International Acclaim and Swedish Obscurity

The Fall and Rise of David Enskog

MATS FRIDLUND

INTRODUCTION

This essay deals with a figure who is peripheral to the history of Swedish physics, even though his research in the kinetic theory of gases, according to Stephen G. Brush, "amounted to a milestone in the modern development of the subject" and pointed out "the path to be followed by subsequent workers."[1] His name is David Enskog (1884–1947), and he formulated what came to be known as the Chapman-Enskog theory. He was the first to find a general solution to Boltzmann's equation and thereby solve what had been one of the central problems of the kinetic theory of gases for over 40 years.[2]

Early in his career, Enskog's work received little notice in Sweden, but eventually, thanks to the indirect and direct influence of foreign scientists, particularly the Englishman Sydney Chapman (1888–1970), his findings also gained recognition in his native country. Another major reason for the reevaluation of his importance was the application of his findings in the American atomic bomb program. This essay depicts David Enskog's scientific career and concludes with a discussion of the various factors that contributed to the Swedish reappraisal of his achievements.

RELIGION, ETHICS, AND PHYSICS

David Enskog was born in 1884 on a farm at Västra Ämtervik in rural Värmland in the west of Sweden, a province portrayed in many of the novels of the Nobel laureate Selma Lagerlöf. Enskog's father, Nils Olsson, had a small farm, but his main concern was religion, and he was active in the Swedish Missionary Society, a revivalist movement that had arisen in the late nineteenth century from divisions within the Lutheran state church.

Enskog's father had acquired his holding when as an itinerant preacher he met and married a farmer's daughter, Karolina Jonasdotter. David Enskog was the fifth of twelve children, and he grew up in a strongly religious environment. His father gave the children a strict and pious upbringing: for example, they were not allowed out to play on Sundays but had to stay indoors and read their gospels. The family was not at all well off, and three of the children emigrated. Two of the sisters followed the example of many other Swedes around the turn of the century in setting off to seek their fortune in America. Like so many of those voyagers, Enskog's sisters were children of a farmer whose holding was not big enough to support them all.

After six years at elementary school (folkskola) and two years at a voluntary continuation school run by a clergyman, David Enskog began work at fifteen as an assistant at the chemist's shop of the Värmland village of Sunne. The chemist soon noticed Enskog's ability and asked whether he had thought of pursuing further studies at secondary school (läroverk). Enskog replied that he was surely too old for that. He had gone right through elementary school and was therefore six years behind pupils of his own age at secondary school.[3] But after the chemist had promised to help him, "it was decided" that Enskog would sit the entrance examination.[4] He received help from his father, who was however obliged to take a bank loan, and from the chemist, who gave him textbooks and let him sit and study in the shop during the summer.[5] During this summer Enskog crammed in four years of the syllabus, and in the autumn of 1900, he took and passed the fifth-year examination of the nine-year secondary school in Karlstad. Studying at secondary school meant that he could no longer live at home on the farm, but his father's free-religious contacts enabled Enskog to find accommodation with the children of a landowner who provided school lodgings in Karlstad. He began on the classics side, which represented the standard educational ideal. It was the largest course program at secondary school and the traditional choice of those planning to go on to university. However, after only one term, Enskog changed over to the modern side, with its more scientific subjects. After his first year at school, he used the next two summers for further private study, completing the last four years of the syllabus in two years. In 1903, after only three years at secondary school, he passed the matriculation examination, obtaining the highest possible marks in mathematics and physics. The speed of his school career was a record for the province, and when Enskog left for Uppsala University later the same year, he was regarded by his fellow-students in Karlstad as obvious professorial material.[6]

At Uppsala the young David Enskog felt that he had come to "a veritable *embarras de richesses*."[7] Uppsala was admittedly a small town, but it was dominated by the students and their traditions. Students from different parts of the country had their own clubs, known as "nations." These were the scene of organized banquets with formal speeches but also of more unrestrained jollifications at which the singing was hearty and the arrack punch flowed freely. For Enskog, whose spare time had previously been largely taken up by activities of a religious character, such as prayer and temperance meetings, this must have necessitated quite a mental adjustment. Abstinence from liquor and worldly pleasures was a fundamental tenet in dissenting circles, and Enskog had when younger been an active member of a blue-ribbon association that sought to convert people to teetotalism.[8] But now he took part in the life of his nation, being for a year the treasurer of the Värmland nation, and for a while also the leader of its community singing. The social setting, too, must have been a contrast: sons of farmers and artisans were a small minority among Uppsala students, barely a tenth, and this gave Uppsala more of an upper-class image than Sweden's other ancient university, Lund.[9]

All the same, the greatest attraction to Enskog was not student life but the freedom to find his way in a new world of learning and sources of knowledge. Now that he was released from the tight rein at home and from the religious environment in which he had grown up, he was at liberty to choose what he wanted to study. Here in Uppsala, he wrote in his diary, "[I] am allowed to *think* about everything and that puts things in a new light."[10] He made use of the great opportunities offered by the university, easing up on the pace of study that he had maintained at school and reading "widely and deeply" without keeping strictly to his examination syllabus.[11] In addition to various scientific subjects, Enskog chose also to study philosophy, writing in his diary:

> How manifold are the different opinions on life's most important questions, on the cosmos and its genesis and purposes. What is one to believe? Reason cannot plumb the secret depths, intellect cannot even grasp the foundations of knowledge. I may think that Christianity is the highest of religions, I may see that Christ rises immeasurably above all other giant figures, his morality may be based on a more highly developed standpoint than the most modern ethical systems, I know of no flaw in him, yet I cannot help lacking Luther's steadfast belief. My humble intelligence wants to play its part and to weigh everything in the balance, and when I feel most certain in my belief, there imperceptibly arises a little doubt. And then another, and a third, and soon my whole soul is in tumult.[12]

These reflections caused Enskog's religious belief "to be shaken to its roots."[13] Finally his doubts grew so strong that he renounced his Christian

faith. After this he felt that life had lost its charm; even nature was no longer beautiful.[14]

But after a while, Enskog discovered a new doctrine in the Norwegian dramatist Henrik Ibsen and his play *Brand*, first published in 1866. The consistent theme of this play is that every individual must stand up for what he believes in its entirety. One should not submit to what is considered proper simply to make life easier; one should live without the slightest compromise with one's conscience.[15] Enskog wrote that *Brand* came into his hands "as if sent from heaven" and for Ibsen, he felt "an aesthetic and ethical admiration for his whole life. That is how a life should unfold."[16] Ibsen's ethics were an ideal of many young people at this time. These cultural radicals criticized the prevailing bourgeois double morality and were also associated with a new world view based on scientific theories rather than religious doctrines or philosophical systems.[17] Enskog resolved to live a totally uncompromising life, making no concessions on matters of principle. But he soon discovered that this was a practical impossibility that made neither him nor anyone else happier.[18] "I finally realized that the route I had chosen was not the right one," he wrote.[19] Enskog gave up his attempt. "What is one to believe?" he had wondered earlier. He had now tried and rejected both "Christ" and "the most modern ethical systems." The only faith that remained unshaken was in science.

After four years study, Enskog finally took his bachelor's degree in mathematics, mechanics, astronomy, chemistry, and theoretical philosophy in 1907. Most students at the university considered their goal achieved when they obtained their first degree, but for those who were interested in an academic career, the route led on to a licentiate and then a doctorate. The doctor's degree opened the door to a docentship and the start of a university career or, for those who left the path of research, a post at one of the provincial secondary schools. In the autumn of 1907, Enskog began to read for his licentiate in physics.

Physics research enjoyed high status at Uppsala during this period, and the subject was regarded as one of the most important at the university, as is illustrated by Rector Henrik Schück's letter of invitation to the inauguration of Gustaf Granqvist (1866–1922) as full professor of physics in 1910, in which Schück stated that this subject, more than any other, had recently made "Uppsala's name known and respected abroad."[20] At the turn of the century, the department of physics at Uppsala was the largest and most important in Sweden. It had long been the seat of a strongly experimentalist "dynasty," with a succession of prospective professors trained by their predecessors in the post. They had all been experimentalists, unlike their colleagues in Lund or Stockholm. The international reputation of the department rested primarily on the research of its "patriarch," Anders Ångström (1814–1874), in the field of spectral analysis, which had led to a unit of length (10^{-10} m) being given his name.

When Enskog had to decide on a subject for his licentiate's thesis, he turned to Granqvist, a strong representative of this experimentalist tradition. And it was in this environment of measurement and instrumentation that Enskog received his first training in physics. For his thesis he chose to carry out an experimental study of gas diffusion, a subject that was not among Granqvist's own fields of research. Enskog, who was "decidedly speculative and analytical,"[21] seems on this account to have clashed with Granqvist, a physicist with no feeling for "bold and daring conceptions."[22] According to one of Enskog's fellow-students from his Uppsala days, Granqvist considered that Enskog had approached the problems far too theoretically.[23] However, Enskog's thesis, *Studier öfver vattenångans diffusion vid olika tryck* [Studies on the diffusion of water vapor at different pressures], was passed in 1911.[24] But in the meantime, he had decided that he would abandon the path in experimental physics along which he had set out and instead devote himself to research in theoretical physics.[25]

OUT IN THE COLD

Then, as now, it was considered virtually essential for a budding Swedish physicist to study abroad at various European universities both to gain knowledge and to forge links with foreign scientists working in the same fields. Enskog therefore tried to obtain a travel scholarship, but in vain.[26] During his time in Uppsala, he had in part financed his studies himself with bank loans, but he had also received grants from the university and support from his student nation.[27] The various nations helped their impecunious students both by reducing the fee for nation membership and through their benevolent societies, which granted short-term loans and premiums. Enskog had often borrowed from his nation, and he was allowed to pay a reduced membership subscription throughout his time at Uppsala.[28] But this was insufficient to finance his further studies, and he was now obliged to leave the university and find employment.[29]

The traditional resort of those unsuccessful in making an academic career was to look for work as secondary school teachers, but for physicists and chemists there was a new alternative: a job in one of the new industrial laboratories.[30] Enskog considered this possibility,[31] but finally opted for teaching. In 1913, after completing a probationary year in Stockholm, he obtained a temporary post as a teacher of mathematics and physics at a municipal *gymnasium* in Skövde, then a small town of just over 7,000 inhabitants.

Regular employment meant that he could now afford to start a family. While still in Karlstad, he had met Anna Jönsson, one of the daughters of the school household in which he had been lodging. They had resumed their acquaintance towards the end of Enskog's time at Uppsala, and although her nonconformist parents disapproved of Enskog's free-thinking, they married in 1913. During Enskog's period as a secondary school teacher, the couple had two daughters, Birgit and Ulla, and a son, Björn.

Enskog enjoyed his job as a teacher, but he had not abandoned his research. However, this had to be done in his own time: in the evening when his pupils' books had been corrected, at weekends, and during the summer holidays. He had decided to write his doctoral thesis for the professor of mechanics and mathematical physics at Uppsala, Carl Wilhelm Oseen (1879–1944). While still a licentiate student, Enskog had published his first work on the kinetic theory of gases, and he now explored this subject in more depth.

Almost 50 years earlier, in 1866, James Clerk Maxwell (1831–1879) had derived equations to describe the state of a non-equilibrium gas. Using these equations of state for a specific molecular model, he was able to calculate values of various transport coefficients, such as thermal conduction and viscosity, in a gas. However, this model was valid only for one of all the possible force laws that could apply to real molecules of gas. To be able to make corresponding calculations for a more general molecular model, it was necessary to know the expression for f, the velocity distribution function of the gas molecules, which depends on the forces between the molecules. Five years after Maxwell, Ludwig Boltzmann (1844–1906) succeeded in deriving the integro-differential equation that a correct f must satisfy. From this equation it was also possible to derive Maxwell's formulae. But Boltzmann, too, found that the solution of his equation was possible only for the same specific force law—for all others it became so complicated that he almost despaired of ever achieving a general solution.[32] Different scientists, using different methods of calculation, had obtained a number of irreconcilable values for the coefficients. This was one of the fundamental problems of gas theory at this time: finding a method of resolving Boltzmann's equation, which, given the general assumptions concerning molecular forces, enabled practical values to be deduced for the different coefficients.

This was the problem that Enskog had set about solving. Most contemporary physicists thought that research in kinetic theory "would probably be fruitless until . . . the quantum theory had been established and applied to the simpler problems of atomic structure."[33] In the first of his two previous papers, Enskog had tried to find a general expression for f, but without success.[34] The second paper was a more detailed treatment of diffusion in gases. Here he showed for the first time the existence of a previously unknown physical phenomenon in gases,[35] later given the name "thermal diffusion," viz., that if there is a temperature gradient in a mixture of two gases, there will be a separating force between the gases. Enskog deduced the existence of this force, but without laying any great emphasis on it.[36] In a later paper, he also calculated the coefficient of thermal diffusion, but both of these achievements passed unnoticed.

A breakthrough in Enskog's research came in 1912, when the great mathematician David Hilbert (1862–1943) published a paper, "Begründung der kinetischen Gastheorie," in which he applied his mathematical theory of integral equations to the kinetic theory of gases.[37] Hilbert's treatment did not produce a generally valid expression for *f*, but the mathematical approach showed Enskog that "from the theory of integral equations the logical structure of the gas theory follows naturally,"[38] and that the solution of Boltzmann's equation could be reduced by an approximation method to the solution of a system of integral equations. Modifying Hilbert's method, Enskog succeeded in 1915 in obtaining an expression for *f* that satisfied the Boltzmann equation.[39] By then developing a new mathematical method of solving the component integral equations, he finally managed to solve Boltzmann's equation and derive formulae for the coefficients of viscosity, thermal conduction, and diffusion of any moderately dense gas. This theory, unlike previous ones, made it possible to carry out these calculations for general molecular models.[40] Enskog completed most of the calculations during the summer holidays of 1915, corresponding at the same time with Oseen, who commented on his findings and his design. Oseen, who had begun his career as a mathematician, had a highly developed critical faculty, particularly when it came to what he regarded as "mathematical imperfections."[41] In his comments on Enskog's results, Oseen found fault on the grounds that Enskog's findings were not adequately justified mathematically:

> As far as the matters of physics are concerned, all the results obtained appear to me interesting, if they are reliable [. . .] Is it now certain that all the terms that appear in your calculations have a real significance? Is it in other words certain that the function [*f*] which is sought can be developed in a series of the type assumed? But however fundamentally important I may consider this question, and however much I may advise that everything be done to demonstrate the correctness of the assumptions made, I would nevertheless conclude by saying that I do not regard it as impossible to defend the study in question, even if the difficulty cannot be overcome.[42]

The following year, Enskog devoted the summer holidays to writing his doctoral thesis. As the date for defending it approached, Oseen wrote that he did indeed still have matters that he would have liked to discuss, but that he could not now do this. This was partly because he was to be the principal opponent at Enskog's disputation, but the main reason was to avoid delaying the publication of the thesis, concerning which Oseen wrote: "[One may] at any time expect publication of the Hilbert-Hecke textbook on gas theory, which must surely contain much of what appears in your doctoral thesis."[43] Had they "been free from all such extraneous considerations," Oseen would have asked Enskog to come to Uppsala to discuss the thesis in greater detail, but, he continued, "as I see the matter now, we will therefore postpone this discussion until the disputation."[44]

This took place at Uppsala University on April 14, 1917, when Enskog became the first of Oseen's doctoral students to defend a thesis. In his thesis, *Kinetische Theorie der Vorgange in massig verdunnten Gasen*, Enskog had not proved that the mathematical process that he used to deduce his physical results converged, i.e., that it yielded finite-limit values. Enskog excused this by saying, "A similar gap occurs in all earlier writers in the same field. The physicist does not attach excessive importance to this point."[45] Enskog was not one of the many mathematical physicists in Sweden who placed greater emphasis on the elegance of the mathematical analysis than on the physical interpretation of the phenomena.[46] With his training as an experimental physicist, his main aim, notwithstanding his advanced mathematical treatment, seems to have been to deduce results that physicists could use in practice, and the physical credibility of the theories appears to have had priority over the mathematical.[47] He was surely also expressing something of his own attitude when he later wrote of another physicist that if "a thing seemed to him physically evident, he had no great scruples about dispensing with the mathematical proof."[48] Enskog had assessed the correctness of his theoretically calculated values by comparing them with earlier experimentally determined ones and had found that they agreed satisfactorily. But this physical verification had evidently not been enough for one of Oseen's critical disposition. Oseen later wrote with reference to the findings in the thesis that if Enskog:

> [. . .] had been able to prove that the process of calculation, to which his approach gives rise, is convergent, he would have solved the problem of the theory of gases. But he has been unable to do this. It is as true of his method as of the pre-Hilbertian methods, that for the main question of all, the possibility of reaching the desired solution by using the calculating process, one has to rely on pure faith.[49]

The disputation was graded by the professors of the department of mathematics and science, including Granqvist and Oseen. The latter, who had the task of assessing the thesis, found Enskog's complex treatment of

The inhabitants of the boarding school of Johan Jönsson. David Enskog is standing in the middle of the back row. In the middle of the front row sits the maid who took care of the household. To her left, Anna Jönsson, later to become Mrs. Enskog. (Photo: Ulla Fornander Collection)

the problem obscure and difficult to grasp,[50] and recommended the grade *Cum laude* (2 out of 3) for the composition of the thesis.[51] Enskog was given an even lower grade for the defense, *Non sine laude* (1½ out of 3). These grades were far too low for a docentship, the essential first step in an academic career.

When Enskog was to be presented with his degree in May of the same year, he at first felt that he could not afford to travel to Uppsala for the

ceremony, partly because he would have to wear a dress suit.[52] Hearing of this, his landed father-in-law, Jönsson, sent him money. Having gained his doctor's degree, Enskog could now obtain a permanent teaching post, and the next year he was appointed *lektor* (senior master) in mathematics and physics at the *Högre Allmänna Läroverk* (state grammar school) in Gävle.

IN FROM THE COLD

After the disputation in 1917, Enskog made his first approach to the Englishman Sydney Chapman, sending him his thesis. Chapman had started work on the same problem in kinetic theory as Enskog in 1911 and had published three papers with a solution to the problem in 1915–1917.[53] With this he succeeded, at the same time as Enskog and independently of him, in calculating and stating numerical values for the different coefficients. However, in one of his papers, Chapman said:

> To comply with the requirements of the pure mathematician, the results should be proved to be in conformity with Boltzmann's equation. Progress has already been made in this direction [. . .] As the insertion of these would be unsuitable in memoirs intended primarily to deal with questions of physics, they are reserved for a future paper.[54]

This was because Chapman had followed the method of Maxwell, whose calculation of the coefficients was not dependent on knowing the *mathematical* function *f* derived from the solution of Boltzmann's equation as in Enskog's method. Instead Chapman found them indirectly by using values of different *physical* quantities that could be approximately calculated without knowing *f*.[55] When Chapman began to study Enskog's thesis, he realized that they had reached almost identical physical results with their two different methods. Chapman wrote to Enskog in July 1917 that he was now abandoning all efforts to produce a "rigorous justification" of his method, which had been "more intuitional and less rigorous than in your own elegant analysis."[56] Chapman added that:

> . . . it is very clearly seen how my analysis can be related to yours, on the rigorous foundation which you have built up on the Boltzmann integral equation [. . .] [Boltzmann's equation], I have all along realized, is the only sure foundation from a mathematical standpoint, but until reading your paper I did not see how it could lead to a simple general solution.[57]

Chapman finished his letter by saying that if he wrote any more on this subject it would be in the form of a general treatise on the mathematics of the kinetic theory "from our joint standpoint."[58]

In the years that followed, foreign interest in Enskog's findings began to be noticed in Sweden. This interest first showed itself in the numerous letters received by Uppsala University and Oseen from foreign physicists and universities enquiring about Enskog's thesis. Enskog had supplied the university with 330 copies of the thesis when he defended it in 1917,[59] but in a letter to Enskog barely three years later, Oseen regretted that he had only one copy left and therefore had to ask Enskog himself to satisfy the latest request that Oseen had received for the thesis.[60] A more explicit expression of foreign approval came in the complimentary references to Enskog's work in the third edition of James H. Jeans' *The Dynamical Theory of Gases* in 1921.[61]

Later the same year, a continuation of Enskog's thesis was printed in one of the publications of the Royal Swedish Academy of Sciences.[62] Before deciding to publish, the Academy had asked Enskog for a summary of the contents. He took this opportunity to add extracts from letters that he had "received from prominent scientists on the first part of the work."[63] These included the letter from Chapman, quoted above, expressing admiration for Enskog's results. It was Chapman who had earlier seen to it that Jeans was made aware of Enskog's thesis, and Enskog now quoted from the letter he had received from Jeans, congratulating Enskog on his "success in this difficult problem."[64] A third letter came from Arnold Sommerfeld, perhaps the best versed in mathematics of the physicists of the period, who praised Enskog for solving the problem that had defied the efforts of his compatriot Hilbert: "As far as I can see you have really accomplished what Hilbert intended."[65]

This second part of Enskog's thesis consisted largely of an account of the many calculations that lay behind the different formulae, but at the end of his paper, he also mentioned Chapman's results and compared them with his own. The comparison showed some errors in Chapman's results that affected certain formulae, but in all other respects, Enskog could state that their results were in agreement. Enskog also concluded this essay with a comment on the question of priority in the discovery of thermal diffusion. In one of his essays, Chapman had deduced the occurrence of the same physical phenomena as Enskog had first noted in 1911, and in 1916 Chapman had also seen to it that an experimental confirmation was carried out.[66] In the *Dynamical Theory of Gases*, Jeans had given Chapman the credit for this discovery.[67] Enskog therefore wrote:

> The assertion of Chapman and of Jeans [. . .] that I discovered the process of thermal diffusion later than Chapman is incorrect. I demonstrated its existence in 1911 (in an article which Chapman quoted in his very first work on gas theory). In 1912 I gave the exact value for the coefficient [of thermal diffusion] in a particular case.[68]

Alexander J. Dessler, in an article on Chapman's attitude to the Norwegian Kristian Birkeland and the Swede Hannes Alfvén, has asserted that Chapman was "influenced by typical Victorian, British insular feelings regarding continental Europeans that kept him from giving fair consideration to their ideas."[69] However, this does not seem to be true of Chapman's reactions to Enskog's research, quite the reverse. In response to Enskog's essay, Chapman, now a professor in Manchester, wrote a letter to Enskog on December 23, 1921 saying he was:

> . . . very sorry that misstatements about your priority of discovery [. . .] have got into print, & I will see that the matter is [corrected] [. . .] I must either not have read it fully, or else completely forgotten the part about thermal diffusion [. . .] My own view about our work in general on kinetic theory is that we are entitled to roughly equal credit, and I personally don't care whereabouts the exact line is drawn. You began a little earlier than I did, and we both solved the problem only at our second attempt [. . .] So far as the theory is associated with our names at all, I think it should be on an equal footing, & so far as I can I will promote this in England.[70]

Enskog continued his research along with his work as a senior master. In 1922 he published an attempt to extend his theory to include dense gases and liquids.[71] With this theory, Enskog succeeded in explaining qualitatively a major difference between fluids and gases: that the viscosity of a liquid decreases as temperature rises. The viscosity of liquids was one of Oseen's particular interests, and according to him, this was "one of the most valuable results gained in kinetic theory in recent years."[72] In the 1920s Enskog's mathematical method of solving integral equations was also noted by mathematicians abroad. In 1922 Erich Hecke, a student and assistant of Hilbert who had helped Hilbert write his paper of 1912,[73] took up this "method based on a very simple and beautiful mathematical idea."[74] Hecke added that another reason for mentioning it was that "this work seems to be little known in mathematical circles."[75] However, the mathematician Hecke, like Oseen, considered that Enskog's physical results were of only heuristic value as the convergence of his process was not proved. A year or two later, Enskog attracted further attention among mathematicians when his method was included in the well-known *Methoden der Mathematischen Physik* of Richard Courant and David Hilbert.[76]

A travel scholarship from the Royal Swedish Academy of Sciences made it possible for Enskog to go abroad in 1922 and 1923 and undertake the studies in theoretical physics that he had been unable to carry out in his Uppsala days ten years earlier. This meant a lot to Enskog, who had felt isolated from modern developments in physics, and he wrote to a friend that he now had "a chance to renew acquaintance with science, which is badly needed after 10–12 years behind the teacher's desk."[77] At the secondary school, he had not had much time to think about the questions occupying "contemporary scientists."[78] He went to Göttingen and Munich and attended lectures by Niels Bohr, Hilbert,[79] Sommerfeld, Courant, and Max Born. This brought him into contact for the first time with the latest developments in atomic theory and the new quantum theory, and inspired by this,[80] he began on his return to do research in this "modern" theoretical physics. In 1928 Enskog applied to the Royal Swedish Academy of Sciences for the "greatest possible [financial] support" to continue his new research.[81] A committee of the academy, whose members included Oseen and Manne Siegbahn, responded by giving Enskog, instead of a grant, a prize in cash for his "contribution to the kinetic theory of fluids and gases."[82]

In 1929 Enskog requested a transfer to a secondary school in Stockholm, applying also at the same time for two vacant professorships in Stockholm: one in mechanics and mathematical physics at the Stockholm University College and one in mathematics and mechanics at the Royal Institute of Technology. At the Stockholm University College, the Swedish professors Torsten Carleman and Oseen, together with Niels Bohr and Arnold Sommerfeld, had been selected to give their opinions as experts. Enskog's fellow-applicants were Bohr's Swedish pupil, Oskar Klein, and Oseen's pupils, Ivar Waller and Hilding Faxén. The outcome was that Klein was given the professorship, and Enskog was placed third on the list behind Waller, after Faxén had withdrawn his application.[83] Several of the experts and the professors on the teaching staff at the Stockholm University College had recommended a representative of "modern" theoretical physics, such as Klein or Waller, rather than Faxén or Enskog, whose work was largely in "classical" theoretical physics. A typical observation was that of the professor of physics, Erik Hulthén:

> As matters have developed here in Sweden we find all the chairs in theoretical physics at our universities and institutes of technology occupied now or in the near future by representatives of classical physics. It seems therefore to me to be of some importance for the Stockholm University College to break with this tradition [. . .] Enskog's more sporadic contributions to the treatment of problems of atomic theory [seem] not to have the same lasting value [as those in kinetic gas theory].[84]

Nor did Enskog at first seem likely to enjoy any better luck with his application for the chair of mechanics and mathematics at the Royal Institute of Technology. For this post, too, Faxén was among the candidates. Faxén had defended a thesis that was an expansion of earlier work by Oseen and had subsequently held two docentships at Uppsala and been temporary professor at the Stockholm University College from 1927 to 1930. Enskog was aware of Faxén's impressive qualifications and had previously written to Chapman that he believed that the position would go to Faxén.[85] However, one of the three experts, Nils Zeilon (1866–1958), preferred Enskog to Faxén, partially on the grounds that Enskog had tackled more important and more difficult problems of theoretical physics and that as a mathematician he had produced "ideas of greater originality and independence" than Faxén.[86] Oseen, who was also one of the experts, referred to the interest that Enskog's findings had attracted overseas and praised his research into liquids. He pointed out that Enskog had done all his research on his own, while working as a teacher, which "very seldom leaves time and energy over for scientific activity."[87] But Oseen also stressed that Enskog had not succeeded in his intention of solving the fundamental problem of the theory of gases, and that his theory rested "on pure faith."[88] In his summing-up, Oseen wrote:

> Almost all Enskog's scientific work is subject to the usual fate of physical theories. It runs the risk of becoming obsolete as the physical hypotheses on the nature of matter change. And not only because of this. The greater insistence of a new generation on mathematical precision may also have this effect.[89]

At Stockholm University College, Oseen had made it clear that if the chair had been one of pure mechanics, and not mechanics and mathematical physics, only Faxén could have been considered.[90] But at the Royal Institute of Technology, conditions had changed, to Faxén's disadvantage, as a result of the trial lectures that had preceded the delivery of the experts' opinions. Enskog had come through these brilliantly, whereas Faxén had cut an unimpressive figure.[91] When it came to the final decision, Oseen was unable to give precedence to either Enskog or Faxén, and placed them both first. The third member of the expert panel, the professor of physics at the University of Helsinki in Finland, Hjalmar Tallqvist, put Faxén first and Enskog only fourth, one of his reasons being that Enskog lacked "independent work in mechanics proper," and another being that Enskog had no experience of teaching at this level.[92] In addition to Faxén's scientific output, Tallqvist attached great importance to his "experience and merits as a college teacher."[93] The choice was thus between Enskog and Faxén, each having gained two firsts.

Just over three months after these opinions had been made public, Sydney Chapman happened to come to Sweden to attend the general assembly of the International Union of Geodesy and Geophysics, which took place in Stockholm from 14–23 August 1930. Chapman was by now well known for his research in geophysics, and he had been a Fellow of the Royal Society since 1919. He used his foreign contacts to spread knowledge of Enskog's findings, and Chapman and Enskog had continued their correspondence since 1917. They now met for the first and only time, and one evening Chapman visited Enskog at his Stockholm flat.[94] When Chapman heard about the situation with regard to the professorship at the Royal Institute of Technology, he decided, as he later put it, to try "to influence the electors in favour of Enskog."[95] While in Stockholm he wrote a letter of recommendation for Enskog. It began:

> Having learned that Dr David Enskog is a candidate for a professorship, I would like to be allowed to express my high opinion of his mathematical ability, as exemplified by the distinguished researches which he has published during a period of many years.[96]

Chapman pointed out that Enskog's thesis had become "increasingly known and esteemed all over the world," and that his more recent work had "attracted much interest and attention" among many people engaged in research in atomic physics and quantum theory.[97] Chapman concluded his letter with something of a reproach to Sweden's physicists:

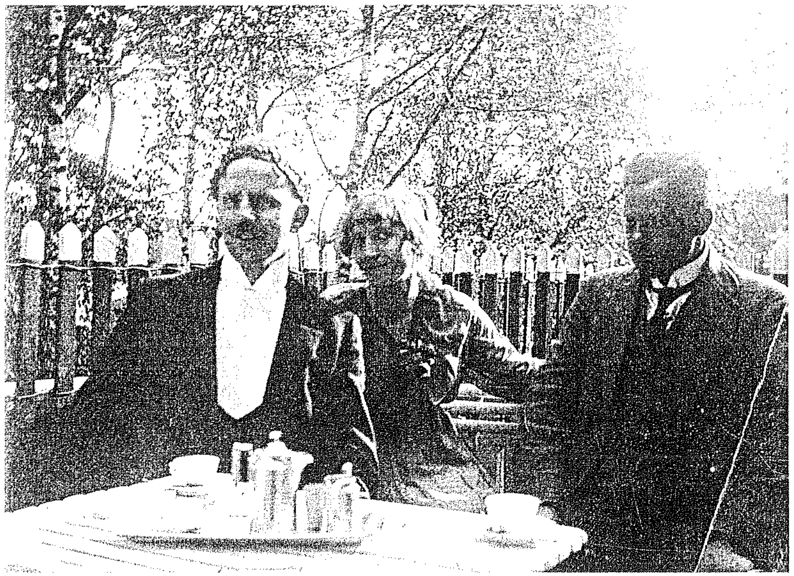
> I admire his work the more, from my knowledge that most of it was produced, not as the outcome of the leisure which is afforded by a university position or a research studentship, but in the midst of arduous teaching duties in school, with comparatively little leisure, &, to a great extent, without the intellectual stimulus given by contact with other men of science. For some years past I have cherished the hope that his proved capacity for original research of a high order might be recognized in Sweden by his appointment to some university chair in which his abilities might be more fruitfully employed. While recognizing that in Sweden there cannot often be vacancies among the university professorships of mathematics or mechanics, I have felt that there must indeed be a wealth of mathematical talent in competition with him if a mathematician so distinguished as he is be left to work so long under conditions in which the exercise of his best gifts is hampered. I sincerely hope that he may be successful in his present candidature.
>
> Sydney Chapman, F.R.C.
> Chief Professor of Mathematics in the
> Imperial College of Science & Technology,
> South Kensington, London.[98]

Enskog gave copies of this letter to two of the professors on the teaching committee of the Royal Institute of Technology, Gudmund Borelius and Henning Pleijel.[99] Both in the capacity of the subjects they represented—Borelius being professor of physics and Pleijel professor of electromagnetic theory—and as powerful personalities in general, these were two of the most important persons concerned in awarding the professorship. When the committee discussed the applicants, Borelius and Pleijel, together with the professor of mathematics Johannes Malmqvist, were those who argued most strongly in favor of Enskog. Enskog later wrote to Chapman that they had given "exhaustive speeches in my favor."[100] They also strongly criticized the negative verdict on Enskog delivered by Tallqvist and the great importance that Tallqvist attached to the applicants' university teaching experience.[101] When the teaching committee took its vote, Enskog received 21 votes and Faxén six. On December 12, 1930, David Enskog was appointed professor of mechanics and mathematics at the Royal Institute of Technology in Stockholm.

A PURE PHYSICIST APPLIED

As a newly appointed professor, Enskog's time was fully claimed by the preparation for and planning of his teaching—the extra time that Chapman had hoped Enskog would find for research did not materialize. The main duty of professors at the Royal Institute of Technology in those days was not to engage in research but to teach.[102] Enskog's teaching duties, the production of course material, and other tasks took all his energies. Just as foreign contacts had been important earlier in Enskog's career, so they were important to him now in his new role as a professor. One of his first acts as a new professor in 1931 was to set off on another study trip abroad, but this time to study the instruction in mathematics and mechanics given at various European institutes of technology.[103] Most of these were in Germany, which was at that time regarded as having the best engineering training. In this way the Royal Institute of Technology tried to keep abreast of international developments and to adopt what appeared worthwhile. One such innovation was a new degree course, mainly on German lines, for engineering physicists. This was started in 1932 by the professors in Enskog's section, the natural science section, all of whom were, unlike those in most of the other sections of the Institute, university-trained scientists.

In 1939, Sydney Chapman and Thomas Cowling (1906 —) published their monograph, *The Mathematical Theory of Non-Uniform Gases*, in which they developed a more general and extensive account of the Chapman-Enskog theory and of the determination of the coefficients of



David Enskog celebrating at an outdoor restaurant in Uppsala. He is wearing a dress suit and a laurel crown, the symbol of the Doctor of Philosophy. (Photo: Ulla Fornander Collection)

viscosity, thermal conduction, and diffusion. Throughout this book Chapman and Cowling used Enskog's method rather than Chapman's, and they even dedicated their work: *To David Enskog*. The book soon became the most widely used introduction to the theory of non-uniform gases and the Chapman-Enskog method for solving the Boltzmann equation, and it was later published in two new editions. When Enskog was elected to the Royal Swedish Academy of Engineering Sciences in 1941, he was proposed by Manne Siegbahn. Siegbahn referred to the international interest in Enskog's findings and in particular to Chapman and Cowling's "distinguished monography," emphasizing the great value that these two authorities in the field attached to Enskog's work.[104] Siegbahn also emphasized the new topicality that the kinetic theory of gases had acquired "in modern isotopic research" thanks to Enskog's results.[105] Chapman had suggested in 1919 that thermal diffusion might be used to separate isotopes of different elements, and in 1938 the German chemists Klaus Clusius and Gerhard

Dickel had developed a technical method, based on thermal diffusion, for the separation of gas isotopes.

In April 1946 the Royal Swedish Academy of Sciences awarded Enskog its Svante Arrhenius Gold Medal. After the Nobel Prize, this was the academy's highest distinction for physics, and it was awarded every five years to a Swedish or foreign scientist who had carried out "pioneering research" in physics or chemistry.[106] The medal was not actually due to be awarded again until 1949, but in March 1946, Ivar Waller (who had now succeeded Oseen at Uppsala) had proposed awarding it to David Enskog that very year. The reason for such a course of action was not explicitly stated, but the most probable explanation lies in the significant recognition that Enskog had received on account of the American atomic bomb. The year 1945 had seen the publication of the Smyth Report, the official U.S. report on the scientific work behind the development of the bomb. It mentions just one Swedish scientist: David Enskog. This description of the development of the mightiest-ever product of physics names Enskog, together with Chapman, as the discoverer of thermal diffusion, the basis of one of the technical methods used in the enrichment of the uranium that the atomic bomb required:

> The possibility of accomplishing practical separation of isotopes by thermal diffusion was first suggested by theoretical studies [. . .] Such studies made by Enskog and Chapman before 1920 suggested that if there were a temperature gradient in a mixed gas there would be a tendency for one type of molecule to concentrate in the cold region and the other in the hot region [. . .] The theory of thermal diffusion in gases is intricate enough; that of thermal diffusion in liquids is practically impossible. A separation effect exists, however, and has been used successfully to separate the light and heavy uranium hexafluorides.[107]

In justification of his proposal, Waller pointed to the importance attached to Enskog in Chapman and Cowling's "standard work," where "Enskog's methods [form] the basis of the exposition."[108] Waller concluded by drawing particular attention to Enskog's discovery of thermal diffusion and the way it had "in recent years been used in the separation of isotopes, including uranium isotopes,"[109] a direct reference to the Manhattan Project. However, this was not the only mention of the atomic bomb in connection with the Arrhenius Medal, and after the presentation at the Royal Academy of Sciences' annual dinner, Enskog also heard a speech by the secretary relating how the news of the atomic bomb was going to influence the work of the academy's Research Institute for Experimental Physics.[110]

Enskog had thus received several distinctions during the 1940s, but he still lacked the ultimate recognition from his peers: election to the Royal Swedish Academy of Sciences. Its physics section, which selected the winner of the Nobel Prize for Physics each year, contained Sweden's most influential and distinguished physicists. In 1947 they finally elected Enskog, once again proposed by Ivar Waller, to their number.[111] At a gathering of the academy on May 28, Enskog took his seat and was welcomed by the other members. This was Enskog's first and last meeting as a member of this august body. Three days later, riding on a tram to a lecture at the Royal Institute of Technology, Enskog felt unwell. He left the tram and went to his doctor, who sent him to the hospital. He died early the next morning, June 1, 1947.

DISCUSSION: STRATEGIES FOR SUCCESS IN PHYSICS

In conclusion, Enskog's career will be considered from a more socio-scientific and contextual perspective, making some use of the theory of symbolic capital developed by the French sociologist Pierre Bourdieu. *Symbolic capital* is made up of the social conditions and qualities that social groups recognize as valuable. Bourdieu's theory sees the scientist's career and actions as based on the need to accumulate various kinds of *educational capital* and *scientific capital*, which he can then convert, mainly with the aid of his *social capital*, i.e., his personal and professional connections and contacts, into different forms of *capital of recognition* and of *capital of scientific and academic power*.[112] The embodiment of the acquired symbolic capital is the *habitus*, the system of social dispositions and cognitive structures that exists in a person and generates his actions, perceptions, evaluations, and appreciations.

Against the background of this theory, it is possible to speculate that the slow progress of Enskog's career was due to his short time as a secondary school pupil and a graduate student, two of the most important periods in building up a person's social capital and shaping his *habitus* for a future academic career. The task of the secondary school was not only to give pupils an *educational capital* but also to provide them with a *cultural* and *social capital*; to nurture and to "shape youngsters into nationally conscious and Christian people."[113] This was mainly the education of the higher social strata, and it was in its essence a preparation for future higher education.[114] This preparation was something that Enskog largely missed, and for this reason, his *habitus* does not appear entirely in harmony with the environment that the secondary school was meant to prepare for, as may perhaps be illustrated by his abandonment of experimental physics. The strict and patriarchal Uppsala tradition that Granqvist maintained as head of the department and as a tutor may have led to tension between him and Enskog, a clash between two radically different types of *habitus*.[115] A person's *habitus* may in

> . . . certain social situations [. . .] be applicable and [he] feels "at home." In other contexts friction may arise, and in this case there are two alternatives. If the habitus is stronger, [the person] may to some extent transform the existing social conditions. If on the other hand the social conditions are stronger, either the individual may depart from the field or his habitus may gradually be modified. It should be added that it is not easy to remould a habitus [. . .] a habitus often survives the social conditions which have shaped it.[116]

The cultural radicals advocated a *radical educational ideal*, which saw education as a process of self-tuition, with the individual being responsible for acquiring knowledge, in contrast with the previously dominant *patriarchal educational ideal*, which placed responsibility for education on the teacher and saw knowledge as something received passively and without reflection.[117] A further indication that this may have contributed to Enskog's abandonment of experimental physics lies in Enskog's choice of topic for his thesis, which was, in Bourdieu's terminology, a typical *subversion strategy*, characteristic of rebels against the established academic order:

> Depending on the position they occupy in the structure of the field (and also, no doubt, on secondary variables such as their social trajectory, which governs their assessment of their chances), the "new entrants" may find themselves oriented either towards the risk-free investments of *succession strategies*, which are guaranteed to bring them, at the end of a predictable career, the profits awaiting those who realise the official ideal of scientific excellence through limited innovations within authorised limits; or towards *subversion strategies*, infinitely more costly and more hazardous investments which will not bring them the profits accruing to the holders of the monopoly of scientific legitimacy unless they can achieve a complete redefinition of the principles legitimating domination: newcomers who refuse the beaten tracks cannot "beat the dominant at their own game" [. . .] since the logic of the system is against them.[118]

What Enskog missed as a result of his doing research work by himself was the apprenticeship and instruction that are given by the guidance of a professor—in the words of Bourdieu, an "objective orchestration of the practical schemes inculcated by explicit instruction and familiarisation."[119] During this time there is an influence on the *habitus* that enables it to adjust to the new environment, and along with a scientific methodology, a social methodology is acquired, including such techniques as, for example, how to go about obtaining employment. The up-and-coming academic is able to become acquainted with the different decision makers in his particular sphere, and accumulates new forms of social capital.

Instead of working in this environment, Enskog did nearly all his research in scientific isolation while being employed in small towns peripheral to the scientific centers of Uppsala, Lund, and Stockholm. He did not have access there to the well-stocked libraries of books and journals that were and are the most important tool of the theoretical physicist. Enskog was isolated both professionally and intellectually as a result of his having left his traditional group—the experimentalist Uppsala School—to work alone on his own ideas, and he did his research without any real contact with or support from other scientists. Nor did he belong to any definable group in the Swedish community of physicists, where he stood between the experimentalists and the theoreticians. At the same time, this intermediate position and isolation emerge as important factors in the success of his research: his experimental experience enabled him to see that results of practical value lay within reach and prevented him from being deterred by what appeared an insuperable theoretical obstacle, and his isolation protected him from pressure to switch his research to more "fashionable" problems.

Enskog's support from representatives of the influential and prestigious international community of physicists implied a wider recognition that made him valuable to the aims of Swedish physicists: first to the discipline of theoretical physics and later to the community of Swedish physicists as a whole. Elisabeth Crawford has mentioned something that illuminates the situation in Sweden at this time and Oseen's reappraisal of Enskog's results:

> In the interwar period, increasing specialization made for a new breed of international disciplinary leaders. They limited their activities to specific disciplines and fields, which they promoted internationally, often with the aim of adding a dimension to the power and authority that they already enjoyed within their national scientific communities. The international activities of disciplinary leaders are of little interest when they merely served to increase the individual's "capital" of prestige and resources or to facilitate travel. Of much more interest are the questions of *how this added dimension entered into the process of validation and justification of new knowledge.*[120] [My emphasis]

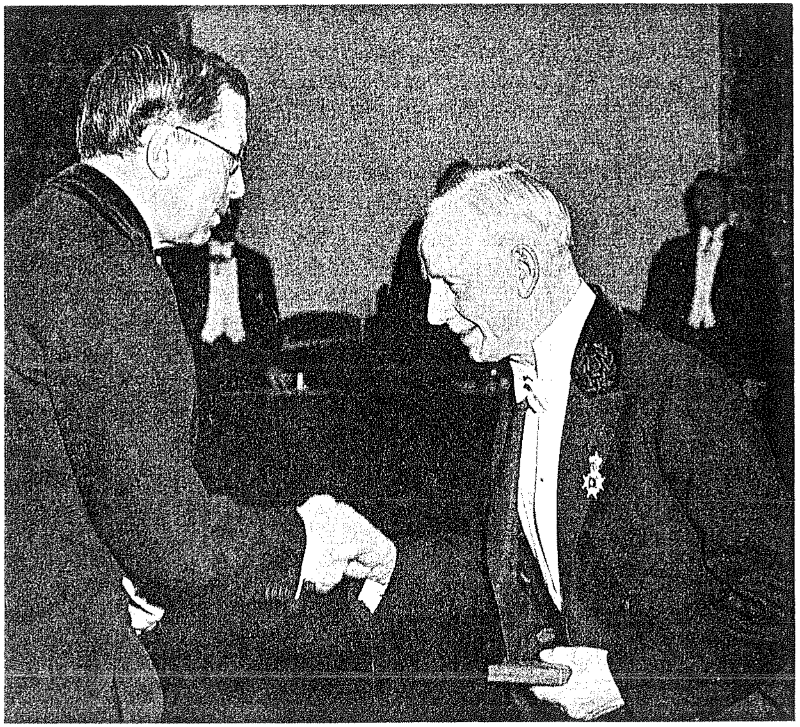
Oseen began such a promotion in the 1920s with a view to improving the national and international standing of Swedish physics. Earlier he had regarded it as more important to develop an independent Swedish physics,

which dared "to pose and work on its own problems, irrespective of whether they happen at the moment to be in favour abroad or not."[121] But he had soon realized that Swedish physics did not have the means or the strength to live in isolation, and he also believed that the work of Swedish physicists deserved more appreciation from fellow-physicists abroad. According to Robert Marc Friedman:

> [Oseen's] vision called for an overhaul of Swedish physics: stronger links with major foreign research centres, and greater visibility and prestige to ensure adequate research funds and university positions.[122]

The overseas interest in Enskog's findings ought therefore to have been welcome to Oseen. For his national and international purposes, it was important to give prominence to the few Swedish theoretical physicists whose research had attracted attention in the international centers of physics. This "central pressure"—the support that Enskog had received from his "three wise men," Chapman, Jeans, and Sommerfeld, with their "belief" in Enskog's theories—seems to have altered Oseen's view of the value of Enskog's results, although he continued to doubt their *scientific* value. Here was a Swedish theoretical physicist who had achieved international recognition, and it was thus to the advantage of Swedish physics to give him its support. It may also have been important not to jeopardize the attempt to build up a new credibility and prestige for Swedish physics among foreign physicists. If Sweden were now incapable of appreciating the significance of an internationally acknowledged achievement within its own borders, this might eventually also threaten the credibility and prestige of the Nobel Prize. All these were considerations that must have carried weight with Oseen when he began in the 1920s to support Enskog with prizes and awards. It may safely be said that Enskog's academic career would have come to an end after the defense of his thesis, had not his foreign social capital had more "purchasing power" than his Swedish.

The acknowledgment Enskog received after he obtained his professorship in 1930 may similarly be seen as showing that international recognition carried great weight with Swedish physicists, but above all, it was significant as an expression of the view of the importance of pure research in physics to technological applications. During the 1930s and 1940s, the Swedish government began to see research as an increasingly important factor contributing to industrial and social progress. There was now a debate on how research should be organized. The physicists argued in favor of independent and extended basic research, and this view was particularly expressed in the work of the Atomic Committee set up in 1945 to examine the implications of the atomic bomb for Swedish research and development. This committee included many well-known Swedish physicists, such as



The Crown Prince of Sweden, Gustav Adolf, awards David Enskog (to the right) the Svante Arrhenius medal on April 1, 1946. (Photo: Ulla Fornander Collection)

Hannes Alfvén, Manne Siegbahn and Ivar Waller.[123] The theme running through this and other commissions dealing with the subject of research during this period was that technical development work was really applied basic research and that independent basic research was essential to technical applications.[124]

The new course in engineering physics, Enskog's election to the Royal Academy of Engineering Sciences on the strength of the technological spin-off from his basic research, and his earning the Svante Arrhenius Medal are all representative examples of the view taken in the Swedish community of physicists of the connection between technology and science. The medal was a symbolic manifestation of the participation of Swedish physics in this monumental technoscientific achievement through the independent and purely scientific basic research of the Swedish theoretical physicist David

Enskog. The award of the Arrhenius medal to Enskog was an expression of the scientific ideology embraced by Swedish physicists at this time and was thus something of a plea for increased support for basic research. The future research that was envisaged was primarily in nuclear physics. Manne Siegbahn was planning to build his second cyclotron and had applied for half a million Swedish kronor in government grants for this purpose. The government committee was due to deal with the application on April 5,[125] four days after the medal was awarded, and Siegbahn's planned cyclotron was given special publicity by the Secretary of the Academy of Sciences at the awarding ceremony.[126] When the various ministers and physicists sat down to the banquet after Enskog had received his gold medal, they did so to celebrate not only Enskog's previous successes but also anticipated accomplishments in Swedish physics research.

NOTES

1. Stephen G. Brush, *Kinetic Theory III: The Chapman-Enskog Solution of the Transport Equation for Moderately Dense Gases* (Oxford, 1972), Preface.
2. No comprehensive biography of Enskog has been written; there is no official biography in the transactions of the Royal Academy of Sciences, and apart from brief biographical remarks, there is in Swedish only an article *in memoriam*: Karl Kärre and Nils Svartholm, "David Enskog," *Kosmos* 26 (1948), 7–15. In English Enskog is discussed in an autobiographical article by Sydney Chapman, "The Kinetic Theory of Gases Fifty Years Ago," in: W.E. Britten (ed.), *Lectures in Theoretical Physics:Kinetic Theory*, vol. 9 C (New York, 1967), 1–13, and in Stephen G. Brush, "Enskog, David," in: Charles Coulson Gillespie (ed.), *Dictionary of Scientific Biography*, 16 vols., (New York, 1981), vol. 4, 375–376. Brush has also published a monograph (cit. n. 7), that provides a brief survey of the scientific research that has developed from the Chapman–Enskog theory. It also contains some biographical material on Enskog, a slightly revised version of Chapman's earlier article, and an English translation of Enskog's doctoral thesis of 1917. The present essay is based mainly on the papers and correspondence left by Enskog, which are in the possession of his daughter Ulla Fornander and which she has kindly made available to the author. These will henceforth be referred to as the *Enskog Papers*.
3. At this time there were in Sweden two partially parallel forms of schooling, the six-year *folkskola* (elementary school) and the nine-year *läroverk* (secondary school).
4. *Royal Swedish Academy of Sciences*, Secretary's Archives: K.25b, David Enskog, "Självbiografiska anteckningar."
5. Björn Enskog to the author, personal communication; letter to the author from Birgit Ryman, née Enskog, April 2, 1990.

6. Kärre and Svartholm (1948), 8. The speed of his schooling is probably largely explained by the fact that Enskog was studying on borrowed money and that he was older than most students when he entered secondary school. When he went to university in 1903 he had made up the time he had lost at elementary school and was of the same age as other freshmen.
7. *Enskog Papers*, K.6:1, David Enskog's diary, September 11, 1904. Henceforth referred to as *Diary*.
8. These associations held meetings at which speakers warned of the dangers of alcohol, and Enskog himself addressed such meetings, on one occasion giving a lecture explaining how alcohol is produced and its structure of molecules and atoms. (See *Enskog Papers*, föredrag "Hållet på Danielsfesten i Betel, den 11 dec 1903.")
9. Sten Lindroth, *Uppsala universitet 1477–1977* (Uppsala, 1976), 228.
10. *Diary*, September 11, 1904.
11. Kärre and Svartholm (1948), 8.
12. *Diary*, January 21, 1904.
13. *Ibid.*, September 11, 1904.
14. Letter to the author from Birgit Ryman, née Enskog, April 2, 1990.
15. Crister Skoglund, *Vänsterstudenter, kulturradikalism och bildningsideal i sekelskiftets Sverige*, Idéhistoriska uppsatser, no. 13 (Stockholm, 1987), 18.
16. *Diary*, June 13, 1907.
17. Skoglund (1987), 18.
18. *Diary*, June 13, 1907.
19. *Ibid.*
20. Quoted in: Anna Beckman and Per Ohlin, *Forskning och undervisning i fysik vid Uppsala universitet under fem århundraden: En kortfattad historik*, Acta Universitatis Upsaliensis, no. C.8 (Uppsala, 1965), 27–28.
21. Kärre (1948), 9.
22. Martin Sjöström, "Gustaf Granqvist," *Kosmos* 3 (1923), 4.
23. Karl Kärre, "David Enskog död," *Dagens Nyheter*, June 2, 1947, 9. Granqvist is not mentioned here by name, only as "the experimentally inclined professor who was his tutor for physics."
24. *Enskog Papers*, K.6:2, examinations book. Enskog's thesis for his licentiate was never published, and it has not been possible to trace it in the university archives. However, its contents are reported in Ruben Adils' licentiate thesis of 1924, which forms a reappraisal of Enskog's experiments. This reproduction of Enskog's experiments was produced at the request of Granqvist, who was apparently unconvinced of the correctness of Enskog's results. However, it gave the same results as Enskog had obtained. See *Uppsala University Library*, Department of Physics, uncatalogued material, Ruben Adils, "Studier öfver vattenångans diffusion vid olika tryck."
25. *Enskog Papers*, K.2, draft letter from Enskog to Sydney Chapman, undated, but 1922.
26. *Ibid.* Cf. Chapman (1967), 9.

27. Interview with Ulla Fornander, October 2, 1989; *Enskog Papers*, K.6:3, David Enskog's cash book.
28. *Uppsala University Library*, Värmland Nation Archives, U1564 n:2, minute-book of board of Värmland Nation Benevolent Association Committee 1906–1932; *Uppsala University Library*, Värmland Nation Archives, U1585 a, record of reduction of term fees, 1883–1925.
29. *Enskog Papers*, K.2, draft of letter from Enskog to Sydney Chapman, undated, but 1922. Cf. Chapman (1967), 9.
30. See Gunnar Eriksson, *Kartläggarna* (Umeå, 1978), 77–79; Bosse Sundin, *Ingenjörsvetenskapens tidevarv* (Umeå, 1981), 30–33; Sven Fagerberg, "Några svenska industrilaboratorier I," *Kosmos* 14 (1936), 148–186; *idem*, "Några Svenska industrilaboratorier II," *Kosmos* 15 (1937), 145–179.
31. In the notebook he used at Uppsala, Enskog had copied the following advertisement for a vacancy: "*Senior chemist's position* at Helsingborg Copper Works vacant. The applicant should have a university degree and practical experience of metal analysis together with the ability to direct work in a large laboratory. Applications within 14 days to Helsingborgs Kopparverks Aktiebolag, Helsingborg" (*Enskog Papers*, K.6:5, notebook).
32. Sydney Chapman and T.G. Cowling, *The Mathematical Theory of Non-Uniform Gases: An Account of the Kinetic Theory of Viscosity, Thermal Conduction and Diffusion in Gases* (Cambridge, 1939), 382.
33. Brush (1972), 5.
34. David Enskog, "Über eine Verallgemeinerung der zweiten Maxwellschen Theorie der Gase," *Physikalische Zeitschrift* 12 (1911), 56–60.
35. David Enskog, "Bemerkungen zu einer Fundamentalgleichung in der kinetischen Gastheorie," *Physikalische Zeitschrift* 12 (1911), 538–539.
36. *Ibid.*
37. David Hilbert, "Begründung der kinetischen Gastheorie," *Mathematischen Annalen* 72 (1912), 562–577. This article was taken from his otherwise entirely mathematical monograph on integral equations, *Grundzüge einer allgemeinen Theorie der linearen Integralgleichungen* (Leipzig, 1912), in the last chapter of which he applied his mathematical theory of integral equations to kinetic gas theory.
38. David Enskog, *Kinetische Theorie der Vorgange in massig verdünnten Gasen*, dissertation (Uppsala, 1917), 5. Original in German: "Auf Grund der Theorie der Integralgleichunger ergibt sich dann der logischen Aufbau der Gastheorie in ungezwungener Weise."
39. Chapman and Cowling, 385. Cf. Clifford Truesdell and Robert G. Muncaster, *Fundamentals of Maxwell's Kinetic Theory of a Simple Monoatomic Gas: Treated as a Branch of Rational Mechanics* (New York, 1980), 432.
40. Truesdell and Muncaster, 433.
41. Ivar Waller, "Carl Wilhelm Oseen," in *Levnadsteckningar över Kunql. Svenska Vetenskapsakademiens ledamöter* 8 (Stockholm, 1949–1954), 135.
42. *Enskog Papers*, letter to Enskog from Oseen, November 14, 1915.

43. *Enskog Papers*, K.1, letter to Enskog from Oseen, December 18, 1916. Hecke seems to have done most of the work on this, although the book was never completed. Three years after Enskog's thesis, Max Born wrote to him saying that Hecke had told Born that he was going to "publish a complete treatment of the theory of gases." *Enskog Papers*, K.1, letter to Enskog from Born, October 28, 1920.
44. *Enskog Papers*, K.1, letter to Enskog from Oseen, December 18, 1916.
45. Enskog (1917), 21. Original in German: "Eine ähnliche Lücke findet sich bei allen früheren Verfassern auf demselben Gebiete. Der Physiker wird auf diesen Punkt nicht allzu grosses Gewicht legen."
46. I am indebted to Professor Robert M. Friedman for pointing out these circumstances to me.
47. Cf. Truesdell and Muncaster, 433.
48. David Enskog, "Hendrik Antoon Lorentz," *Kosmos* 7 (1929), 14.
49. *The Swedish National Archives*, Ministry of Education and Ecclesiastical Affairs, Cabinet Papers, December 4, 1930, no. 31, Professuren i mekanik och matematisk fysik 1930, 62.
50. *Enskog Papers*, K.1, letter to Enskog from Oseen, December 18, 1916.
51. *Uppsala University Archives*, Faculty of Humanities Archives, vol. Alc:19, Records of the Department of Mathematical Sciences, 1917, April 14, 1917, § 4.
52. Interview with Björn Enskog, October 2, 1989.
53. Sydney Chapman, "On the Law of Distribution of Molecular Velocities, and on the Theory of Viscosity and Thermal Conduction, in a Non-Uniform Simple Monoatomic Gas," *Phil. Trans. Roy. Soc. London*, A, 216, (1916), 279–348; *idem*, "The Kinetic Theory of Simple and Composite Monoatomic Gases: Viscosity, Thermal Conduction and Diffusion," *Proc. of the Roy. Soc. of London*, A, 93 (1916–1917), 1–20; *idem*, "On the Kinetic Theory of a Gas: Part II, A Composite Monoatomic Gas: Diffusion, Viscosity and Thermal Conduction," *Phil. Trans. Roy. Soc. London*, A, 217 (1917), 115–197.
54. Chapman, "Kinetic Theory of Simple and Composite," 2.
55. Brush (1972), 9. According to Robert Muncaster, this difference in methods, the Maxwell–Chapman and the Boltzmann–Enskog, "merely illustrates a difference of tradition: British and Teutonic." See Truesdell and Muncaster, 432. Chapman said of his own method that it had "the characteristic rather typical of things English, of being effective without elegance & with very incomplete knowledge of the subject I was dealing with." *Enskog Papers*, letter to Enskog from Chapman, October 6, 1922.
56. *Enskog Papers*, K.1, letter to Enskog from Chapman, July 9, 1917.
57. *Ibid.*
58. *Ibid.*
59. *Enskog Papers*, K.1, letter to Enskog from Oseen, March 6, 1917.
60. *Enskog Papers*, K.1, letter to Enskog from Oseen, May 10, 1920.
61. For these references see index in James H. Jeans, *The Dynamical Theory of Gases* (1904), 3rd edition (Cambridge, 1921).

62. Oseen had first believed that it would be possible to publish the whole thesis in the *Transactions of the Royal Swedish Academy of Sciences*. When it was realized that the academy had stopped publishing doctoral theses as such, he recommended Enskog to divide the thesis into two parts on account of the high printing costs: the first part to be paid for by Enskog himself and the second to be published later, after the disputation, in the *Transactions of the Royal Swedish Academy of Sciences* as an article. See *Enskog Papers*, K.1, letters to Enskog from Oseen, June 8, 1916, December 18, 1916, January 19, 1917.
63. *Royal Swedish Academy of Sciences*, Appendix to Records 1921, I, 462.
64. *Ibid.*, 463–464.
65. *Ibid.* Original in German: "Soviel ich sehe haben Sie das, was Hilbert gewollt hat, wirklich durchgeführt."
66. Theoretical derivation in Chapman, "Kinetic Theory of a Gas, Part II," 157–159, 181–185. Experimental confirmation in: Sydney Chapman and F.W. Dootson, "A Note on Thermal Diffusion," *Philosophical Magazine* Series 6, 33 (1917), 248–253.
67. Jeans (1921), 324.
68. David Enskog, "Die Numerische Berechnung der Vorgänge in mässig verdünnten Gasen," *Arkiv för matematik, astronomi och fysik* 16:16 (1921), 60. The article in which Enskog calculated the coefficient of thermal diffusion was David Enskog,"Zur Elektronentheorie der Dispersion und Absorption der Metalle," *Annalen der Physik*, 4th series, 38 (1912), 731–763. Original in German: "Die Behauptung von Chapman und von Jeans [. . .], dass ich den Vorgang der thermischen Diffusion spater als Chapman entdeckt habe, ist unrichtig. Ich habe 1911 die Existenz desselben angezeigt (in einem Aufsatze, den Chapman schon in seiner ersten gastheoretischen Arbeit zitiert). 1912 habe ich in einem speziellen Falle den exakten Wert des Koeffizienten [der thermischen Diffusion] gegeben."
69. A.J. Dessler, "The Evolution of Arguments Regarding the Existence of Field-Aligned Currents," in Thomas A. Potemra (ed.), *Magnetospheric Currents*, Geophysical Monograph no. 28 (Washington, 1984), 27.
70. *Enskog papers*, K.1, letter to Enskog from Chapman, December 23, 1921.
71. David Enskog, "Kinetische Theorie der Wärmeleitung, Reibung und Selbstdiffusion in gewissen verdichten Gasen and Flüssigkeiten," *Transactions of the Royal Swedish Academy of Sciences*, New Series, 63:4 (1922), 1–44.
72. *The Swedish National Archives*, Ministry of Education and Ecclesiastical Affairs, Cabinet Papers, December 4, 1930, no. 31, Professuren i mekanik och matematisk fysik 1930, 63.
73. Hilbert, *Grundzüge*, 277.
74. Erich Hecke, "Über die Integralgleichung der kinetischen Gastheorie," *Matematische Zeitschrift* 12 (1922), 275.
75. *Ibid.*, 284. Original in German: " . . . diese Arbeit in matematischen Kreisen wenig bekannt zu sein scheint."

76. Richard Courant and David Hilbert, *Methoden der matematischen Physik*, 2 vols. (Berlin, 1924), vol. 1, 136.
77. *Lund University Library*, letter to Ossian-Nilsson from Enskog, July 30, 1923.
78. *Ibid.*
79. According to Jagdish Mehra, Enskog attended Hilbert's lectures on the kinetic theory of gases in Göttingen as early as 1912–1913. See Jagdish Mehra, "Einstein, Hilbert, and the Theory of Gravitation," in Jagdish Mehra (ed.), *The Physicist's Conception of Nature* (Boston, 1973), 178. I have not been able to find any evidence of this, and I am sceptical, both because Enskog was doing his probationary year as a grammar school teacher in Stockholm during this period and also because his children have no knowledge of it. It seems likely that there has been an error of ten years in the date.
80. *Royal Swedish Academy of Sciences*, Appendix to Records 1923, II, 184–94.
81. *Royal Swedish Academy of Sciences*, Appendix to Records 1928, II, 242.
82. *Royal Swedish Academy of Sciences*, Minutes of Meetings of the Royal Swedish Academy of Sciences Classes and Committees 1928, 239. At the same time, they also allocated a similar sum as a *grant* to another applicant. A total of seven people had applied. Oseen had also played a part in the decision of the Society of Sciences in Uppsala, of which he was an influential member, to award Enskog the Thalén Prize in 1923 for his thesis on a theory for liquids.
83. *The Swedish National Archives*, Ministry of Education and Ecclesiastical Affairs, Cabinet Papers, December 4, 1930, no. 31, Professuren i mekanik och matematisk fysik 1930, 100–101. However, Enskog had been the first choice of one of the experts, the mathematician Carleman. But he, too, considered that the situation would be different if one had to take into account the importance of the applicants to modern theoretical physics. During the autumn term of 1930, Enskog was appointed to the professorship temporarily, pending a permanent appointment. He was then on part-time secondment from his regular position as a teacher at the classical grammar school at Norrmalm to which he had been transferred in the autumn of 1929.
84. *Ibid.*, 97–98.
85. *Enskog Papers*, K.2, draft of letter from Enskog to Chapman, undated in 1929.
86. *Royal Institute of Technology*, Main Archive, Records of the Teaching Committee, AII:42, May 27, 1930, § 5, Appendix C, 20.
87. *Ibid.*, Appendix D, 16–17.
88. *Ibid.*, 5.
89. *Ibid.*, 17.
90. *The Swedish National Archives*, Ministry of Education and Ecclesiastical Affairs, Cabinet Papers, December 4, 1930, no. 31, Professuren i mekanik och matematisk fysik 1930, 87.

91. *Royal Institute of Technology*, Main Archives, Record, of the Teaching Committee, AII:42, May 27, 1930, § 5, Appendix D, 13,17; *ibid.*, October 15, 1930, § 3.
92. *Ibid.*, Appendix B, 19.
93. *Ibid.*
94. In Chapman (1967), 11. Chapman states that it was after Enskog had obtained his professorship that they met for the first and only time, but this is not correct. According to their exchange of letters and a letter to Anna Enskog, the only time Chapman and Enskog met was on this occasion in 1930. *Enskog Papers*, K.2, letter to Anna Enskog from Chapman, January 17, 1948.
95. Chapman (1967), 11.
96. *Enskog Papers*, K.1, letter of recommendation to Enskog from Chapman, August 19, 1930. The letter is written on the paper of the geophysics congress he was attending in Stockholm.
97. *Ibid.*
98. *Ibid.*
99. *Enskog Papers*, K.2, draft of letter from Enskog to Chapman, August 21, 1931.
100. *Ibid.*
101. *Royal Institute of Technology*, Main Archive, Records of the Teaching Committee, AII:43, October 15, 1930, § 3.
102. That the professors at the Royal Institute of Technology should also conduct research was not expressly stated in the statutes until 1932.
103. *Royal Institute of Technology Library*, Reseberättelse 1931–1932, David Enskog, "Reseberättelse (rörande undervisningen i matematik och mekanik vid de tekniska högskolorna i Berlin, Dresden, Wien, Zürich, Prag and München)," 1931.
104. *Royal Swedish Academy of Engineering Sciences*, slip-case: "Inval svenska ledamöter 1941," Item 10: Professor David Enskog, 1.
105. *Ibid.*
106. Brita Stina Nordin-Pettersson, *Vetenskapsakademiens konstsamlingar* (Stockholm, 1971), 105.
107. Henry DeWolf Smyth, *Atomic Energy for Military Purposes: The Official Report on the Development of the Atomic Bomb under the Auspices of the United States Government, 1940–1945* (Princeton, N.J., 1945), Sect. 9:21–9:23. The method used was based on *liquid* thermal diffusion, but the *Smyth Report* stresses how this method was based on the one for gaseous thermal diffusion that had been developed by Clusius and Dickel in 1938. Cf. Richard Rhodes, *The Making of the Atomic Bomb* (1986; New York: Touchstone, 1988), 550–553, 602, caption to picture no. 57; Nuel Pharr Davis, *Lawrence and Oppenheimer* (New York, 1968), 209–213; Thomas P. Hughes, *American Genesis: A Century of Invention and Technological Enthusiasm, 1870–1970* (1989; New York, 1990), 410, 414–416. Thermal diffusion was also used for the separation of uranium isotopes in the Japanese atomic bomb project, in this case *gaseous* thermal diffusion, but without success. See Rhodes, 580–582.

108. *Royal Swedish Academy of Sciences*, Minutes of Meetings of the Royal Swedish Academy of Sciences' Classes and Committees 1946, 67–68.
109. *Ibid.*, 68.
110. *Stockholmstidningen*, April 12, 1946, 13.
111. *Royal Swedish Academy of Sciences*, Minutes of Meetings of the Royal Swedish Academy of Sciences Classes and Committees 1947, 99.
112. Pierre Bourdieu, "The Specificity of the Scientific Field and the Social Conditions of the Progress of Reason," *Social Science Information*, 14:6 (1975), 19–47. For a more quantitative and specific analysis, see *idem*, *Homo Academicus*, (1984), Eng. transl. (Cambridge, 1988).
113. Bourdieu (1975).
114. Sigfrid Åkerblom, "En kvartett lektorer vid läroverket i Karlstad," in *Nationen och hembygden: Skriftserie utgiven av Värmlands nation i Uppsala och Föreningen Nationen och hembygden*, no. 9 (Uppsala, 1964), 30.
115. Sten von Friesen, "Manne Siegbahn: Minnesteckning," in *Kungl. Fysiografiska sällskapet i Lund årsbok 1979* (Lund, 1979), 77.
116. Donald Broady, *Kapital, habitus, fält; några nyckelbegrepp i Pierre Bourdieus sociologi*, Arbetsrapport 1989:2 (Stockholm: National Swedish Board of Universities and Colleges, 1989), 22–23.
117. Skoglund (1987), 7, 31.
118. Bourdieu (1975), 30. The word strategy may be a little misleading, because it does not usually refer to calculated actions. Cf. also Lewis Feuer on the relationship between the research of the young Einstein and his private revolutionary dispositions and revolt against the university order: "Einstein's high interval of original thought was sustained by a strange little circle of young intellectuals, filled with emotions of social and scientific generational rebellion, [. . .] [a group] moved in a revolutionary time to see the world in a new way," quoted in Bourdieu (1975), 44.
119. *Ibid.*, 34.
120. Elisabeth Crawford, "The Universe of International Science, 1880–1939," in: Tore Frängsmyr (ed.), *Solomon's House Revisited: The Organization and Institutionalization of Science*, Nobel Symposium, no. 75 (Canton, Mass., 1990), 238.
121. *The Royal National Library of Sweden*, Carl Benedicks' Collection, letter to Carl Benedicks from Oseen, 25 March 1914.
122. Robert Marc Friedman, "Nobel Physics Prize in Perspective," *Nature* 292 (1981), 795.
123. Waller was a member from 1947.
124. Stefan Lindström, "Implementing the Welfare State: The Emergence of Swedish Atomic Energy Research Policy" (in this volume), 179–195; Hans Weinberger, "Physics in Uniform: The Swedish Institute of Military Physics, 1939–1945" (in this volume), 141–163.
125. Stefan Lindström, *Hela nationens tacksamhet: Svensk forskningspolitik på atomenergiområdet 1945–1956*, (Stockholm, 1991), 65–66.
126. *Stockholmstidningen*, April 2, 1946, 13.

REACHING OUT

Janne Rydberg's Struggle for Recognition

PAUL C. HAMILTON

INTRODUCTION

No serious student or teacher of physics or chemistry, nor any professional working in either of these fields today, can fail to recognize the name *Rydberg*. Scientific terms in daily use, to mention only the most prevalent, include: the Rydberg constant, the Rydberg formula, Rydberg spectroscopy, Rydberg states, Rydberg transitions, and the Rydberg atom. In July 1954, an international conference on spectroscopy was held at Lund University in honor of the 100th anniversary of Janne Rydberg's birth. In his introductory remarks, Dr. William Meggers of the United States National Bureau of Standards cited Rydberg as "the first true patron of theoretical spectroscopy," and as a man "whose extraordinary intuition for spectral series sets him apart from all his contemporaries as a genius." Niels Bohr also addressed the conference and paid tribute to the "pioneering work" of the man whose spectral laws he had cited in his first paper of the 1913 "trilogy,"[1] through which Bohr introduced the initial concepts of what eventually would become the new world of quantum physics.[2]

Despite this particular kind of name recognition, few scientists or historians are familiar, in any substantive way, with the man behind the name. What follows is a synopsis of an intriguing chapter in Rydberg's life: his long and difficult struggle to gain professional recognition from a largely insular and conservative scientific establishment. Rydberg was not the first, nor would he be the last, to suffer from a lack of appreciation and understanding from his fellow Swedish scientists. His case is historically important for many reasons, not the least of which is that it signalled the beginning of the end of what had become, in the last half of nineteenth-century Sweden, a period of introspection and relative isolation for much of Swedish physical science. Rydberg was one of the first, if not the first, Swedish university educator of this period to reach beyond his national boundaries and seek support for his professional standing from the international community of scientists.

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CENTER *on the* PERIPHERY

Historical Aspects of 20th-Century Swedish Physics

SVANTE LINDQVIST
EDITOR

Marika Hedin and Thomas Kaiserfeld
Associate Editors

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