Nobel Centennial Essays

A Century of Chemical Dynamics Traced through the Nobel Prizes

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1903: Svante Arrhenius

by J. Van Houten

Nobel Prize in Chemistry 1903
Svante August Arrhenius (1859–1927)

in recognition of the extraordinary services he has rendered to the advancement of chemistry by his electrolytic theory of dissociation

This is the second of a series of 13 articles about Nobel laureates in chemical dynamics; the first discussed Jacobus van't Hoff's contribution to our understanding of the nature of molecules in solution and to the study of solution-phase reaction dynamics (*1*).[W]

Svante Arrhenius won the Nobel Prize in 1903 for his electrolytic theory of dissociation, which extended van't Hoff's ideas about the nature of molecules in solution into the realm of aqueous salts, and acids and bases. However, Arrhenius's ionic dissociation theory was initially considered quite controversial, and his 1884 doctoral dissertation, *Recherches sur la Conductibilité Galvanique des Électrolytes* (Investigations on the Galvanic Conductivity of Electrolytes) received the lowest possible passing grade, "not without merit", at the University of Uppsala (*2*).

Svante Arrhenius was the first Swede to win a Nobel Prize in any field. Although he was recognized for his electrolytic theory of dissociation, his name is most familiar to modern chemistry students because of its association with a definition of acids and bases and through the equation that relates reaction rate constants to activation energies and temperature. Both of Arrhenius's contributions, the electrolytic theory and the activation energy concept, are important to the development of the concepts of chemical dynamics.

Arrhenius studied with Jacobus van't Hoff and with Wilhelm Ostwald (whose work that received the 1909 Nobel Prize will be described next in this series). The 1901 Nobel presentation speech for van't Hoff included a hint regarding the connection between the work of van't Hoff and Arrhenius with references to "other investigators, including those in our country [Sweden]" (*3*). The mention of other investigators in the presentation speech for van't Hoff shows that the connections between the work of van't Hoff and Arrhenius were recognized in 1901. The notion of ionic dissociation had been described qualitatively much earlier by another Swedish scientist, Jöns Berzelius (1779–1848). Although Berzelius died eleven years before Arrhenius was born, the relationship between the work of those two Swedish chemists is implicit in the concluding sentence of the 1903 Nobel presentation speech for Arrhenius. It refers to Arrhenius as "the compatriot of Berzelius who rehabilitated the fundamental notion of his theory" (*4*). Based on the glowing references to Berzelius appearing in the Nobel citations for Arrhenius in 1903 and for Wilhelm Ostwald in 1909, one could hypothesize that the Royal Swedish Academy would have liked to award a Nobel Prize to Berzelius were there not a specific prohibition of posthumous awards.


Photo: Aaron Ihde collection

Svante Arrhenius

During his doctoral studies with Erik Edlund in Stockholm in the 1880s, Arrhenius began developing his theory of electrolytic dissociation while investigating the passage of electrical current through solutions. Arrhenius proposed that salts were ionized in solution and that the movement of those ions was responsible for carrying the electrical charge. Arrhenius's theory of dissociation showed why the freezing point depression of solutions of electrolytes were integer multiples larger than for non-electrolytes at the same concentration, and how the van't Hoff equation could be modified to apply to electrolyte solutions. That modification, which came to be known as the "van't Hoff *i factor*", extended van't Hoff's ideas about the nature of molecules in solution into the realm of aqueous salts and acids and bases, showing how van't Hoff's principles of chemical dynamics could be applied to ionic solutions.

Arrhenius is also remembered for extending his theory of ionic dissociation to solutions of acids and bases, giving us the well-known "Arrhenius definition" of acids and bases as substances that dissociate in water to form hydrogen ions and hydroxide ions, respectively. The Nobel presentation for Arrhenius continues by saying that his "theory also claimed that when an acid and a base react upon one another, water is the primary product and salt the secondary, and not reversely, as was then generally believed. Ideas so contrary to those current at that time could not be accepted immediately. A struggle lasting more than ten years and an enormous number of new experiments were required before the new theory was accepted by everyone"(*4*). Now, almost a century later, the Arrhenius definition remains as the first organizing principle of acid–base theory taught in all introductory chemistry courses.

The conclusion of Arrhenius's presentation speech recognizes the connection between the work of Arrhenius and that of his predecessors van't Hoff and Berzelius. "One of the most important consequences of Arrhenius's theory was the completion of the great generalizations for which the first Nobel Prize for Chemistry was awarded to van't Hoff. Without the support of Arrhenius's theory, that of van't Hoff would never have gained general recognition. The names of Arrhenius and van't Hoff will go down in history of chemistry as marking the modern period of this science and it is for this reason that the Academy, despite the fact that the experimental basis of the theory of dissociation belongs to physics, did not hesitate to award the Nobel Prize for Chemistry to Arrhenius (*4*).

Arrhenius was considered for the physics as well as for the chemistry prize in 1903. His 1903 Nobel presentation speech states: "During this long battle over Arrhenius's theory of dissociation tremendous advances were made in chemistry and ever closer links were established between chemistry and physics—to the great benefit of both sciences" (*4*). In 1905 the Royal Swedish Academy of Sciences established a Nobel Institute for Physical Chemistry with Arrhenius as its first chief (*4*). Arrhenius went on to become chairman of the Nobel Committee for Physics of the Royal Swedish Academy of Sciences, and in that capacity gave the presentation speech for Albert Einstein in 1921 (*5*) and for Niels Bohr in 1922 (*6*).

Arrhenius's interest in another branch of physics is illustrated by his theory regarding the effect of atmospheric CO_2 on climate. In 1908 he argued that the greenhouse effect from the combustion of coal and petroleum was warming the globe (*2*). This presages the 1995 chemistry Nobel Prize awarded to Paul Crutzen, Mario Molina, and Sherwood Rowland for their work in atmospheric chemistry.

The work for which Arrhenius was recognized with the Nobel Prize in 1903 is, of course, just part of his contribution to the study of chemical reaction dynamics. He is much better remembered today for the so-called "Arrhenius equation", $k = Ae^{-E_a/RT}$, first published in 1889 (*2*), which is so central to our current understanding of reaction rates in terms of activation energies and collision geometries. It remains at the heart of the teaching of chemical kinetics today, but Arrhenius's Nobel citation makes no mention of that aspect of his work. Of course he is not the only person to have won the Nobel Prize for something other than that for which he is now best remembered. Albert Einstein was awarded the physics Nobel Prize in 1921 "for his discovery of the law of the photoelectric effect" (*5*), not for the theory of relativity nor for the famous equation describing the mass-energy relationship, $E = mc^2$, that is now inextricably linked to his name. It is interesting that Arrhenius served as chairman of the committee that selected Einstein for the physics Nobel Prize; and it is ironic that both Arrhenius and Einstein are each best remembered for two theories that were not the subjects of their prizes.

[w]Supplemental Material

A list of all recipients of the Nobel Prize in Chemistry, their affiliations, and work for which the award was made is available in this issue of *JCE Online*.

Literature Cited

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