A Tribute to the Memory of

Theodor Svedberg

(1884–1971)

by Professor Björn Lindman

and

Professor Lars-Olof Sundelöf

Royal Swedish Academy of Engineering Sciences (IVA)

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Theodor Svedberg

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Presented at the 2010 Annual Meeting
of the Royal Swedish Academy of Engineering Sciences

by Professor Björn Lindman and Professor Lars-Olof Sundelöf

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Foreword

Every year, the Royal Academy of Engineering Sciences (IVA) produces a booklet commemorating a person whose scientific benefit to the society of his or her day. The commemorative booklet is published in conjunction with the Academy´s annual meeting.

This year, Nobel Prize winner Theodor (The) Svedberg (1884-1971) is honored with IVA´s commemorative booklet. The Svedberg received many awards during his lifetime. In 1942 he was awarded the John Ericsson Medal, in 1944, he was honored the Berzelius Medal and in 1949 he received the Medal of the Franklin Institute. But most important of them all, in 1926 The Svedberg was awarded the Nobel Prize in Chemistry. He received the Nobel Prize for his studies of dispersed systems, studied with help of the ultracentrifuge that he developed. With The Svedberg´s ultracentrifuge, chemists were able to separate macromolecules from each other and this feature came to be a break-through for enhanced understanding of proteins and other macromolecules.

The Svedberg studied at Uppsala University and received his Ph.D. degree in 1908 when he presented his thesis study "Studien zur Lehre von den kolloiden Lösungen"

(Studies of Colloidal Solutions). In 1913 he was elected a member of the Royal Academy of Sciences and in the years 1912 to 1949 Svedberg was Professor of Physical Chemistry at Uppsala University.

We give our sincere thanks to the authors, professor Björn Lindman and professor emeritus Lars-Olof Sundelöf for the work they have devoted to this year´s commemorative booklet.

Björn O. Nilsson
President of the Academy

Mauritz Sahlin
Chairman of the Medals Committee

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Introduction

Theodor (The) Svedberg is famous for his work on colloidal dispersions for which he was awarded the Nobel Prize in chemistry in 1926. He is also known for developing the ultracentrifuge, making possible a breakthrough in the understanding of proteins and other macromolecules. However, Svedberg's contributions to science were much broader than this and included areas as diverse as radiation research and botany. In parallel with his scientific achievements, Svedberg also managed to work in close collaboration with scientists all around the world. When his new institute was created in the early 1930s, it became a highly fruitful and productive meeting place for scientists from very diverse research fields.

Starting with his earliest studies on metal dispersions, he was one of the main scientists to turn the arcane field of colloid chemistry into a vigorous and productive field of study. Colloids are substances dispersed (as opposed to being dissolved) in a medium. Colloids cannot be observed directly under a microscope, nor do they settle out under the force of gravity. However, in the increased centrifugal force field of the ultracentrifuge developed by Svedberg, colloids can be made to move and, using intricate optical systems, resolved according to size. Svedberg's development of the ultracentrifuge made it possible to study not only colloidal dispersions but also macromolecular solutions, which proved to be of enormous importance. The ultracentrifuge thus became one of the most fundamental and useful tools in the modern biomedical laboratory. Svedberg's work was not only innovative but also cross-disciplinary, having valuable applications in a variety of fields, beginning with colloid chemistry. This field has seen a revival in recent decades and has attracted much attention. It is referred to today by physicists as nanoscience and nanotechnology.

Besides the deep scientific principles behind the construction of the ultracentrifuge, it also presented many intriguing engineering problems that needed to be solved. To achieve a practical construction that could withstand the high speeds involved (several hundred thousand times *g*), it was necessary to carefully consider material properties and design. One of the most difficult problems was the design of the cell containing the colloid and especially the windows for optical observation in the high force field so as to avoid excessive distortion or cracking.

Several instrumental inventions from Svedberg's institute were developed and later industrially manufactured. Svedberg had in general close relationships with Swedish industry where he acted as an advisor. During World War II, for example, his institute created a new process for the manufacture of synthetic rubber called Svedoprene.

Family and Childhood

Theodor Svedberg was born on 30 August 1884 at Fleräng Manor in the parish of Valbo close to the town of Gävle about 100 km north of Uppsala. Svedberg's childhood and school days were a happy time and also a time that shaped his future development. He was the only child of Elias Svedberg, an industrial executive educated as an engineer in mining and metallurgy, and his wife Augusta Alstermark. While Svedberg was a school boy the family moved several times; from Valbo to Rommelviken in Norway where Elias Svedberg was head of a copper plant, and back to Sweden where Elias Svedberg became head of various steel works in Västmanland. Elias Svedberg was a naturalist who collected minerals and plants and often took his son on botanical excursions. This awakened in Theodor an early interest in science and nature. The five years from 1895 to 1900 when Elias Svedberg was head of Karmansbo Steelworks were among the happiest of The's youth. He was able to go on his own botanical excursions along Hedströmmen River and also perform physics and chemistry experiments in his own small laboratory.

Most of The Svedberg's schooling was provided at Köping Elementary School and Carolina Grammar School in Örebro. In both schools he had understanding teachers who allowed him to carry out his own experiments in the physics and chemistry laboratories. In December 1903 Svedberg received his high school diploma after taking a private examination in Gothenburg, not wanting to wait for the regular examination period in Örebro in spring the following year.

Svedberg was married four times – in 1909 to Andrea Andreen, in 1916 to Jane Frodi, in 1938 to Ingrid Blomquist and in 1948 to Margit Hallén. He had twelve children – six sons and six daughters.

The Svedberg with colleagues and pupils in front of the Chamistry Department. Arne Tiselius to the far left, Herman Rinde in black hat. (Chemistry Department archives)

Uppsala University

Svedberg matriculated and began his lifelong association with Uppsala University in January 1904. He gained his Bachelor of Arts degree in 1905, his Master's degree in 1907 and his PhD in 1908. Svedberg accepted a post as assistant at the university's Chemical Institute in 1905 and in 1907 he was given the additional position of lecturer in chemistry at the university. He obtained a special appointment in 1909 as lecturer and demonstrator of physical chemistry and in 1912 he was elected Professor of Physical Chemistry at Uppsala University. He became emeritus in 1949 and at the same time Director of the Gustaf Werner Institute for Nuclear Chemistry at Uppsala University, from which position he retired in 1967.

Svedberg began his university studies at Uppsala University directly after finishing school and started his research while still a freshman in 1904. He was therefore able to publish his first research paper, on metal colloids, as early as 1905 at the age of 21. Svedberg came to Uppsala at the very beginning of the last century, but rumours of his capacity and ingenuity had reached the University before his arrival. His basic interest was botany and biology, but he understood that in order to succeed in that field, he had to first study mathematics, physics and chemistry. He never pursued the subject of botany during his undergraduate years. He was instead attracted by chemistry, a subject that was developing dramatically at that time. The particulate state of matter was beginning to become a generally accepted truth, but was still by no means universally accepted. Famous chemists such as Wilhelm Ostwald did not believe in it. The Svedberg's inventive capacity and ability to use his imagination to reach new horizons brought his experimental activity to investigations into the colloidal domain. This was a field at the periphery of knowledge at that time – much discussed but little known. The Svedberg always believed in the particulate state of matter and probably saw in colloids a possible means of observing the direct action of particles. It was during this period that, as an extension of his thesis work, he collected all the evidence he could proving the existence of molecules. His work was published in 1912 as one of his great contributions to science in the book entitled *Über die Existenz der Moleküle* (On the existence of molecules).

This marked the beginning of a new era in chemical research at Uppsala University, which until that time had been largely descriptive, preparative and analytical. Svedberg started to independently conduct research to prepare colloids in organic liquids using electric discharge. In particular he introduced physical measurements to study the size, size distribution, electric charge and random motion of the colloidal particles. He also used theory to describe and interpret the results. By 1912 at the age of just 28, Svedberg was made Professor of Physical Chemistry, the first chair in this field in Sweden.

During the long period of his professorship – thirty-seven years between 1912 and 1949 – as the first professor of physical chemistry in Sweden, Svedberg initiated a vast number of research studies that almost invariably set their marks on the development of science. His colloidal studies for his dissertation in 1907 led, in due course, to the development of the ultracentrifuge. Early tentative work on the equilibrium machine in the 1920s, which showed that the potential existed, was followed by extensive development work on the velocity machine, which was completed in the 1930s. In a way, this was also the golden age for Svedberg in terms of his international reputation. Scientists from all around the world gathered at his institute to try to solve intricate problems in biochemistry and polymer science with the help of the equipment developed in

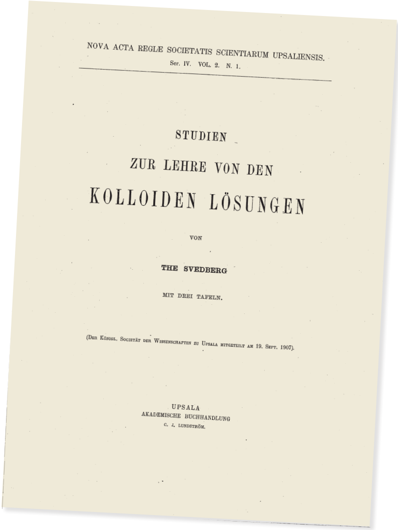
Svedberg lecturing in 1915. In the audience among others some later well-known chemists: Arvid Hedvall, Herman Rinde, Arne Westgren and Harald Nordenson. (Photo I. Nordlund)

Uppsala. This international congregation formed a vibrant body which was perhaps even more productive than the equipment itself. At the time the ultracentrifuge was developed, Svedberg's student Arne Tiselius developed electrophoresis as an efficient complimentary tool, which in the long term has proved to be even more useful in biochemistry than the ultracentrifuge itself. Another student of Svedberg, Ole Lamm, made considerable contributions relating to refinements in the recording of transport processes and the theory of sedimentation. Ole Lamm went to the Royal Institute of Technology (KTH) as professor of Theoretical Chemistry, which subsequently became Physical Chemistry. From his department, as well as from Uppsala, the next generation of physical chemists in Sweden was recruited.

The Svedberg was always keen to work in untouched areas. During the early days of his colloid studies he attempted to investigate the influence of a magnetic field on the diffusion process. Basic research on particle interaction in colloid dispersions, of the van der Waals type, was being carried out long before the 1920s. The variety and originality of the studies conducted in the 1910s ranked among his most outstanding scientific achievements, although they may seem less noteworthy and are not as well known. In the 1930s light scattering was brought to the laboratory by visiting scientists, but unfortunately it never developed to maturity there. Thermal diffusion was tackled experimentally in the early 1940s. The list could go on. Svedberg was restless in those days, always striving to discover something new. The war put an unfortunate end to the powerful scientific exchange that had been taking place.

Early Studies in Colloid Chemistry

By his second year at university, Svedberg had already published his first paper which dealt with the production of metal colloids in different media using an electrical technique. Within this general field there followed a number of studies which he summarised in his doctoral dissertation in December 1907, *Studien zur Lehre von den kolloiden Lösungen* (Studies of Colloidal Solutions). In his thesis Svedberg described the preparation of colloids of more than 30 metals in organic solvents. The thesis also included investigations on the movement of the colloidal particles – the so-called Brownian movement. Meanwhile Einstein was developing a theory on the


NOVA ACTA REGLÆ SOCIETATIS SCIENTIARUM UPSALIENSIS.
Ser. IV. VOL. 2. N. 1.

STUDIEN
ZUR LEHRE VON DEN
KOLLOIDEN LÖSUNGEN

VON

THE SVEDBERG

MIT DREI TAFELN.

(Der Königl. Societät der Wissenschaften zu Upsala mitgeteilt am 19. Sept. 1907).

UPSALA
AKADEMISCHE BUCHHANDLUNG
C. J. LUNDSTRÖM.

Studien zur Lehre von den kolloiden Lösungen mechanism of Brownian motion relating to collisions between particles and solvent molecules. The timely emergence of this theory during Svedberg's experimental work meant that Svedberg's results on the dynamics of colloids using an ultra-microscope were able to confirm the theory and provide final proof of the existence of molecules. In 1912 Svedberg published the aforementioned famous work on "The existence of molecules."

In these early studies of colloid systems, Svedberg realized that in order to determine the size and formation of particles, it was necessary to develop an optical system to obtain the particle concentration at different levels in a sedimenting system. In order to study smaller particles, it was necessary to increase the rate of sedimentation and this could only be done with centrifugal force. These ideas later led to the development of the ultracentrifuge.

It is a common misconception that Svedberg received the Nobel Prize for developing the ultracentrifuge. It was, in fact, awarded for his early work on colloidal systems, in particular for confirming Einstein's theory of Brownian motion.

A stay in Madison was influential

In 1923 Svedberg was invited to the University of Wisconsin, Madison, as a visiting professor. His stay there turned out to greatly influence his future research. He was invited to assist in developing the new field of colloid chemistry at the university. He started a new research programme and gave a series of lectures. The lectures, which were well attended both by academic and industrial researchers from all around the US, were published in a book the following year. Svedberg brought with him research projects representing his broad area of interest, including colloidal metals, sedimentation studies of emulsions and colloidal clays. However, the most important outcome was progress in the field of ultracentrifugation. This work was conducted largely in collaboration with J. Burton Nichols. Svedberg was also invited to be the keynote speaker at a colloid symposium attended by scientists from throughout the US and Canada. This was the first in a long series of annual North American colloid symposia. Svedberg's time in Madison had a profound influence on the development of colloid science in the US. Svedberg had a number of enthusiastic and competent students at the university, such as E. O. Kraemer who continued to work in the field of colloidal synthesis, and J. W. Williams who subsequently worked with others to make important contributions to the theory of sedimentation.

Svedberg's stay in Madison had a lasting impact in that he learned how science was conducted and organised in the US and also because it gave him many new ideas for research projects. He realised that characterising colloids not only required centrifuges but also methods such as electrophoresis and diffusion. However, the most immediate result of his stay at the University of Wisconsin was that by the time Svedberg returned to Sweden, a small, crude centrifuge had been developed in Uppsala to the point where it was possible to take pictures of sedimenting gold sols and clays. The equipment still had many limitations, with the problems of vibration, convection and temperature control still to solve. Now the most important task was to construct an improved centrifuge. On the trip back across the Atlantic in August 1923, Svedberg was already making sketches of rotors, cells and centrifuges, which would provide better analytical resolution and stronger centrifugal fields than those possible in the centrifuge built in Madison.

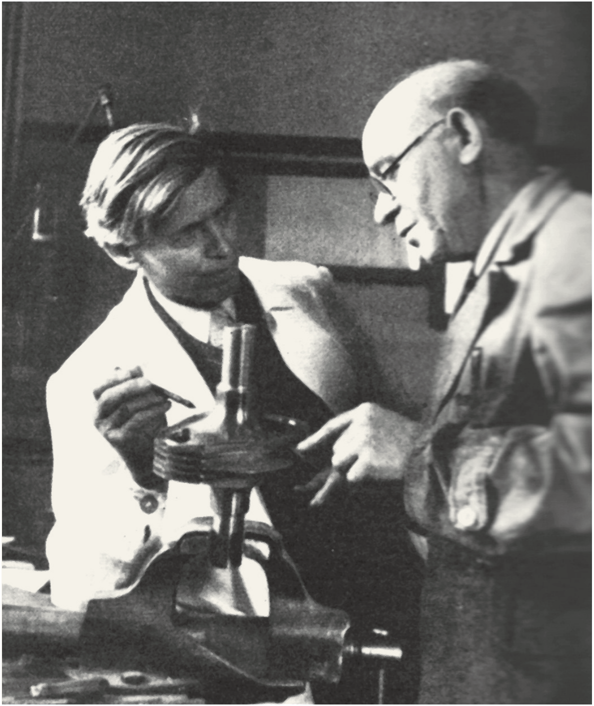
The Svedberg centrifuges

In the construction of his ultracentrifuge, Svedberg faced three basic problems that needed to be solved. The main one was designing a rotor capable of withstanding the force of several hundred thousand time g. The second was a driving mechanism that would allow smooth acceleration and stable operation without vibration throughout the entire experiment which normally lasted for several hours, if not days. The third problem to be solved was how to construct the compartment for the sample – the centrifuge cell. Here the biggest problem turned out to be the windows necessary for optical registration of the sedimentation process. The centrifuge cell was cylindrical so that it would fit into a hole in the rotor closed at both ends by circular and fairly thick quartz windows. It was necessary to use quartz to enable UV-registration of concentrations. Even though the cell was assembled with great care, the windows quite often cracked during a run. This actually limited the centrifugal force that could be used. The maximum successful trial by Svedberg was slightly below1,000,000 *g*, which was his ultimate goal. The very high centrifugal fields turned out to be of less interest, however, since the optical distortion in the windows coupled with the compression of the solution did not allow concentration to be correctly recorded. In much later commercial constructions, synthetic sapphire windows were used, which almost completely solved the problem of window distortion.

One important question was how to drive the rotor. Svedberg contacted F. Ljungström of the Ljungström Steamturbine Co. in Stockholm who proposed using oil-turbines, which would address the lubrication problem. One of his engineers, A. Lysholm from the same company, assisted Svedberg in constructing and testing the first machine built at Ljungström Steamturbine Co.

In the early equilibrium centrifuges the solution chamber of the cells was parallelepipedical. However, for velocity sedimentation, this shape caused severe convections. The realisation that the cavity needed to be sector shaped constituted a major step forward. Mechanically, it was challenging to construct such an opening with the sector angle centred exactly on the axis of rotation and with a very well-defined base. It had to be made by hand using the simplest of tools, which indicates the skill of the mechanicians. It was largely due to the extreme skills of the craftsmen in the workshop that it was possible to overcome all of the difficulties involved in the practical development of the ultracentrifuge. Here, Chief Engineer Ivar Eriksson played a crucial role. It was thanks to him that the angles of the twin turbine wheels at both ends of the rotor axis were finally correct, enabling the driving force of the high pressure oil stream to be maximised.

The rotors were made from special steel and cut in a lathe to a shape that together with the tensile strength of the steel would allow the cells to be positioned at a maximum distance of approx. 10 cm from the centre of rotation. This was possible due to the tensile strength of the steel.



The Svedberg and Ivar Eriksson discussing the rotor design in the workshop. (Chemistry Department archives)

Large, heavy steel blocks with a cavity that matched the rotor served as safety screens as well as temperature stabilisers. The rotors were running in an atmosphere of low pressure hydrogen gas to create an efficient heat flow and temperature balance between the rotor and the surrounding cavity walls.

The description above clearly illustrates the fact that developing the ultracentrifuge was a demanding task – both scientifically and technically. Although Svedberg was the intellectual driving force, the success of the project also depended on several of his colleagues. Gustav Boestad, then an engineer at AB Ljungströms Ångturbin, was instrumental in the development of the appropriate steel and especially the theoretical calculations of the tensile strength and shape of rotors and the design of the turbine wheels used to drive the rotors. Boestad later became a highly esteemed professor at the Royal Institute of Technology (KTH) in Stockholm and a member of IVA. Herman Rinde, a student of Svedberg, who in his thesis developed the basic theory to determine particle distribution from sedimentation data, also made a considerable contribution working in close cooperation with Svedberg to both the technical and theoretical development of the sedimentation process. He probably also played a central role in the development of the sector cell.

Macromolecules in the 1920s

Proving the existence of molecules was clearly a priority in the very early part of Svedberg's career and his research in the field was crucial. Even more significant was his research on the existence of macromolecules or polymers in the 1920s. Leading organic chemists were then involved in characterising natural substances like alkaloids, vitamins and hormones as well as synthesising and characterising new molecules. A fundamental property of any compound is its molecular mass or weight. Molecular mass determinations revealed that organic compounds generally had molecular masses up to a few hundred Daltons. Since solubility and melting decrease significantly as molecular weight increases for the substances generally studied, it was considered unreasonable that a compound could have a molecular weight of several hundred thousand Daltons and still be soluble in some solvents. Organic chemists and colloid chemists alike opposed the idea of high molecular compounds, but on the grounds that gigantic molecules were not needed to explain observations like gel formation and solution viscosity. Instead it was argued – as a plausible explanation – that the high molecular weight was only apparent and due to the association or complex formation of small molecules. However, the strongest opposition to the concept of polymers was presented by crystallographers. For example, X-ray analysis had shown that the elementary cell in the case of cellulose, rubber and some other systems was so small that one whole molecule could not fit into one elementary cell, but only a small part of it depending on the suggested molecular mass. A common theory at that time was that a molecule could not be larger than the elementary cell.

In 1920 Hermann Staudinger published an article on "Polymerisation" in which he claimed that several synthetic and naturally occurring substances like rubber and polystyrene have a chain structure in which monomer units are held together by normal covalent bonds. A year later similar claims were made for cellulose. With the arguments described above, Staudinger's macromolecular theory of synthetic and natural polymer initiated a long and intense scientific discussion. In order to resolve the controversy, the German Chemical Society arranged a famous meeting in September 1926 in Düsseldorf. Leading researchers participated in the meeting and strongly questioned Staudinger's ideas, stressing in particular the crystallography argument in combination with the alternative association explanation.

Here Svedberg's ultracentrifuge work came at just the right time and finally solved the problem. By first demonstrating the well-defined high molecular weight of several proteins and then also demonstrating high molecular weights for polystyrene in organic solvents, he provided very strong support for Staudinger's macromolecular concept, leading to its firm acceptance by the end of the 1920s.

It was in the field of proteins that Svedberg's ultracentrifuge work had the strongest immediate impact. The outcome of the experiments came as a real surprise to Svedberg. He writes the following and provides a sense of the accepted thinking at the time: "I had always been of the opinion that protein solutions were rather ill-defined systems containing all kinds of sizes, the so-called molecular weight only being a mean value, and I was therefore very much astonished when the centrifugal method showed that the haemoglobin solutions were built up of special-sized well-defined molecules."

As mentioned above, like other colloid scientists at the time, Svedberg was convinced that proteins were polydisperse lyophilic colloids with no definite molecular weight and he had planned to work out methods to determine the size distribution. He had attempted to centrifuge egg albumin without any result. Then in September 1924, Robin Fåhraeus, a professor at Karolinska Institutet in Stockholm, came to Uppsala to study with Svedberg. After studying casein which yielded a broad range of particle sizes, Fåhreus proposed investigating haemoglobin. Although Svedberg was sceptical, the experiment was performed. Initial attempts in October 1924 showed clear sedimentation of the protein, but experimental difficulties occurred – a crack in the cell window caused the solution to leak out. However, a new experiment one month later confirmed that haemoglobin had a well-defined molecular weight (68,000). This was the first demonstration of a mono-disperse protein and it constituted a radical change in the understanding of proteins.

Svedberg and his colleagues then studied a large number of proteins of different sizes: ovalbumin (molecular mass 34,000), serum albumin (70,000) and serum globulin (175,000). According to Svedberg, the most dramatic aspect of these studies related to the investigation of the blue haemocyanin from the blood of the vineyard snail. Due to the copper content a molecular weight of approx. 17,000 was suggested indicating a very slow sedimentation rate. Instead the experiments showed very fast sedimentation with a sharp cell boundary, indicating a molecular mass of millions of Daltons.

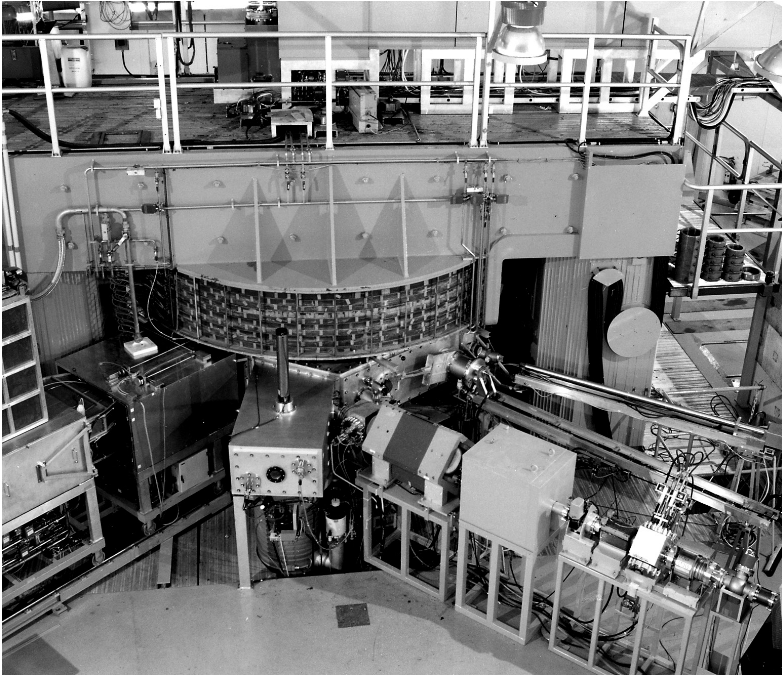
In a way it was extremely fortunate that the earliest studies performed in the ultra-centrifuge were on globular proteins where the inter-particle interaction is weak and hence the concentration dependence of the sedimentation rate is small. This meant that the true molecular weight could be obtained with reasonable accuracy either from the equilibrium concentration distribution or from the sedimentation rate after only minor corrections for the concentration dependence. The situation turned out to be much more complex for solutions of synthetic polymers and cellulose.

The new Institute of Physical Chemistry

Due to Svedberg's successes, the department attracted a large number of new employees and visitors from all around the world. This, combined with the increasing number of new instruments that had been developed, meant that the department was becoming very crowded – to the extent, in fact, that cloakrooms and toilets had to be used. The working conditions in the old chemical institute had deteriorated and the message was spreading. In October of 1926 there was an article in the Stockholm newspaper Dagens Nyheter with the headline "The professor has to work in a dark coal cellar and his students in a toilet." The following month Svedberg was awarded the Nobel Prize and in December the Swedish Parliament provided funds to build a new institute of physical chemistry.

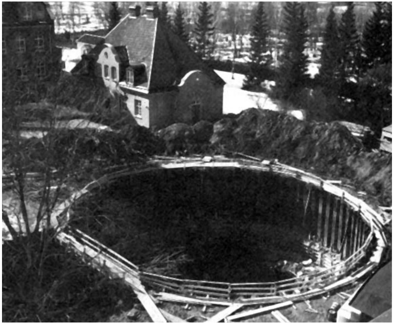
The field of physical chemistry in Uppsala in particular and Sweden in general was intimately linked to The Svedberg for many years. His importance for Swedish research is evidenced by the speed at which a decision to create a new institute for Svedberg and his collaborators was made. After several years of careful planning it was opened in 1931. The year of Svedberg's arrival in Uppsala, 1904, had also been a year of transition. After sharing a building with the physicists for a long time, the chemists at Uppsala University were in 1904 able to move into a new building. This was where Svedberg performed his first classic colloid chemistry experiments and this is also where research on liquid crystals took place.

Plans for the construction of a new institute started to materialize in 1924 after Svedberg's return from the US. They were described in 1926 in a request to the faculty to secure funding in the budget year 1927 – 28 for a grant of SEK 1.2 million to construct a new physical chemistry laboratory. The requested sum was granted by the Swedish Parliament at the beginning of 1927. Work on the new institute started in 1928 and construction took place from 1928 to 1931. It was built right next to the 1904 Chemical Institute with connecting corridors in between. One of the main driving forces behind the detailed layout of the new institute was Yngve Björnståhl, a former student of Svedberg. The building's design was extremely efficient and flexible for all types of physical experiments. For many years it served as a model for similar constructions all around the world. It is described in detail by Yngve Björnståhl in the book "The new Laboratory of Physical Chemistry at Uppsala University" (1934). One important part of the new institute was its well-equipped mechanical workshop which had a large staff and excellent equipment. One unusual feature was a "calculation department" where seven people performed data processing tasks more or less manually; tasks which nowadays are exclusively performed by computers. Svedberg's institute grew quickly in size and until it could accommodate more than 100 people working there simultaneously.

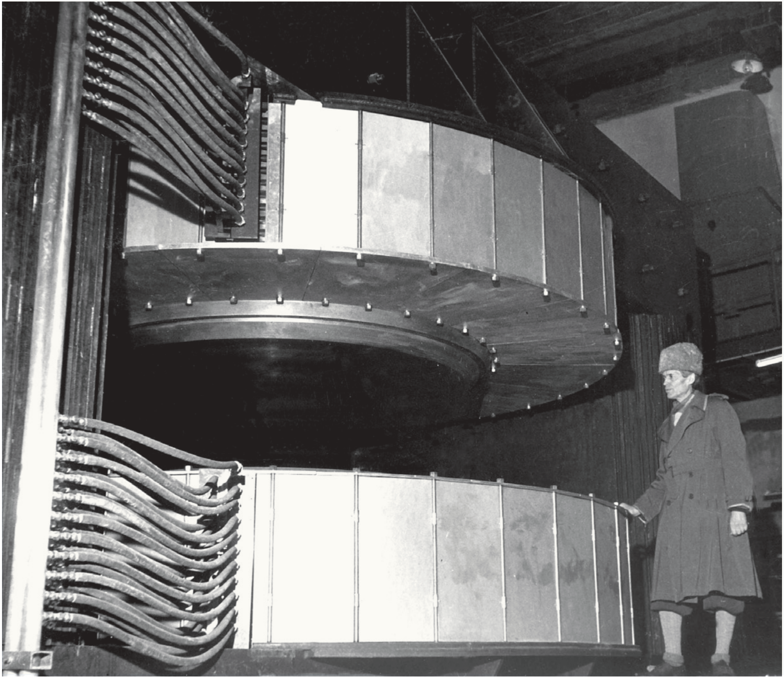


The cyclotron in operation with experimental installations. (Gustaf Werner Institute archives)

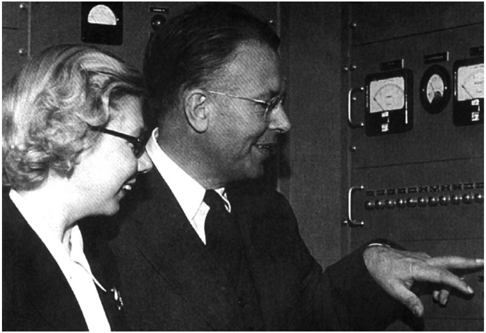
The Svedberg showed an early interest in radiation research using UV-light, X-rays and particle beams for various studies in the fields of chemistry, biology, medicine and physics. In particular he wanted to find out how various forms of radiation interacted with proteins. This launched a whole new field and revealed important and unexpected effects. His initial interest was using particle beams for the production of radioisotopes for medical use. One of his students, Helge Tyrén, constructed a neutron generator for this purpose in the late 1930s. But Svedberg wanted something better and planned for an accelerator capable of 20 MeV. When Helge Tyrén was in the US in the early 1940s he was asked by Svedberg to get the latest information on the new accelerator technology. Together they decided to construct a synchro-cyclotron for energies of about 200 MeV. Funding



An aerial view of the pit that was digged out to put the cyclotron in. Photo taken 5 april 1947. (Uptecknaren, nr 3 1986, Teknikum)



Svedberg in front of the cyclotron magnet under construction. (Gustaf Werner Institute archives) was provided by Gustaf Werner, a textile magnate in Gothenburg, and with some additional financial support, their plans were realised. The Gustaf Werner Institute for Nuclear Chemistry was inaugurated by Crown Prince Gustaf Adolf of Sweden on 8 December 1949, and the recently retired The Svedberg became Director of the institute, a position he held until 1967. On 8 December 1951, the inventor of the cyclotron, Nobel Laureate Ernest O. Lawrence, pressed the start button on the new synchro-cyclotron. The accelerator-based research carried out using this machine has been extremely fruitful and has included pioneering investigations at intermediate energy levels, proton therapy and neutron applications.



Mrs Margit Svedberg observing Ernest O. Lawrence press the start button (left). Crown Prince Gustaf Adolf and The Svedberg at the inauguration of the Gustaf Werner Institute (right). (Gustaf Werner Institute archives)

Svedberg pioneered academic-industrial collaboration

Svedberg had a strong interest in the relationship between applied and basic research. He understood the role of intuitive, unconditional research and that the most important discoveries are those that are least expected. He notes a number of examples on the theme stating: "The ability to see the unexpected is a rare gift." A classic example is Newton's discovery of the law of gravity (as the Swedish poet Kjellgren expressed it: "You who in the apple's fall found the laws for stars"). Other examples include Raman's discovery of the effect that bears his name when he noted the blue opalescence of the Mediterranean Sea, the discovery of noble gases by Lord Rayleigh, the discovery of radioactivity by Becquerel and Chadwick's discovery of the neutron.

Svedberg notes that "basic and applied research must be carried out simultaneously," arguing that it is just as important for basic research to be able to develop freely as it is for organised, target-oriented research to be pursued.

On the subject of how research is organised he argues strongly for teamwork. He notes:"Objections have been raised against team research here in Sweden on the grounds that Swedes are poorly suited to working in this manner; they are individualists and prefer to work alone." Citing his own positive experiences of organising teamwork in academic environments, he expresses his strong opposition to such views.

Svedberg started reflecting on the uses of science early on. In 1918 he published a collection of scientific essays under the title "Research and Industry" and, even at this early date, he presented his views on the importance of science for industrial development. His preface stated: "The technical application of scientific results has enabled us to increase enormously our production of goods, in fact our whole material civilisation is based on it. We must clearly realize that research and industry ……. are both equally important to us." He expressed clear views about scientists' collaboration with industry, arguing that contacts should not be limited to occasional consultations, but that there should be a continuous joint effort between basic and applied research and industrial production. Among the multitude of contacts he had with industry, a few should be mentioned in particular.

In 1938, this academy (IVA) together with the Federation of Swedish Industries (Sveriges Industriförbund) appointed a committee for the advancement of technological research. The committee included Svedberg and made many of his ideas its own. The committee, called the Malm committee after its chairman, was one of the most successful governmental committees. One of its achievements was the creation in 1942 of the first research council in Sweden, the Technical Research Council. Svedberg was one of its members and played a very significant role there until 1957, when, at the age of 73, he resigned. (The council continued its activities under the names the Swedish Board of Technical Development and VINNOVA.)

Svedberg's concern about the role of science in society, the development of industry, the role of science in warfare and the misuse of research results is clearly expressed in a lecture entitled "The aims and the means of research," delivered at the inauguration of the Höganäs-Billesholm AB research laboratory in Sweden in 1947 (and published in Swedish in IVA 18, 127-133 (1947)). Many of the issues raised are still discussed frequently today, showing that here, as in many other ways, Svedberg was well ahead of his time.

Svedberg was one of the first in Sweden to establish organised cooperation with industry. By around 1940 he had already put in place an effective collaboration between his institute and the Swedish cellulose industry. Both basic and applied research projects were organised in such a way that his institute served as the centre where both equipment and theories could be tested on real world problems. It was also a means of bringing in essential monetary resources for the institute. This cooperative undertaking lasted well into the 1970s when the cellulose laboratory connected to the Royal Institute of Technology (KTH) in Stockholm took over.

Sometimes more intimate partnerships were formed. In one case, three industrial companies built a joint research laboratory on the basis of Svedberg's research and modelled it closely on Svedberg's institute. The laboratory, headed by a Svedberg collaborator and located in Stockholm, could be considered a branch of the institute. In 1943 the laboratory developed into the company LKB-Produkter AB. (The name is an abbreviation of the three main companies: Liljeholmens, Kema, Bryggerierna.) The company, which mainly produced instruments for laboratories and medical applications but was also active in food technology and pharmaceuticals, was founded on research conducted at Uppsala University by Svedberg, his younger colleague Arne Tiselius and others. Their work led to several separation methods.

Many Swedish industries contacted Svedberg once the new institute was up and running; in particular the cellulose, rayon fibre, fat and soap, drug, brewing and synthetic resin industries. It was also well known that the doors of the institute as well as Svedberg's home in Uppsala were always open to leaders of industry. Collaboration was particularly intense during the period of isolation due to the war. One product that was attracting a lot of attention at the time was synthetic rubber. Since Sweden has no natural rubber, it was necessary to produce synthetic alternatives. Svedberg opened his institute for experiments on the production of neoprene and much of the work at the institute was devoted to this issue. This was matched by basic research in the area. Industrial production began near Sundsvall in central Sweden based on development work conducted at the institute. This Swedish oil-resistant rubber was named Svedoprene after Svedberg.

Svedberg's broad range of talents

The Svedberg had many interests outside of his main scientific profession. His fondness for botany began when he was a boy and stayed with him throughout his life. Over the years he published several scientific papers in the field. As a gift from friends on the occasion of his seventieth birthday he received a trip to Greenland, a part of the world that he had never visited before. He was able to pursue his interest in the northern hemisphere and study and photograph various plants, especially those that indicated possible connections between continents long ago.

Photography was another field in which he had a keen interest. In addition to being an active photographer, he assembled an impressive library which focused in particular on the early development of both the technical equipment and the chemistry involved in the photographic process.

Svedberg had a profound interest in culture which was all-encompassing, with the exception of music. He loved literature and had an extensive library of works by Swedish and foreign authors. He was especially interested in poetry and had a fine collection which included French poetry. He published papers in several languages. During his final years after leaving Uppsala, he enjoyed re-reading much of the classical literature. During his later years Svedberg gave the impression of having an artist's mind. This lay deep within him and he was a skilled painter. He even designed two magnificent patterns for commercial textile prints: Atomics and Genetics, tying in with the theme of the modern development of biology and physics. In a sense Svedberg's whole approach to science was very much that of an artist who was seeking broad, essential truths – perspectives that open into new horizons.

Svedberg in front of his textile print Atomics. (Gustaf Werner Institute archives)

References

T. Svedberg, *Die Existenz der Moleküle. Experimentelle Studien.* Leipzig: Akademische Verlagsgesellschaft. 1912.

T. Svedberg, *Forskning och industri. Naturvetenskapliga essayer.* Stockholm: Hugo Gebers Forlag. 1918.

T. Svedberg. *Colloid Chemistry.* Wisconsin lectures. (American Chemical Society Monograph Series No. 16.) New York, 1924.

T. Svedberg, K. O. PEDERSEN. *The ultracentrifuge.* Clarendon Press, Oxford, 1940.

S. Claesson and K. O. Pedersen: *The Svedberg. 1884–1971,* Biographical Memoirs of Fellows of the Royal Society, Vol. 18 (Nov., 1972), pp. 595-627.

Hedvall, J. A. 1944. *Från Nya Kemikums första tid. In The Svedberg 1884 30/8 1944.* Uppsala: Almqvist and Wiksell, pp. 681-725.

Brohult, S. and Gralen, N. 1944. *The Institute of Physical Chemistry at the University of Uppsala. Some notes on its history and activities. In The Svedberg 1884 30/8 1944.* Uppsala: Almqvist and Wiksell, 623-638.

Sundelof, L.-O.(1999) *'THE SVEDBERG', Journal of Dispersion Science and Technology,* 20: 5, 1289–1294.

Rånby, Ed. *"Physical Chemistry of colloids and Macromolecules"*, Blackwell, Oxford, 1987.

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