous suggestion by Zsigmondy that the motion of larger particles was of an oscillatory nature rather than translation by a random walk, he devised an experiment in which particles were observed in the ultramicroscope while the sol as a whole flowed through the apparatus at a known linear velocity. Svedberg reasoned that the superposition of the oscillatory Brownian motion and the linear motion of the fluid would result in a sinusoidal curve. He reported what appeared to be waveforms and from the velocity and wavelength he calculated a period of oscillation. From the amplitude and the period he then calculated a velocity which he identified with the gas kinetic velocity of the colloid, considered as a very large molecule.

Shortly thereafter, he encountered Einstein’s 1905 paper on Brownian motion and, identifying his measured amplitude with Einstein’s displacement and his period with Einstein’s characteristic time, he claimed that his data, obtained in liquids of various viscosities, verified Einstein’s treatment. This was challenged immediately by Einstein, who pointed out that the motion was not oscillatory and that the relaxation time for the random motion made observation of a velocity quite impractical. Somewhat later he was attacked very sharply by Jean Perrin. Svedberg actively defended this work for nearly 2 decades and it continued to be cited in the colloid literature. Indeed, it provided the main basis for the award to Svedberg of the Nobel Prize in Chemistry in the same year that Perrin was honored for his Brownian motion experiments in physics.

Editors’ Note: This article is the third in a new feature which will treat some of the key figures who have laid the foundations of colloid and interface science. Persons contemplating a contribution should enter first into correspondence with Dr. Kerker, who will coordinate and edit the feature.
This episode and its consequences have been discussed by us in some detail elsewhere (3).

Svedberg was appointed doctor upon completion of his dissertation whereupon he and his students expanded upon these initial projects, so that Uppsala became known as a center for quantitative work on colloids. He provided further support for the kinetic molecular view by experimental tests of Marian Smoluchowski’s theory of thermal fluctuations. This was obtained by observing, for a microscopically small fixed volume, the variation of concentration of particles in a gold sol using the ultramicroscope and of polonium ions in a solution by counting scintillations. In still other experiments, colloidal particle size calculated from diffusion data was compared with values obtained with the ultramicroscope.

All of this work on Brownian motion, thermal fluctuations, and diffusion were subjects in which young Einstein was also intensely interested at this time, illustrating Svedberg’s talent for relating colloidal phenomena to that most fundamental current scientific problem, the question of the reality of atoms and molecules. His work on radioactivity, in which he retained a lifelong interest and to which he was to dedicate the last phase of his career, provides another instance of his ability to tackle fundamental problems. In addition to exploring the effect of X rays on the stability of gold colloids, he and D. Strömholm in 1909 investigated the isomorphous cocrystallization of radioactive compounds. They discovered that thorium X (radium) cocrystallized with lead and barium salts, indicating the existence of isotypes (4).

From about 1914 through 1922, Svedberg’s published work was devoted mainly to two new subjects. There were studies of anisotropies produced by electric and magnetic fields in substances now known as liquid crystals, including measurements of electrical conductivity, reaction rates, and diffusion. Starting in 1920, there were several papers published in photographic journals devoted to the relation between the size and the sensitivity of the grains in a photographic emulsion.

Then came the Wisconsin interlude which marked his career’s watershed. In 1922 J. H. Mathews invited Svedberg to the University of Wisconsin to lecture and to do research during the 1923 spring semester and then to participate in a symposium which evolved into the National Colloid Symposium of the American Chemical Society (5). The Wisconsin colloid symposium inaugurated the oldest such specialized annual meeting within the American Chemical Society and stimulated the formation of the Division of Colloid Chemistry (6).

For Svedberg the Wisconsin sojourn led to his development both of the ultracentrifuge and, through his student Tiselius, of the moving boundary electrophoresis apparatus—two instruments that have had a profound influence on the recent spectacular advances in macromolecular chemistry, biochemistry, and molecular biology. He had just developed a technique for following the variation of optical density with height in a sedimenting system in order to determine the actual distribution of colloidal particle size, rather than merely the average size (7). However, only relatively large particles settled in the gravitational field and in order to study the formation and growth of particles, it would be necessary to increase the rate of sedimentation by centrifugation (8).

This was done in Wisconsin where J. B. Nichols, one of the six graduate students assigned to Svedberg, built what was to evolve into the ultracentrifuge. The centrifugal force attained by the Wisconsin ultracentrifuge was only 150 times gravity; but, upon returning to Uppsala, Svedberg and Herman Rinde built a centrifuge which attained a force of about 7000 times gravity, and, with this instrument, they were able to determine the size of gold particles much smaller than those which would be visible in the ultramicroscope. In analogy with the ultramicroscope and ultrafiltration they proposed the name ultracentrifuge. In 1925–1926 Svedberg was able to obtain funds to build a still larger instrument, which attained 100,000 times gravity and made it possible to cover a still broader range of sizes, so that, using the sedimentation velocity technique, he was able to penetrate into the macromolecular domain of proteins. His first paper on a protein appeared in 1926, the year in which he was awarded the Nobel Prize. In this paper he confirmed earlier studies by G. Adair, using osmotic pressure, that the molecular weight of hemoglobin was 68,000 rather than 16,700 based on the iron content, making that molecule a tetramer consisting of four monomeric subunits.

By now Svedberg had left the domain of colloidal particles which comprised Ostwald’s “world of neglected dimensions,” and he was to devote his career mainly to proteins and other biological macromolecules, using the ultracentrifuge as the principal tool. A key finding of his that in many cases soluble proteins had molecules with well-defined uniform size was first treated with skepticism, yet later confirmed. However, Svedberg’s proposal that the molecular weights of proteins were multiples of a basic unit did not have the generality that he had expected. Svedberg remained involved in the continued development of greater centrifugal fields and the study of new macromolecular systems up to the outbreak of World War II when he was charged with the development of Swedish production of synthetic rubber.

In 1949 he retired from his Chair of Physical Chemistry and became head of the Gustaf Werner Institute of Nuclear Chemistry. His early interest in radiation chemistry had actually been revived in the late 1930s in connection with the effects of ultraviolet light, α particles, and ultrasounds on hemocyanines. And so when after the war he succeeded in getting a wealthy industrialist to build a new research institute, he plunged into a new phase of research, problems which overlapped high-energy physics, chemistry, and biology. The last paper bearing his name, published in 1965, dealt with high-energy proton radiotherapy.

Svedberg’s work belongs to three broad areas of science—colloid chemistry, physical biochemistry, and ra-
diation chemistry. Yet we can claim him as a colloid chemist not only by training and because of his contributions to that discipline but also because his work in the latter two areas flowed from his earlier work with colloids.

REFERENCES AND NOTES

1. For biographical material see the article on Svedberg by Stig Claesson and Kai O. Pedersen in “Dictionary of Scientific Biography” (C. C. Gillispie, Ed.), Vol. 12, pp. 155–164. Scribner’s, New York, 1975; also further biographical references are given therein.


4. None other than Frederick Soddy credits StrömmHolm and Svedberg generously in his 1921 Nobel Prize lecture. He quotes them, “Perhaps we can all see as an indication in this direction, the fact that the Mendeleev scheme is only an approximate rule as concerns atomic weight, but does not possess the exactitude of a natural law; this would not be surprising if the elements of the scheme were mixtures of several homogeneous elements of similar but not completely identical atomic weight.” Then Soddy comments, “Thus StrömmHolm and Svedberg were the first to suggest a general complexity of the chemical elements concealed under their chemical identity.” Cited by Claesson and Pedersen, op. cit.

5. See “Remarks of J. H. Mathews at the opening of the 40th National Colloid Symposium” J. Colloid Interface Sci. 22, 409 (1966). See also Lloyd H. Reÿerson “Early history of the National Colloid symposia presented on the occasion of the 40th annual session at the University of Wisconsin at Madison,” J. Colloid Interface Sci. 22, 412 (1966). Svedberg appears to have returned as the “foreign guest of honor” on the occasion of the 20th Symposium at the University of Wisconsin in 1946. Tiselius was the foreign guest of honor at the 12th Symposium at Cornell University in 1935.

6. The papers presented at the Wisconsin meeting appeared as “Colloid Symposium Monograph” (J. Howard Mathews, Ed.), published by the Department of Chemistry, University of Wisconsin, Madison 1923. The 23 papers provide an overall view of the current state of colloid chemistry. Authors whose names are familiar to this writer are Wilder D. Bancroft, Harry N. Holmes, Harry B. Weiser, Hugh S. Taylor, Elmer O. Kraemer, Floyd E. Bartell, Louis Kahlenberg, E. F. Burton, Joel H. Hildebrand, Jacques Loeb, J. H. Mathews, Jerome Alexander, J. E. Sheppard, and Ross A. Gortner. It was a stellar group.

7. Einstein had analyzed and Perrin had performed the appropriate experiments on the equilibrium distribution in a gravitational field as another manifestation of Brownian motion. Svedberg was quite familiar with this work, particularly since he and Perrin had engaged in a polemic over the validity of Svedberg’s own Brownian motion experiments. These experiments as well as Svedberg’s measurements of the optical density of colloidal systems stemmed from his doctoral work and figured prominently in his writings down to his 1924 treatise on colloid chemistry.

8. Svedberg’s paper entitled “Colloid Chemistry Technique” was a plea for the development of appropriate instrumental techniques since “colloid chemistry requires its own technical facilities different from the ordinary equipment of a physicochemical laboratory. . . . In the following paper the writer will try to outline the colloid chemistry technique at our disposal at the present time together with a few suggestions for new methods.” In one case he reports that “Nichols and the writer (in this laboratory) have carried out measurements of size of particles in fine grained soils by using a special centrifuge which allowed determinations of the movement of the boundary between the soil and a clear medium during centrifuging. This method is now being worked out more in detail and seems to be rather promising.” As for the electrophoresis, he notes that “Jette, Seott and the writer have worked out a procedure for measuring cataphoresis based upon the fluorescence which many colorless substances, e.g. the proteins, show when illuminated with ultraviolet light . . . the position of the boundary is indicated by the fluorescence is recorded from time to time by taking photographs.”

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