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Newtonianism in the Scandinavian Countries, 1690-1790

HELGE KRAGH*

1 Introduction

In the present context, the Scandinavian countries refer to two national or administrative units, the one being Denmark and the other Sweden. In the period here considered, largely the century from 1690 to 1790, 'Denmark' means really Denmark-Norway, for until 1814 Norway was part of the double monarchy ruled by the king and his government in Copenhagen. It should also be kept in mind that parts of what is today Germany, namely Schleswig-Holstein, belonged to the kingdom. However, as far as language and culture were concerned, these parts of southern Denmark were more German than Danish, and they played no important role in the scientific life of the kingdom.

Sweden covered a much larger geographical area than it does today. The country had expanded greatly during the seventeenth century, when not only Finland but also parts of the Baltic area and northern Germany came under Swedish rule. About 1720, after the Great Northern War, Sweden lost most of its possessions, but the major part of Finland remained as part of the country until

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1809. One important difference between the two countries was that whereas Denmark had only one university (in Copenhagen), Sweden could boast of three: in addition to the old university in Uppsala, there were also universities in Lund in southern Sweden and in Turku (or Åbo) in Finland. However, in the present essay Finland is not included as part of Sweden.[1]

In the light of the geographical closeness of the two countries, and the many similarities between them in history, language and culture, one might expect there to have been close scientific and learned contacts between Denmark and Sweden. However, this was not the case at all. On the contrary, throughout the eighteenth century, contacts between Danish and Swedish natural philosophy, whether on the institutional or the personal level, were very limited. Danish natural philosophers interacted with their colleagues in Germany and elsewhere, and so did Swedish natural philosophers, but there was almost no inter-Scandinavian interaction. Generally speaking, Sweden was a much stronger scientific nation in the age of the Enlightenment than Denmark was, a difference which is clearly illustrated in the case of the reception of Newtonianism.[2]

2 Denmark

Natural philosophy was at a low point in Denmark in the early decades of the eighteenth century, when the field was ignored by the king and his advisors, and when the University of Copenhagen was a conservative stronghold rather than an

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[1] For Finland, see Kallinen 1995 and also Maija Kallinen's chapter "The Reception of Newton in Finland and the Baltic States" in Mandelbrote and Pulte, eds., *The Reception of Isaac Newton in Europe* (note *).

[2] A comparison of scientific developments in the two countries is offered in Jamison 1982. On the pre-Enligthenment period, see Danneskiold-Samsøe 2004, and, for a general survey, Shackelford 1994.

institution promoting research and an international outlook (Kragh 2005; Kragh et al. 2008). In 1731 an attempt was made to lure the prominent Dutch Newtonian natural philosopher, Pieter van Musschenbroek, to become professor in Copenhagen, but nothing came of it. Things began slowly to improve in the 1740s, first with the foundation of the Royal Academy of Sciences and Letters in 1742 (Pedersen 1992) and next with the establishment five years later of Sorø Academy, to the west of Copenhagen. However, even then the country was scientifically backwards. The sciences that began to develop under state patronage in the 1760s were primarily those that were regarded to be economically relevant, such as botany, zoology, cartography and mineralogy. There was little interest in physics and astronomy and almost no research activity that attracted attention outside the country. Remarkably, the reception of Newtonian natural philosophy was so weak and scattered that it is difficult to identify Newtonianism as a trend or movement in Danish cultural and scientific life in the age of Enlightenment.

2.1 Early Danish encounters with Newton

The first Danish natural philosopher who encountered Newton's new physics was undoubtedly Nicolaus Mercator, sometimes known as Kauffman (Applebaum 1986; Hofman 1950). However, as a native of Holstein, who lived most of his adult life outside the Danish monarchy, he does not fully qualify as a Dane. After studies at the universities of Rostock and Leiden, he arrived in Copenhagen in 1648 to continue his studies of astronomy and mathematics. In 1655 the 36-year old mathematician left the country for England, where he remained until 1683, when he went to Paris. Mercator, who in 1666 had been elected a member of the Royal

Society, was part of the flourishing British environment of the exact sciences, and it was through a work of his that Newton first became aware of Kepler's second law, a crucial step towards his formulation of the universal law of gravitation as a basis of celestial mechanics (Wilson 1970, 128-33). Newton, who owned a copy of Mercator's *Institutionum Astronomicarum Libri Duo* (1676), mentioned the Danish-German natural philosopher in the *Principia*. The only other Danish author that Newton cited was Ole Rømer. Although Mercator was undoubtedly an important figure in the earliest phase of Newtonian mechanics, his work does not belong to the context of Danish natural philosophy. As far as is known, after 1655 he did not have contact with Denmark or with Danish natural philosophers.

Although, with hindsight, science was in decline in Denmark in the last part of the seventeenth century, the country could still boast of its contemporary achievements in natural philosophy, notably through the work of Ole Borch, Erasmus Bartholin and Ole Rømer. The latter two, best known for their important contributions to optics and astronomy, respectively, seem to have been acquainted with Newton's *Principia* and may possibly have studied it. From the catalogue of his books prepared after the death of Rømer, it is clear that he owned a copy of Newton's work (Kragh 2004). Most of Erasmus Bartholin's books were inherited by his son Johan Friedrich Bartholin, in the catalogue of whose library from 1708 there appears a copy of the 1687 edition of *Principia,* which most likely had belonged to his father (Friedrichsen 2005). However, neither Bartholin nor Rømer ever referred to Newton and so it cannot be known how they responded to the new mechanical physics, if indeed they responded at all.

In their correspondence with Rømer, both Huygens and Leibniz mentioned Newton's theories, but apparently Rømer took no interest in the matter. In a letter of 1690, Huygens wrote (Rømer 2001, 231):

> I have no doubt that you have seen Newton's book entitled *Philosophiae principia mathematica*, a work which includes many obscurities. But there are also many ingenious observations. I think he is too bold in his construction of hypotheses. … I would like to know if you share my opinion?

In another letter, of 1705, Leibniz similarly asked Rømer about his view of Newton's theories, and especially their relationship to the Keplerian ellipses (Rømer 2001, 335). Apparently Rømer did not respond to the enquiries of either of his correspondents.

The first trace of Danish academic interest in Newton's physics dates from 1720, when the theology student, Detlev Gotthard Zwergius, while staying in Wittenberg, wrote a dissertation on Newton's theory of colour, as expounded in the *Opticks* (Zwergius 1720). The forty-page dissertation aroused no interest, and Zwergius, who later became a priest in Elsinore, did not follow it up. What little natural philosophy there was in Denmark in the first decades of the eighteenth century was solidly founded in Cartesianism. As to Newtonian physics, it was conspicuously missing not only in textbooks, but also in dissertations and other learned works. For example, the textbook that dominated university teaching in Copenhagen in natural philosophy for more than half a century, *Specimen Philosophiae Naturalis*, was based on a mixture of Aristotelian and Cartesian doctrines (Bartholin 1688). The author was Caspar Thomesøn Bartholin, a son of the eminent anatomist Thomas Bartholin (and the nephew of Erasmus Bartholin) and himself a professor of physics, anatomy and medicine. The book, first published in 1688, was reprinted several times and only removed from the university curriculum in 1777. As late as 1754, it was published in an English translation, with the anonymous translator liberally adapting the text to the Newtonian system (Bartholin 1754).

Rømer's successor as professor of astronomy, Peder Nielsen Horrebow, was no less attached to Cartesianism than was Bartholin. As late as 1748, he published a revised edition of Bartholin's textbook in natural philosophy, entitled *Elementa Philosophiae Naturalis*. Horrebow, who in 1727 erroneously claimed to have detected a stellar parallax, explained the Copernican universe in terms of the vortex hypothesis introduced by Descartes (Aiton 1972). He was familiar with Newton's critique of the Cartesian celestial vortices, which was spelled out in the *Principia*, but did not accept the Newtonian alternative based on the law of universal gravitation. On the contrary, in his *Basis Astronomiae* of 1735, a work that was widely known among contemporary astronomers, Horrebow argued against Newton's explanation of planetary motion. He repeated the criticism in his *Elementa Philosophiae Naturalis*. According to the Danish astronomer, the only way to obtain a physical understanding of the motion of planets and comets was by means of the heavenly vortices that Newton had so "thoughtlessly" rejected.

By the mid-eighteenth century, Newton's mechanical system of the world had finally become known, if not widely accepted, in Denmark. It was known not only by a few mathematicians and natural philosophers but also to other professors and men of culture. The learned Norwegian-Danish author and playwright, Ludvig Holberg, was a central figure in the early Danish enlightenment. A professor of history and geography in Copenhagen, he generally distrusted the mathematical and physical sciences, which he considered to be a scholastic waste of time. Although on occasions he ridiculed Cartesian natural philosophy, he found it more satisfactory than the Newtonian alternative. In a series of works (*Epistler*) published between 1748 and 1754, Holberg dealt briefly with the question of how to explain the motion of comets. Holberg was not really interested in the truth of the matter, but argued that the Cartesian vortex explanation was simpler and more easily visualized, and hence that it was more attractive than the explanation based on Newton's system.[3] At about the same time, Frederik Christian Eilschov, a young philosopher, referred to Newton in connection with an analysis of the concept of time. Eilschov had studied Leibniz's correspondence with Samuel Clarke and in this way acquired insight into Newton's philosophy, including his ideas of absolute space and time. But he firmly rejected the notion of absolute time, which he found to be nothing but the imagination of a mathematician (Eilschov 1748; Koch 2003, 231-56).

2.2 Jens Kraft, an apostle of Newton's system

Eighteenth-century Denmark could boast of only one natural philosopher, Jens Kraft, who truly mastered the mathematical and experimental physics in the Newtonian tradition (Christensen 1988; Pedersen 1973; Kristiansen 2001). The Norwegian-born Kraft started his studies at the University of Copenhagen in 1740 and soon became acquainted with Newton's *Arithmetica Universalis* and other works of the new mathematics. While a student, he wrote a brief "disputation" on Newton's mathematics (Kraft 1741). Kraft spent the years from 1744 to 1746 abroad

[3] Epistel no. 42. A selection of the *Epistles*, which includes comments on Descartes and Newton, is translated into English in Holberg 1991. On Holberg and natural philosophy, see Spang-Hanssen 1965.

on a Royal stipend, first studying in Halle under the famous Christian Wolff, whose eclectic teaching provided him with a solid knowledge of natural philosophy of both the Cartesian and Leibnizian brand. More importantly, in Basel and Paris, Kraft met and interacted with some of Europe's most distinguished mathematical physicists, including Johan Bernoulli, Daniel Bernoulli, Jean d'Alembert and Alexis Claude Clairaut. When he returned to Copenhagen at the end of 1746 he was not only an accomplished mathematician and natural philosopher but also had converted to Newtonianism. In the following year, he was appointed professor at Sorø Academy, a college for the sons of the nobility located some fifty miles from the capital. As a further sign of his rising academic standing, he was admitted as a fellow of the Royal Danish Academy of Sciences and Letters, which had been created only five years earlier.

In a lecture read to the Royal Academy in 1747, Kraft launched a systematic attack on the Cartesian physics which still dominated natural philosophy in Denmark. "Considerations on the Systems of Newton and Descartes" was a detailed comparison of the two rival systems for understanding nature. According to Kraft, there was no doubt that Newton's system was vastly superior. He repeated Newton's argument that the Cartesian vortices were unable to account for Kepler's planetary laws and in general dismissed the Cartesian system of the world. Not only did he claim that Newton's theory agreed perfectly with experience, Kraft also believed that it was methodologically stronger because it was simpler and more economical. Like most other natural philosophers in the age of the Enlightenment, he greatly valued the doctrine that *natura simplicitatem amat*.

> If nature has acted according to the Newtonian hypothesis, it has worked with the least possible forces and the least mass; and in both these respects

> the Cartesians are most extravagant. … The more we come to understand nature, the more exceptions must we admit in the Cartesian hypothesis. But the Newtonian hypothesis is always and everywhere itself, just like nature, and it always acts in the shortest way.[4]

The final sentence of this quotation suggests that Kraft, like many of his contemporaries, was reading Newton through Leibnizian spectacles.

In his exposition of the virtues of Newton's mechanics, Kraft emphasized its use in astronomy and also dealt in some detail with the theory of matter in terms of hypothetical short-range forces. He optimistically claimed that the mechanics of chemical processes was within the reach of Newtonian theory and that a future mathematical chemistry might well be established on this basis. Admittedly it had not yet been possible to "combine chemistry with mathematics," but Kraft was confident that it was possible. Although Kraft greatly praised Newtonian natural philosophy, his praise was neither unlimited nor uncritical. When it came to imponderables such as light, fire, electricity and magnetism, he had to admit that in this area even the admired Newtonian theory had little to offer.

Kraft's work of 1747 marked the introduction of Newtonian physics in Denmark, and he further developed the field in connection with his teaching at Sorø Academy. Thus, he wrote a series of five textbooks in which he formulated a philosophical system that eclectically built on Leibnizianism and Wolffianism as well as Newtonianism. In one of these books, entitled *Cosmology*, he argued from Leibniz's principle of sufficient reason that the material world must be a plenum

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[4] Kraft 1747, 262: "Saafremt Naturen har handlet efter den Neutonianske Hypothese, da har den giort alt med de mindste muelige Kræfter og den mindste Masse paa hvilke begge Cartesianerne ere overmaade ødsle. … Jo nøyere vi kommer til at giøre udi den Cartesianske Hypothese, da tvertimod den Neutonianske er sig selv over alt liig, ligesom Naturen og handler altid paa det korteste."

whose development is strictly governed by the laws of nature. However, the laws he had in mind were teleological rather than causal. “Thus, everything that is going to happen in the world is strictly determined and fixed by its final purpose,” he wrote (Kraft 1752, 10).[5] Whereas his philosophy of nature in general reflected the Newtonian world system, including corpuscularianism, he did not accept the atomic hypothesis. On the contrary, Kraft denied the existence of “material atoms which have extension but are indivisible” and also that particles of matter could move in a vacuum. Anti-Cartesian as he was, he maintained the Cartesian doctrine of a plenum: “In no world can there be any absent space or an order without things in it; the very idea of a vacant space in the world is entirely imagined” (Kraft 1752, 34).[6] From several other passages in Kraft’s works, it is evident that his Newtonianism was mixed up with significant doses of the thinking of Leibniz and Wolff.

Kraft’s most impressive work in the tradition of Newtonian physics was the massive two-volume textbook *Forelæsninger over Mechanik* (Lectures on Mechanics) published from 1763 to 1764. This richly illustrated work described a large number of experiments, instruments and useful machines, including the first Danish description of Thomas Newcomen’s steam engine or “fire-machine” (Nielsen 1992). Moreover, its descriptive parts were accompanied by mathematical sections in which Kraft demonstrated how the instruments could be understood in terms of Newtonian mechanics. In the first part of his *Forelæsninger*, Newton’s laws of motion were introduced and applied to a number of problems, such as the motion

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[5] ”Saaledes er alt det, som skal skee i en Verden, aldeles determinert og fastsat ved dens endelige Hensigt.”

[6] ”I ingen Verden kand være noget ledigt Rum eller en Orden uden Ting, saa den Tanke om et ledigt Rum i Verden er aldeles imaginert.”

of a particle moving in a constant field of gravitation. Inspired by Leonhard Euler, Kraft formulated the second law of motion as follows:

> If one denotes an infinitesimal part or element of the time as *dt*; an element or infinitesimal increase of the velocity as *dv*; the pressure or force as *p*; and the matter to be moved as *m*. Then, $pdt = mdv$. … Consequently, the quantity *pdt* becomes the entire effect of the pressure, and so does *mdv*, and for this reason $pdt = mdv$ is in general the great and fundamental equation of the increase of motion.[7]

Kraft wrote his works in Danish and after his return from Paris he seems not to have been in correspondence or other contact with foreign natural philosophers. For this reason his works were unknown outside the Scandinavian countries. However, after his death in 1765, at the age of 45, the first volume of *Forelæsninger* appeared in a Latin translation published in Wismar, Germany, and, in 1787, a revision of the Latin edition was translated into German under the title *Mechanik*. Probably inspired by Kraft, the self-taught Diderich Christian Fester published a couple of works in which he demonstrated his knowledge of the new mechanical physics. In a treatise of 1759 on the motion and nature of comets, he adopted a Newtonian framework while rejecting the ideas of Descartes, Jacob Bernoulli and others (Fester 1759). Not only did he support the explanation of comets offered by "the incomparable Newton," he also referred approvingly to Newtonians such as Edmond Halley and William Whiston.

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[7] Kraft 1763, 22-23: "Om man kalder en uendelig liden Deel af Tiden eller et dens Element *dt*; et Element eller en uendelig liden Tilvext af Hastigheden *dv*; Pressionen eller Trykningen *p*; Materien, som skal bevæges, *m*; da bliver $pdt = mdv$. … Følgelig bliver *pdt* den hele Virkning af Pressionen, *mdv* ligeledes, og derfor $pdt = mdv$ som er den store Hoved-Lighed for Bevægelsens Tilvext i Almindelighed."

2.3 A much-delayed Newtonianism

Kraft's Newtonian approach to natural philosophy was for a long time ignored at Denmark's leading institution for science and scholarship, the University of Copenhagen. Nor was it taken up at Sorø Academy (which was closed in 1792) or at the small University of Kiel, which, since 1773, had been part of the Danish monarchy. Among the few who studied and appreciated Kraft's works was the naval officer Henrik Gerner, who had a solid mathematical education from the Naval Academy (Søkadetakademiet) and also had followed lectures on natural philosophy during a stay in England (Rasmussen 1992). Gerner, who was affectionately known as "Denmark's Newton," was familiar with the works of leading scientists such as Newton, Leibniz and Euler, and he was convinced that the new physics was of use not only for purposes of navigation but also in the construction of naval vessels. His lectures at the Naval Academy, starting in 1777, were much in the tradition initiated by Kraft and entirely based on a Newtonian approach to natural philosophy. However, since he never published these lectures or any other work, Gerner's influence on the Danish academic world was limited.

His enthusiasm for Newtonian physics made him prepare a Danish translation of the *Principia*, but unfortunately he never completed or published this work. The translation survives as a manuscript among Gerner's papers.[8] While a Danish translation of the *Principia* has never been published, there does now exist a Swedish translation, made by the distinguished astronomer Carl Charlier as late as 1927 (Newton 1927).

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[8] The unfinished manuscript is kept at the State Archive in Copenhagen, file "Søetaten. Fabrikmesteren pk. nr. 82a-82b, 88, 92."

The construction of naval vessels was an advanced science which in the eighteenth century increasingly relied on Newtonian principles of mechanics and fluid dynamics (Ferreiro 2007). Gerner’s work and attitude was in many ways similar to that of the Swedish naval engineer Fredric Henric af Chapman, whom he met in the 1760s. But contrary to Gerner, Chapman became known internationally through the dissemination of his publications (Frängsmyr 2000, 233-4). In 1768, he published *Architectura Navalis Mercatoria*, and his *Tractat om Skeppsbyggeriet* (Treatise on Shipbuilding), from 1775, was translated into French.

Norway did not have its own university until 1811 and in matters of science the country was underdeveloped compared to Denmark and even more if compared to Sweden. The relatively modest amount of science that was conducted in Norway focused on botany, agriculture, mineralogy and topography. The exception to this rule was Fredrich C. H. Arentz, who spent most of his active life as teacher and headmaster of the cathedral school in Bergen. After having taken a theological degree, he studied mathematics and physics in Copenhagen and, under Pieter van Musschenbroek, in Leiden. Arentz was a competent physicist in the Newtonian tradition, as may be demonstrated from a work of 1776 in which he analyzed circular motion under the influence of frictional forces (Arentz 1776). He also dealt competently with cosmological questions, such as the infinity of the world, but his works, published in Danish only, attracted no more attention than had the earlier works of Kraft.

Newton and Newtonianism were undoubtedly known in Trondheim, where there was a circle of learned people around the cathedral school and the Trondheim Learned Society formed in 1760. The library of Thomas Angell, a wealthy Trondheim merchant who died in 1767, included several works of

Newton. However, there seems to be no traces of Newton during the first half of the century, neither in Trondheim nor elsewhere in Norway (Dahl 2006). The new Norwegian society published its own journal and in 1767 it was officially recognized as the Royal Norwegian Society of Sciences and Letters, a counterpart to the academy in Copenhagen (Midbøe 1960; Andersen et al. 2009). The society's focus was on natural history and economically useful sciences, whereas physics, mathematics and astronomy were given low priority. This may have been the reason why Newtonian natural philosophy was nearly invisible in the first decades of the journal issued by the Trondheim society. The only exception seems to have been the afore mentioned Fester, who in 1768 moved from Denmark to Trondheim, where he taught mathematics and in 1770 was elected a member of the society. Fester published a few mathematical and physical articles in which he referred to Newton's works in mechanics and optics.

It was only at the end of the century that Newtonian physics made its belated entry to the curriculum of the University of Copenhagen, when the theologically trained geodecist, Thomas Bugge, was appointed professor of astronomy. In an elementary textbook on theoretical astronomy from 1796, Bugge made it clear to the university students that physics meant Newtonian physics:

> Newton's ingenious system began as a mere hypothesis but has become a mathematical certainty because it not only explains the motion and existence of all planetary motions without exception, and why they are as they are; but it even makes it possible to calculate and determine their measures and magnitudes.[9]

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[9] Bugge 1796, 132: "Newtons sindrige System er fra ikkun Hypothese; men det gaaer over til mathematisk Vished, fordi alle Planeternes Bevægelser, ingen undtagen, deraf kan ei

Bugge, however, did not himself master more advanced celestial mechanics, and his account of perturbation theory, for example, remained on a qualitative level.

With this, one might have expected that Newtonian natural philosophy had at long last obtained a solid foothold in Copenhagen, especially since a chair in physics was finally established in 1806. Sadly, this is not what happened. For several more decades, Newtonian physics remained ignored or was at most a peripheral subject as far as research and teaching in physics was concerned.

A main reason for this remarkable state of affairs was that the professor of physics, none other than Hans Christian Ørsted, the discoverer of electromagnetism, neither appreciated nor fully understood the Newtonian system of physics. Ørsted's low appreciation of Newtonian mechanics is evident from his *Første Indledning til den Almindelige Naturlære* (First Introduction to General Physics, 1811), where he gave higher priority to advances in "dynamical physics" – chemistry, including heat and electricity – than to those in mechanical physics. In his opinion, "All the progress which the mechanical branch of physics has made since Newton hardly compares with what has been achieved in dynamical physics during the same period" (Ørsted 1998, 303). Faithful to the ideals of a romantic *Naturphilosophie*, he distrusted the mathematization of physics and sought to build up his own alternative of a dynamic philosophy of nature. In part as a result of Ørsted's dominating position in Danish scientific and intellectual life – he remained the sole professor of physics at Copenhagen until his death in 1851 – the full adoption of the Newtonian system of theoretical physics was delayed until the mid-nineteenth century (Pedersen 1988).

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allene forklares, at de maa være til, og hvorfor de er saadanne, som de ere; men endog deres Maal og Størrelse lader sig beregne og bestemme."

3. Sweden

The Enlightenment was a great period in Swedish science. During the years from about 1730 to 1780, the country belonged to the leading scientific nations of Europe – with Linnaeus as the great icon of the age, although he was far from being the only scientist of international repute that Sweden could boast of (Lindroth 1975-81; Frängsmyr 2000). One reason for the strength and vitality of science in eighteenth-century Sweden was the contacts that Swedish scientists established with foreign colleagues during their travels abroad. Another was the high priority given to utilitarian motivations for science, which in the case of Sweden (in contrast to Denmark) not only meant natural history but also the physical, astronomical and mechanical sciences. The Royal Swedish Academy of Science, established in 1739 with Carl Linnaeus and Mårten Triewald among its founding members, was more active and research-oriented than its Danish counterpart (Frängsmyr 1989). Astronomy, in particular, was an interest of the academy, which reinforced its Newtonian orientation. The academy consisted of five classes, of which one was devoted to astronomy, one to experimental physics and mathematics, and one to natural history; the other two classes were oriented towards industry and the Swedish language, respectively.

3.1 The end of Cartesianism in Sweden

Newton and his works were known from an early date by Swedish natural philosophers. The professor of astronomy at Uppsala, Andreas Spole, owned a copy of *Principia* in which he wrote the date "1692," and which was later bought by the astronomer Niels Celsius, the father of Anders Celsius (after whom the temperature scale is named). It is likely that Newton's work was also in the possession of Harald Vallerius, who served as professor of mathematics from 1690 to 1712 and who, as early as 1694, made reference to Newton's fluxion calculus. Newton's view of the shape of the earth, as discussed in the *Principia*, was mentioned in an Uppsala disputation from 1693, *De Centro Terrae* (Rodhe 2002, 15-16). Of even greater interest is the fact that Sven Dimberg, who in 1690 became professor at the new university in Tartu (Dorpat) in Swedish-occupied Estonia, made the acquaintance of the *Principia* shortly after its publication and introduced parts of Newtonian natural philosophy into the curriculum in the 1690s. In a lecture catalogue for the academic year 1697-98, it was stated that (Lumiste and Piirimäe 2001, 10):

> Sven Dimberg, Professor of Mathematics, continues publicly and in general order the analysis of mathematical principles of Newton's Natural science; here the definitions and axioms (*Definitiones & Axiomatica*) of the previous year will be presented, … and certainly these sentences which concern the centripetal forces (*de Virium Centripetarium*); a theory on the movement of bodies along the circle (*in Perimetris cyclicis*) and along the eccentric conic section (*in Sectionibus Conicis Excentricis*); from among the remaining part of these principles, he explains the world system (*Systema Mundanum)* from the third book.

Another learned Swede who took an early interest in Newton's work was Petrus Elvius, Spole's successor as professor of astronomy at Uppsala. He owned a copy of the 1687 edition of *Principia* and mentioned it in publications from 1703 and 1704, but without accepting Newton's system of the world. Like Spole or Niels Celsius, Elvius was a staunch supporter of the dominant Cartesian vortex theory, which he found to be simpler and physically more satisfying than Newton's ideas. This was the general view in the early part of the century and also the conclusion of *De Causis Motuum Coelestium*, a dissertation from 1716. Its author, Johannes Wallander, discussed Newton's law of gravitation, which, however, he thought was obscure and lacked a proper physical foundation (Nordenmark 1959, 138). Wallander knew about the law of gravitation from David Gregory's *Astronomiae Physicae et Geometricae Elementa*, first published 1702. At that time there was a great deal of interest in Newton's physics among Swedish men of science. The interest is reflected, for instance, in the agenda of the short-lived Collegium Curiosorum, a learned society founded in Uppsala in 1710 and lasting until 1719. But, although Newton was on the agenda, there still were no Newtonians.

The young Emanuel Swedenborg spent the years 1710 to 1715 abroad on an extensive study tour, and in London, where he stayed for three years, he engaged in a serious study of Newton's works and established contacts with several British natural philosophers. In a letter dating from 1711, Elvius asked him for information of how astronomers in England regarded "principia motuum Planetorum Newtoni." Elvius was curious, for he considered himself Newton's theory to be "pure abstraction and devoid of physics; for it seems incomprehensible how one of the planetary bodies can act gravitationally on another etc." (Nordenmark 1959, 138).[10] His successor, Niels Celsius, also dismissed Newton's theory and stuck to the more comprehensible vortex theory associated with the Cartesian tradition.

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[10] "… principia motuum Planetarum Newtoni, efter de synas wara pur abstraction och intet physica, nämligen hur det ena corpus planet skall gravitera på ett annat etc. Som tyckes wara orimligt."

It was not only astronomers, however, who found Newton's works of interest. The famous engineer Christopher Polhem – among contemporary Swedes known as the "Archimedes of the North" and today as "the father of Swedish technology" – is best known for his mechanical inventions but was also a natural philosopher of considerable reputation. He was basically a Cartesian materialist, though with the important exception that he believed that the material world consisted of spherical corpuscles moving around in a vacuum (Hård 1986; Dunér 2010). Polhem was acquainted with Newton's theory of the heavens, which he knew from Elvius' copy of the *Principia*, which he borrowed from about 1712. As a Cartesian, Polhem shared Elvius' view that Newton's work was "pure abstraction and devoid of physics." For Polhem, as for many others, the law of gravitation was objectionable as long as no cause could be given for the force of gravitational attraction. Of course, objections of this kind were shared by many natural philosophers in continental Europe. During the 1710s, Polhem corresponded with several Swedish natural philosophers about Newton and his theories, and the opinion that he expressed was always critical, both with regard to Newton's personality and to his theories. For example, in a letter to Eric Benzelius of April 1712, Polhem wrote (Rodhe 2002, 26):

> I have looked over the speculative Newton, whose method is very difficult and intricate. If his principles of centripetal and centrifugal forces were absolutely certain, I should be able to present it all in an easier way.[11]

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[11] "Dhen speculative Neuton har iag igenom sedt, hwars method är mycket swår och intricat, men om hans principia de centripeta et centrifuga wore aldeles säkre så skulle iag visa en facilera wäg til altsammanss."

And, in a slightly later letter, Polhem commented (Rodhe 2002, 26; Nordenmark 1959, 139):

> I must admit that [Newton] has been a great mathematician, but apart from that he seems to me to be rather childish, for I think that he, for reasons of vanity, makes more fuss and presents more elaborate demonstrations of things which could be established in a simpler way.[12]

From about 1720, Cartesianism was on decline in Sweden and the natural philosophers were ripe for the Newtonian world-view, if often in a version that reflected the influence of Wolffianism, which, during the period 1720-50, was a strong force in both Danish and Swedish intellectual life (Frängsmyr 1972). Niels Celsius's successor, Erik Burman, took an important step by introducing Newton formally into the Uppsala curriculum and gave the first lectures in Sweden on Newton's theory. In 1725, he lectured on the two world systems, the Cartesian and the Newtonian, and from 1726 to 1729 he gave lectures on elementary Newtonian astronomy, based on William Whiston's *Praelectiones Astronomicae*, which had first been published 1707 (Nordenmark 1959, 153).

However, Burman was a relatively minor figure – his main interests were music and meteorology – and it was not until Anders Celsius was appointed professor of astronomy in 1730 that the winds really changed. The younger Celsius was Sweden's first true Newtonian, although in his case Newtonianism was still mixed up with elements of Wolffianism (much as it was in the case of Kraft in Denmark). Whereas his father had dismissed Newton's system, the younger

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[12] "Iag måtte till stå att han har warit en stor Mathematicus men der uthi tykkess han warit något barnslig att han för sin gloire skull, kan jag tenka, gör mehra wessande och widlyfftigare Demonstrationer om dhe ting som på simplare sett kunde afgörass."

Celsius dismissed the Cartesian system. In several of his works from the 1740s, he hailed Newton as a genius of science and criticized the Cartesian vortex system as a chimera. The title of one of these works, *Vortices Cartesiani, ut non-Entia* from 1743, speaks for itself (Nordenmark 1936, 107).

From the mid-eighteenth century, Newtonian astronomy was firmly established in Sweden, not only among astronomers but also among the educated public in general. Mårten Triewald is perhaps best known as an engineer and visionary technologist, the constructor of Scandinavia's first steam engine, a Newcomen machine that he completed in 1728, but which never worked satisfactorily (Lindqvist 1984). However, practical engineering works were only one of the interests of the talented Triewald, who was also an early enlightenment natural philosopher in the Newtonian tradition. He gave lectures on the new philosophy of nature in 1729 and in 1735 and 1736 he published *Föreläsningar öfwer Nya Naturkunnigheten* (Lectures on the New Philosophy of Nature), in which he enthusiastically described Newton's *Principia* and his celestial mechanics.

During the following decades, several more books appeared in a similar style, either as translations or original works. For example, James Ferguson's popular astronomy, *Astronomy Explained upon Sir Isaac Newton's Principles*, a work first published in 1756, appeared in 1771 in a Swedish translation (Ferguson 1771). The translator, Erik Wasberg, introduced the book with a lengthy foreword, and the eminent astronomy professor and convinced Newtonian, Pehr Wilhelm Wargentin, provided it with a series of notes (Nordenmark 1939, 295-96). The following year another Swedish astronomer, Fredrik Mallet, published *Allmän eller Mathematisk Beskrifning om Jordklotet* (General or Mathematical Description of the Earth), an advanced handbook on the structure of the earth and the universe. This book, which was thoroughly based on Newtonian principles, was published by the Cosmographical Society (Kosmografiska Sällskapet) in Uppsala, a society founded in 1758 and lasting until about 1778. Another work in the same genre was *Physick Beskrifning ofver Jordklotet* (Physical Description of the Earth) published in 1766 by the famous chemist Torbern Bergmann.

3.2 Celsius and the shape of the earth

Unlike the situation in Denmark-Norway, Newtonian science was not only received passively in Sweden. Swedish natural philosophers also contributed to the international development of Newtonianism, as was the case with Anders Celsius's involvement in the famous debate over the shape of the earth, which was widely considered a crucial test of Newton's idea of universal attraction.

In the *Principia*, Newton had argued that centrifugal force, due to the rotation of the earth about its axis, should cause the earth to bulge at the equator and to be flattened at the poles. He deduced on theoretical grounds that the earth would be higher at the equator than at the poles by some 17 miles, a value he found corroborated in pendulum measurements made in 1672 at Cayenne by the French engineer and astronomer Jean Richer. According to Descartes and his followers, the cause of gravitation was a vortex of matter swirling about the earth, and the Cartesians argued that this vortex would result in a flattening at the equator and in elongation at the poles (Descartes did not himself draw this conclusion). The debate took off in 1718, when the Parisian astronomer, Jacques Cassini, claimed to have confirmed the prediction based on Cartesian theory. British natural philosophers came out in support of Newton, and, in 1732, after Newton's death, the French mathematicians Pierre-Louis Moreau de Maupertuis and Clairaut also supported the Newtonian prediction of an earth flattened at the poles. In order to settle the question the curvature of the earth needed to be measured near the equator and near the poles.

While an expedition, financed by the French government, departed for Ecuador in 1735, the following year a polar expedition under the direction of Maupertuis set off for the northern part of Scandinavia. Celsius had already in 1732 set out on a grand tour that would bring him to Germany, Italy, France and England. In 1735, he made the acquaintance of Maupertuis in Paris, and was thus invited to join the expedition that was just then being planned. He happily accepted and went on to London, where he purchased scientific instruments and was elected a foreign member of the Royal Society. The story of the difficult but successful expedition to Torneå in Lapland (which is now part of Finland) is well known and needs not be recounted at this point (Nordenmark 1936, 59-98; Terrall 2002, 88-172).

The results obtained in Lapland confirmed that the earth was flattened at the poles. In the autumn of 1737, after having returned to Uppsala, Celsius wrote to the philologist Eric Benzelius that “the figure of the earth agrees with the opinion of Newton” (Nordenmark 1936, 70).[13] When Maupertuis at about the same time gave a full report to the Paris Academy it aroused a major controversy with Cassini and other French Cartesians. This only died out several years later, when the measurements from Ecuador turned out to confirm the Lapland results, at least qualitatively. Although Celsius was not originally part of the controversy, he firmly sided with Maupertuis and, in a polemical treatise of 1738, written in Latin,

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[13] ”… och kommer Jordens figur att bli efter Newtons mening.”

he severely criticized the arguments and measurements of Cassini. In *De Observationibus pro Figura Telluris* he charged that "Cassini's observations, terrestrial and celestial, in the southern part of France, are sufficiently uncertain that it is impossible to deduce the shape of the earth from them" (Terrall 2002, 138). Celsius sent his work to several of his colleagues abroad and requested that the journal of the Royal Society, the *Philosophical Transactions*, should review it. As might have been expected, the London natural philosophers were delighted to do so. An extensive account was written by John Eames, a theologian and natural philosopher who was also a Fellow of the Royal Society (Eames 1739).

Anders Celsius is probably best known for his work in thermometry, which gave rise to the scale named after him. In a paper of 1742, published in the newly founded journal of the Swedish Royal Academy of Sciences, he suggested a way to fix the points of the thermometer scale so that the freezing point of water was assigned the value of 100 degrees and the boiling point of 0 degrees (Celsius 1742). The present system, with the scale reversed, was introduced in Uppsala a few years after Celsius's death, possibly by the instrument maker Daniel Ekström. In this context it may be relevant to note that the other internationally used temperature scale has a Scandinavian connection. Although named after the German-Dutch natural philosopher Daniel Gabriel Fahrenheit, the idea of using the freezing and boiling points of water as fixed points goes back to Ole Rømer. It was during a visit that Fahrenheit paid to Rømer in Copenhagen in 1708 that he had the idea of the temperature scale named after him (Van der Star 1983, 171). But these achievements and interests perhaps owed more to the work of the early Royal Society, of Robert Boyle and Robert Hooke, rather than Isaac Newton.

3.3 Newtonian physics, experimental and theoretical

Triewald, the Swedish pioneer of experimental physics, had no university education, but his lack of formal training was compensated for by a burning interest in science and technology (Lindqvist 1984; Beckman 1967-8). He spent the years from 1716 to 1726 in England, where he immersed himself in the literature of the new natural philosophy and became an ardent admirer of Newton and everything Newtonian. He may even have met the great man in London. More importantly, Triewald became acquainted with the French-born John Theophilus Desaguliers, the leading experimentalist and fellow of the Royal Society, whose lectures attracted great attention. Inspired by Desaguliers, Triewald gave his own public lectures with demonstrations of experiments. His lectures in Newcastle and Edinburgh in 1724 and 1725 covered mathematical, optical, hydrostatic and pneumatical experiments, in the tradition of Desaguliers and of the Dutchman, Willem Jacob ’s Gravesande. The lectures must have been successful, for in 1731, after having returned to Sweden, Triewald was elected a Fellow of the Royal Society. In the same year, he published one of his experiments, on the supercooling of water, in the *Philosophical Transactions* (Triewald 1731-2).

Triewald continued his experimental lectures in Sweden, and his efforts did much to disseminate the Newtonian philosophy of nature. He gave his first lecture in Stockholm in 1728, assisted by Daniel Menlös, who in 1732 was appointed professor of mathematics in Lund and gave his own lecture course there in experimental physics. Triewald’s *Föreläsningar* (Lectures), the published version of his lecture series, was modelled on the books of Desaguliers and ’s Gravesande. Triewald was not alone in cultivating experimental physics in Sweden in the first half of the eighteenth century. Apart from Menlös in Lund, Anders Celsius also gave lectures in physics, which he based on the second edition of ’s Gravesande’s *Philosophiae Newtonianae* (1728). He arranged to have the book reprinted as a textbook for the students in Uppsala, where it was published in 1738 under the title *Gulielmi Jacobi Gravesande Institutiones Astronomicae in Usum Iuventutis Patriae*.

Experimental physics in the Newtonian tradition was also pursued by Nils Wallerius, who was appointed lecturer in physics at Uppsala in 1735. Although influenced by Leibniz and Wolff, Wallerius defended the idea of gravitational force as an action at a distance. He abandoned natural philosophy in about 1745, and later became a professor of theology. When Samuel Klingenstierna became professor of experimental physics in Uppsala in 1750 – the first to hold such a position in Scandinavia – he was obliged to give lectures in optics, mechanics, hydraulics, aerometry and Newton’s theory of gravitation. For this purpose, he acquired a physical cabinet and published in 1756 the textbook *Grunderne til Mechaniken* (The Principles of Mechanics). Three years after Klingenstierna was appointed in Uppsala, a similar chair of experimental physics was established in Copenhagen. However, the new professor, the German Christian Gottlieb Kratzenstein, specialized in the theory of electricity and was not a Newtonian (Snorrason 1974; Splinter 2006). In his textbook of 1758, *Systema Physicae Experimentalis*, he explained gravitation in terms of a ‘subtle fluid matter’, rather than accepting action at a distance.

The most important Swedish contribution to Newtonian physics was theoretical and thus, in a sense, anti-Newtonian. As early as 1725, Klingenstierna had written a paper in the *Acta Literaria Sueciae* in which he solved a mechanical problem based on the *Principia*. During his travels abroad between 1727 and 1731, he had met many of Europe's foremost mathematicians, including Johann I Bernoulli, James Stirling, Gabriel Cramer and Alexis Claude Clairaut. While in Marburg, where he followed Wolff's lectures, Klingenstierna wrote a thesis on Newton's theory of curves of the third degree, which qualified him to be a professor of mathematics in Uppsala. The thesis, entitled *Analysis Enumerationes Neutonianæ Linearum Tertii Ordinis*, remains only in a handwritten manuscript (Oseen 1925, 35-38; Rodhe 2002). After stays in Basel and Paris, Klingenstierna came to London, where he was elected a fellow of the Royal Society at the age of thirty-two. A talented mathematician, he was instrumental in introducing the new infinitesimal calculus in Sweden and in applying it to problems of physics. He was aware of Newton's method of fluxions, but, in his mathematical works, he was influenced by Johann Bernoulli and consequently adopted Leibniz's differential calculus. Although he was a highly reputed mathematician, he is best known for a work in physics he published in 1754.

According to Newton's theory of optics, dispersion could not be produced in an undeviated beam of light. For this reason Newton insisted that a spherical lens would necessarily produce chromatic aberration, a result that was of obvious interest to astronomers. Although Euler had challenged this Newtonian orthodoxy in a paper of 1748, it was generally accepted that Newton was right (Taton 2000). However, in a paper from 1754, Klingenstierna argued on mathematical grounds that this law of Newton was not universally valid (Klingenstierna 1754). He was aware that the London instrument maker, John Dolland, had defended Newton's view against Euler and therefore sent a Latin summary of his proof to him. A couple of years later, Dolland took out a patent on the first telescope equipped with achromatic lenses, but avoided making mention of Klingenstierna and his mathematical arguments. We need not be concerned with the controversy that followed, except for noting that Dolland's invention relied significantly on Klingenstierna's theoretical work (Nordenmark and Nordström 1938-9; Hutchison 1991). In 1760 Klingenstierna did what Dolland had been unable to do, namely to deliver a full theory of the optics of achromatic lenses. Like his earlier work, this paper was originally published in Swedish, but a Latin version of it also appeared in the *Philosophical Transactions* (Klingenstierna 1760).

4. A note on natural theology

Newtonianism was more than just mechanical physics and experimental natural philosophy. It also included a substantial element of natural theology, in turn based on Newton's laws and system of the world. This tradition, if rarely in a purely Newtonian version, was very important in the Scandinavian countries throughout the eighteenth century. To give a single example, the English vicar and natural philosopher William Derham's Boyle Lectures of 1714 were translated into Swedish in 1736 as *Physico-Theologie* (Derham 1736). Some years later they also appeared in a Danish translation, together with another of Derham's influential works, the slightly later *Astro-Theology* (Derham 1759). In 1753, Jens Kraft published a small textbook on natural theology that drew on examples from physics and astronomy, but which paid little attention to Newtonian natural philosophy in particular (Kraft 1753).

During the second half of the eighteenth century natural theology or physico-theology was much *à la mode* in Denmark, and Newton's ideas fitted nicely into this trend. For example, the philosopher and scientific author, Tyge Rothe, greatly admired Newton because of his repeated emphasis on science as a means to recognize the existence of a divine being. He quoted with enthusiasm query 28 from Newton's *Opticks*, in which the great natural philosopher had concluded that "though every true Step made in this Philosophy brings us not immediately to the Knowledge of the first Cause, yet it brings us nearer to it, and on that account is to be highly valued" (Newton 1952, 370; Rothe 1797, 3).

Many Swedish, Danish and Norwegian works in the tradition of natural theology took their inspiration from natural history rather than from physics or astronomy. Insects, plants and rocks were the favourite choices to demonstrate the existence of the almighty God, rather than the planets, which revolved under the influence of Newton's force of gravity. Moreover, such writings were coloured as much by Wolffianism as by Newtonianism. With the advent of Linnaeus's successful system of the living world this branch of literature flourished. However, it had little connection to the Newtonian tradition. Linnaeus and his followers would indeed have agreed with William Paley, who in his *Natural Theology* stated: "My opinion of astronomy has always been that it is *not* the best medium through which to prove the agency of an intelligent Creator" (Paley 1805, 417).

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