NORDIC SCIENCE

IN HISTORICAL PERSPECTIVE

by
JOLE SHACKELFORD

NCCP
No. 1

Nordic
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NCCP—the Nordic Culture Curriculum Project—is the acronym for a two-volume work planned by a North American committee of scholars. The primary volume is meant to make up a STUDENT READER in a form suitable for undergraduate instruction. The volume, which consists of a series of pamphlets, will provide short and authoritative introductions (in quarto size: ISSN 1077-2073) to various aspects of Scandinavian Life and Civilization. The pamphlets of the READER are written by scholars with expertise in the areas concerned and are subjected to a voluntary field testing by interested Scandinavianists at various universities. The series will also include a "Guidé for Student Use." The companion volume, a TEACHERS' GUIDE (in octavo size: ISSN 1077-2073), will provide additional information for each of the pamphlets, possible student examinations and research topics, and updatable supplementary bibliographies for students and instructors.

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In 1952 The Nordic Council was established (it is now an 87-member parliament, consisting of delegates from Denmark, the Faroe Islands, Finland, Greenland, Iceland, Norway, Sweden, and Åland), and in 1971 the Nordic Council of Ministers was formed as an instrument to coordinate cooperation between the governments of the Nordic countries. The Council has furnished the financial support necessary to start the NCCP series, which will initially make the following titles available:

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NORDIC SCIENCE IN HISTORICAL PERSPECTIVE

by
Jole Shackelford

Science and the technology it facilitates exert a powerful influence on modern cultures everywhere in a variety of ways. Scientific theories shape much of our moral and intellectual culture by informing our understanding of the cosmos and our place within it, our relationship to the plants and animals around us, and our dependence on a complex ecosystem for survival. These theories and the technologies they support pose moral problems and offer new ways for people to interact with one another and control their environment. Furthermore, technologies made possible by scientific development have reshaped our material culture, and this alone has had a tremendous global *cultural* consequence. It is Western technology, not Western moral or political order, that is taking root in Eastern industrial countries and supporting a global hunger for a material culture that has grown out of what was in origin European science. For all these reasons, spiritual as well as material, science and its history are important aspects of modern societies and should be a part of the general area studies of any region.

Within the Nordic countries science has been particularly influential and prominent, owing both to the historical importance of Denmark and Sweden, which produced scientists of the first rank in the "early modern" period (1500s to 1700s), and to the rapid industrialization of Norden in the late nineteenth and twentieth centuries. Furthermore, the political maturation of Norway, Denmark, and Sweden during the Enlightenment firmly established a tradition of solving economic and social problems *rationally*, defined as applying scientific methods to such problems. The result is that science as an ideal and a particular approach to research and development is today deeply embedded in Nordic intellectual life and industrial production.

This introduction to science in the five Nordic countries (Denmark, Finland, Iceland, Norway, and Sweden) will focus on two main themes: (1) science as part of society's historical consciousness and (2) scientific institutions as a base for funding and controlling the research and technology that help produce the material culture of the modern Nordic industrial societies. The first of these two themes requires an introduction to some of the prominent scientists and scientific developments that have become cultural

Holberg, Science, and Society

Ludvig Holberg (1684-1754), considered by many to be the father of Danish and Norwegian literature, was an astute observer of early eighteenth-century society. His play *Erasmus Montanus* (finished 1723, published 1731) is regarded as a satirical jab at academic speculation and learning for its own sake. The main character, Rasmus Berg (Latinized, Erasmus Montanus) returns from the university to his rural home, where his shallow academic sophistication is ridiculed in contrast to the self-evident truths of common sense. Yet Rasmus's forced admission that the world is flat, an echo of Galileo's recantation of the Copernican hypothesis (that the earth moves around the sun) made before the Catholic Church a century before, reveals the importance of scholarly debate in contemporary Danish society. Conservative theologians had refused to accept the Copernican hypothesis in the absence of decisive proof, which had not yet been found. During Holberg's years as a student and professor at the university of Copenhagen, a tension existed between the theologians and the natural philosophers. Finally, Christian Horrebow, a professor of physics, succeeded in determining the stellar parallax arising from the motion of the earth, which he revealed in his *Copernicus triumphans* (1727). *Erasmus Montanus*, then, provides a rare glimpse into the reception of scientific theory by laymen.

emblems within the North. They are the historical icons that are part of a society's collective consciousness. In America, for instance, this would include such figures as Benjamin Franklin and Thomas Edison and such inventions as the telephone and airplane. In Britain it would feature Isaac Newton and Charles Darwin, the development of the railroad and the discovery of penicillin, and so on. In Denmark scientific laurels have similarly been bestowed on the great astronomer Tycho Brahe, in Norway the famous explorer Fridtjof Nansen, and in Sweden the botanist Carl Linnaeus. Such exemplars from a nation's history recall the past achievements of its people and symbolize the vitality of its culture. They are therefore important elements of cultural history. Furthermore, by studying these exemplary figures and the *institutions* they helped to create, some generalizations can be drawn about the history of the organization and funding of science. In this survey selected examples from the five Nordic countries will illustrate various types of institutional organization, which accommodate private control and philanthropy as well as state funding and regulation.

SCANDINAVIAN SCIENTISTS AND EARLY INSTITUTIONAL DEVELOPMENT

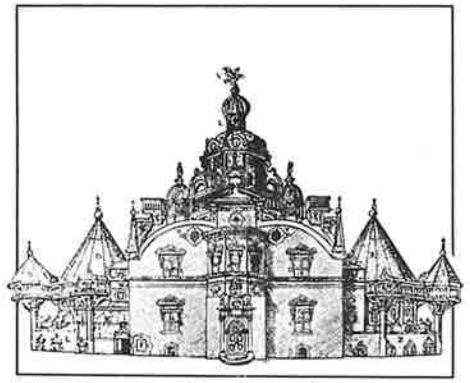
Today, when we think of institutional science, we think first of the universities. Even if they are not the sites of all or even the most productive research and development, universities are the focus of scientific education. Such was also the case in early modern Scandinavia, when "natural philosophers" (those interested in what we today call scientific subjects) were trained at universities and employed by them or by wealthy patrons. The university as an institution initially developed in Italy, France, and England in the twelfth century, and the first Scandinavian universities appeared in the late fifteenth century (Uppsala, 1477; Copenhagen, 1479). Those universities served mainly to train priests and educate civil servants to fulfill the needs of church and state, and it was not until the very late sixteenth century that what we today would recognize as scientific subjects attracted Scandinavian students. Before that, even those choosing to pursue medicine traveled abroad for advanced study.

The first universities were generally divided into four departments or faculties: philosophy, theology, law, and medicine. Scientific subjects were part of the curriculum in both philosophy (for example, mathematics, matter theory, cosmology, classification) and medicine (rudimentary anatomy, knowledge of herbs, astrology, medical theory), and subjects such as astronomy were a part of both. Teaching and examinations within these faculties were governed by a university's constitution and by academic tradition, which guaranteed a fairly uniform standard across Europe. The conservative bureaucratic structure tended to discourage curricular innovation, and therefore the earliest scientists of international repute often worked outside the university. The two most widely known sixteenth-century Danish scientists, for example, were Peter Severinus (1540/42-1602) and Tycho Brahe (1546-1601), neither of whom were professors.

Severinus served as royal physician, and although he maintained close contact with the academic community, he was obliged to travel with the court. His medical theories, which were based on the doctrines of Paracelsus, were influential in seventeenth-century Europe. Tycho Brahe was an astronomer—the first since antiquity to understand that a mass of accurate observations was a prerequisite for sound astronomical theory. It was his data that enabled the German mathematician Johan Kepler to lay the foundations for the modern planetary model with elliptical orbits. The observations that made this breakthrough possible were made by Tycho and his assistants at a unique observatory complex on the island of Hven in the sound between Sjælland and Skåne. There a fortunate combination of royal patronage and autonomous scientific leadership produced a scientific institution that surpassed the universities.

Tycho's reputation as an astronomer and alchemist had become so great by the early 1570s that when he threatened to leave his native Denmark, King Frederik II interceded. Tycho was a nobleman and could not, like Severinus, be "hired" as a royal employee, so the king offered Tycho a feudal estate—the island of Hven—and promised him additional grants to enable him to construct a manor with an observatory and laboratory. The king was interested in furthering both astronomy and alchemy, which were fashionable princely pursuits in those days. Using inherited wealth to supplement the royal largesse, Tycho built *Uraniborg*, a magnificent villa equipped with observational platforms, rooms for student-assistants, and an extensive chemical laboratory in the basement. Although the time and expense Tycho devoted to his chemical investigations produced nothing of lasting scientific value, the laboratory equipment rivalled that of the most enthusiastic princes and was the envy of leading chemists. His observatory was equally enviable. Since Tycho was measuring the angles between stars, the accuracy of his observations depended on the size, stability, and quality of the instruments. To support large instruments properly and protect them from the wind, which would jar them slightly, Tycho built an additional observatory called *Stjærneborg*. There the various apparatus could be set up on large foundation stones and in pits, where they were out of the wind. With his best instruments Tycho doubled the accuracy of his predecessors' measurements.

Tycho's establishment on Hven was much more than an observatory and is considered today to have been the first scientific institution per se in Europe. At *Uraniborg* Tycho housed his student assistants, sometimes for many years, and received visiting scholars and dignitaries. Besides the laboratories and observatories, Tycho set up a press for publication of his work and erected a



East elevation of *Uraniborg*, from the original 16th-century "Marburg Woodcut"

Uraniborg

Tycho Brahe constructed *Uraniborg* at the center of the island of Hven, which rises above the foggy "Danish Sound" (Øresund). Its insular location, yet within sight of the military and political centers Copenhagen, Helsingør, and Landskrona, made *Uraniborg* an ideal location for the pursuit of astronomy and chemistry. It was accessible to those who had business there, but protected from uninvited guests who might disrupt research. In the half century after Tycho's death, *Uraniborg* was dismantled for building material, and today only the excavation remains to stir the imagination of the occasional visitor.

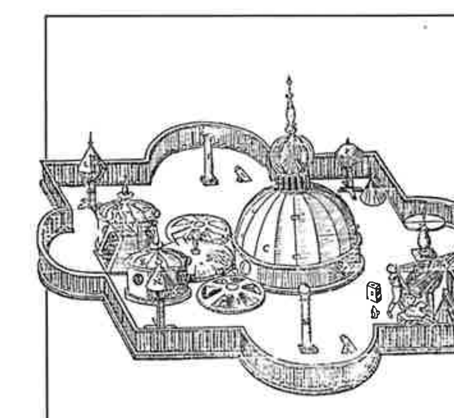
Royal Support for the Sciences in Denmark

King Christian IV established a chemical laboratory and hired Peder Payngk (1575-1645) to prepare the latest chemical medicines, elixirs, and liquors. The crown maintained, throughout the century, an interest in chemical wonder drugs, the artificial production of gold and silver from base metals, and the chemical refining of ores and created an "extraordinary" professorship for Ole Borch (1626-90) at the University of Copenhagen.

The king supported astronomy, too, and had the famous Round Tower (Copenhagen) erected as an observatory. Tycho's student, Christian Sørensen Longberg (Longomontanus, 1562-1647), taught astronomy at the University of Copenhagen, but his work looked backward to Tycho's astronomy, and he therefore did not adopt the newer mathematics and cosmology of Galileo and Kepler. Ole Rømer (1644-1710) was another Danish astronomer, but his major contributions were accomplished abroad before he was appointed professor of mathematics at the University of Copenhagen.

Petrus Severinus

In response to King Frederik II's desire to improve the condition of Danish medicine, Petrus Severinus the Dane (1540/42-1602) received an academic stipend to travel to Germany, France, and northern Italy to study at Europe's best universities. On his travels he became fascinated with Theophrastus Paracelsus's medical ideas, which were causing a tremendous controversy in the 1560s, especially in France. Severinus's book, *The Ideal of Philosophical Medicine* (1571), was one of the earliest attempts to synthesize and build Paracelsian ideas into a coherent system. His novel assertion that diseases were specific entities rather than imbalances in the body's constitution was widely commented upon in the seventeenth century.



Stjærneborg. Illustration from Tycho Brahe's *Epistolarum astronomicarum libri* (1596). From the University of Oklahoma Library's History of Science collection


Künstliche Zerlegung Menschlichen Leibes, Des Hochgelährten und Weitberümbten Herrn D. CASPARI BARTHOLINI; itzo durch Anordnung D. SIMONIS PAULLI. Med. Anat. ac Botan. P.P. In der Königlichen Academien Kopenhagen, mit fleisse Allen Wündartzten zu nütz ins Deutsche übergesetzet. 1 6 4 8.

Detail from Caspar Bartholin and Simon Paulli's book on anatomy, published in Copenhagen, 1648

Thomas Bartholin and Anatomical Study

Thomas Bartholin (1616-80) and Olof Rudbeck (1630-1702) today share credit for the discovery of the lymphatic system in humans: historians have determined that Rudbeck was actually the first to observe the ducts and nodes (1650-52), but Bartholin was the first to publish and describe the lymphatic system (1653). Such cases of near simultaneous, often independent discovery in the sciences increase in likelihood as research agendas become more and more global. However, the priority disputes that have ensued point to the continued importance of individual and national prestige in scientific achievement.

In the seventeenth century, anatomy was one of the cutting edges of scientific research. A century of careful dissection and vivisection had disproved ancient and medieval conceptions of human physiology and resulted in a complete rethinking of the basic cardio-pulmonary system and the role of the blood in the body. A movement to include anatomy in the medieval curriculum had already begun in northern Italy in the late Middle Ages, but anatomy was accepted very gradually and only grudgingly in the north. When Dr. Anders Christensen tried to introduce anatomical demonstration at the University of Copenhagen in the late sixteenth century, he was discouraged by his peers. The "New Constitutions," which were intended to modernize the University in 1621, called for the teaching of anatomy and botany, but the conservative medical professors delayed implementation of those ideals. Finally, Christian IV appointed a German physician, Simon Paulli, to carry out curricular reform, and an anatomical theater was soon completed (1645). The new facility enabled Thomas Bartholin to carry out his detailed anatomical studies without having to work abroad.

paper mill to supply it. A library provided a place for researchers to gather. There they could use Tycho's collection of medical, chemical, and astronomical books, and they could chart stellar observations on the large celestial sphere Tycho had specially made for this purpose by German artisans. Outside *Uraniborg* there were extensive gardens that supplied herbs for use in the chemical laboratories.

From the laying of the first stone for *Uraniborg* in 1576 until Tycho abandoned Hven in 1597, the institution served as an intellectual center and an emblem of Denmark's cultural achievement. Students serving as Tycho's assistants there had access to the best equipment available and a research milieu that fostered advanced inquiry into subjects not well represented at the universities—observational astronomy and medical chemistry. Although no institution replaced *Uraniborg* and *Stjærneborg*, astronomy and chemistry continued to be supported by the crown in the seventeenth century and eventually gained a foothold in the University of Copenhagen. The Thirty Years' War (1618-48) and its aftermath crippled Denmark's economy and weakened the scientific initiative begun by Severinus and Brahe in the last quarter of the sixteenth century. A series of military defeats at the hands of the Swedes confirmed Sweden's ascent in the North and resulted in Denmark's loss of some of its richest lands, which are today part of southern Sweden. The University of Copenhagen continued to produce or employ scientific leaders in the seventeenth century, such as Ole Rømer (1644-1710), the astronomer; Ole Worm (1588-1654), the famous physician and collector of natural curiosities; Simon Paulli (1603-80) the botanist; and Niels Stensen (Steno 1638-86), a pioneer in geological theory and human anatomy. But institutional growth faltered. Stensen was unable to secure a position in Denmark and lived abroad for most of his life. Ole Borch (Olaus Borrichius 1626-90), who strove to keep the university at the forefront of education in medical chemistry, was given an extraordinary professorship (instead of a permanent chair) to teach chemistry and botany. That professorship was discontinued after his departure.

It is perhaps symptomatic of Denmark's decline that Thomas Bartholin (1606-80), the century's greatest Danish anatomist, was locked in controversy with Olof Rudbeck (1630-1702), his Swedish rival, over credit for the discovery of the lymphatic system. Rudbeck himself was largely responsible for revitalizing Uppsala University, from the designing and erecting of new buildings to the establishment of a first-rate botanical garden. By the eighteenth century Sweden had attained scientific leadership within Scandinavia.

The Swedish Enlightenment of the eighteenth century produced first-rate scientists in many fields, men such as the chemists Torbern Bergman and Carl Scheele, who is credited along with Joseph Priestley for the discovery of oxygen. But none surpasses Carl von Linné (1707-78) in international fame. Linnaeus, to use the Latin form of Linné, is certainly one of the best-known names in the history of botany today.

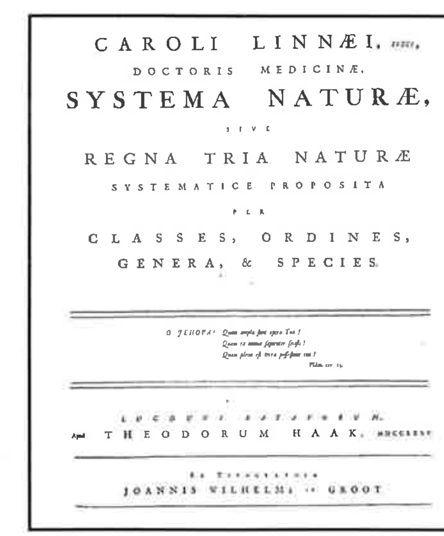
Linnaeus

Beginning with the fifteenth-century voyages of discovery, European awareness of the rest of the globe and the richness of the natural world grew rapidly. Descriptions and specimens of plants and animals from all over the planet reached Europe's ports and universities, including exotic species from the previously unknown continents of the Americas and Australia.

The influx of many previously unknown types of life forms threw existing systems for classifying plants and animals into complete confusion. Although the medieval herbals and bestiaries (*compendia*) were sufficient for ordering the chief forms that were native to the Mediterranean basin and could be stretched to include north European varieties, they could scarcely accommodate the new types from the Far East and transatlantic lands. Leading botanists began to create new systems of classifying and naming plants, but no one system achieved consensus; without standardization, scientific communication was difficult. Reports and specimens of strange animals imported from South Asia, Australia, Africa, and the Americas forced anatomists to ponder the relationships and similarities among animals. Linnaeus, a genius at classifying most everything, was able to provide rules for classification and new names that helped place both plants and animals into some semblance of order.

Linnaeus, painted in 1775 by Alexander Roslin (1718-93)

Linnaeus was well schooled in traditional natural philosophy and a first-rate observer of individual specimens. Following the precepts of Aristotle, Linnaeus understood that observation of the individual was the basis upon which generalizations about species and kinds could be built. And he shared Aristotle's desire to classify organisms according to fixed criteria. But Linnaeus differed from many of his predecessors by attempting to find a "natural" system of classification, one dictated by the characteristics of the things themselves rather than by their utility to man or by other artificial criteria. In medieval herbals, for example, plants were grouped alphabetically. Linnaeus wanted things classified according to their relationships to one another: the *similarities* that grouped individual types or "species" into "kinds" (*genera*) and the *differences* that distinguished species from one another.


CAROLI LINNÆI,

DOCTORIS MEDICINÆ,

SYSTEMA NATURÆ,

SIVE

REGNA TRIA NATURÆ

SYSTEMATICE PROPOSITA

PER

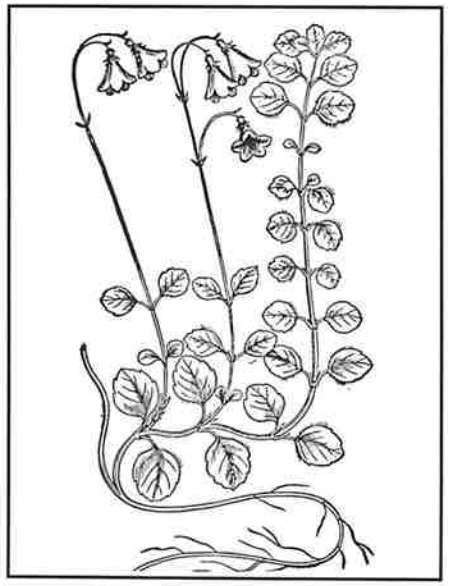
CLASSES, ORDINES, GENERA, & SPECIES.

THEODORUM HAAK,

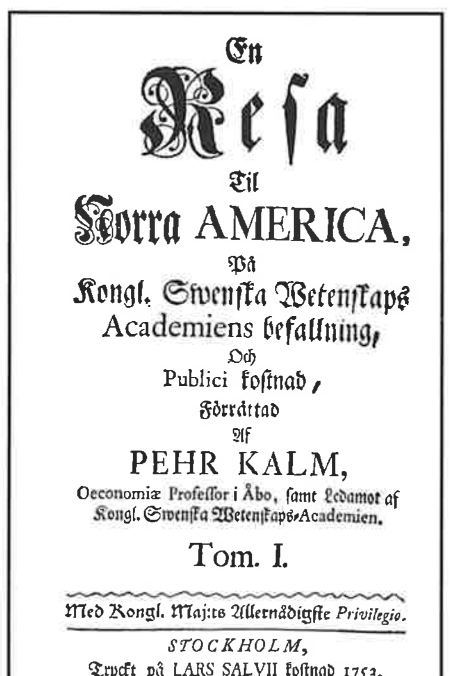
JOANNIS WILHELMI de GROOT

Title page of *Systema Naturae*, in which Linnaeus presented his classification system. It was written in Latin and published in Leyden, Holland, in 1735.

Although lengthy description would be needed fully to identify individual species by their similarities and differences, Linnaeus developed a shorter method of classification by assigning a unique name to each species in the plant and animal kingdoms. Each type would be identified by a two-name, or *binomial*, identifier: the first name would group it with others of its general kind, its *genus*, and the second would differentiate it from other specific forms (*species*) within the genus. Consequently, Linnaeus's system is called



Early Swedish illustration of *Linnaea borealis*. Linnaeus writes: "Linnaea was named by the celebrated Gronovius and is a plant from Lapland, lowly, insignificant, disregarded, flowering but for a brief space —from Linnaeus who resembles it."



En
Resa
Til
Norra AMERICA,
På
Kongl. Swenska Wetenskaps
Academiens befallning,
Och
Publici kostnad,
Förrättad
Af
PEHR KALM,
Oeconomiæ Professor i Åbo, samt Ledamot af
Kongl. Swenska Wetenskaps Academien.
Tom. I.
Med Kongl. Maj:ts Allernådigste Privilegio.
STOCKHOLM,
Tryckt på LARS SALVII kostnad 1753.

Pehr Kalm's *Travels into North America*: title page from the original Swedish edition of 1753

binomial nomenclature and, like many of the names given by Linnaeus himself, achieved international consensus and is still in use.

Linnaeus's lasting fame rested not only on naming things, but also on tirelessly searching for proper criteria for classifying them, which is now called *taxonomy*. In keeping with the natural theologians of the seventeenth and eighteenth centuries, who sought to understand (and worship) God by studying nature and discerning its design, Linnaeus believed that the natural world conformed to an archetype or divine plan conceived by the Creator. The key to understanding Creation—and perhaps learning something of the Creator—was finding the natural ordering of things.

Linnaeus, following early eighteenth-century botanical research, focused his attention and observational skills on the sexual organs of plants and found that he could order the plant kingdom on the basis of its reproductive structures: whether reproduction was sexual or asexual, what kinds of flowers there were, the numbers and forms of stamens and pistils, and so on. The system was based on observations anyone could make and became immensely popular among amateur and professional botanists alike.

Linnaeus made important contributions in zoology as well. As study of animal specimens, especially their anatomical structures, grew in scope and sophistication, it soon became evident that the old classifications were insufficient there, too. Although man was still considered to be distinct from "brutes" on theological grounds—namely, that he had been made in God's image and endowed with an immortal soul and free will—the physical boundary between man and animal was in question. Linnaeus departed from the seventeenth-century Cartesian view that animal bodies were soulless machines and instead conceived of all animals, including man, as possessing souls that decreased in nobility as one descended the chain of being. This was not an entirely new approach, but comparative anatomy and familiarity with new species of higher primates were beginning to erase the stark discontinuity between man and beast; Linnaeus recognized that a new classification needed to be created to reflect the newly added upper steps on the ladder of creation. To this end he abandoned the older scheme of classifying man with the quadrupeds, the four-footed animals, and created the class *mammalia* to group the higher animal forms and *primates* to characterize the highest mammals. His novel binomial classification implicitly tied man, as *homo sapiens*, a species belonging to a larger grouping, directly to this chain of life. As early as 1746 Linnaeus denied that there were any clear anatomical distinctions that could set man apart from the higher primates and suggested that such distinctions are therefore best left to the theologians—well over a hundred years before similar claims would be launched in defense of Darwin's theories.

Linnaeus's research and extensive writing contain much that seems prescient for the middle of the eighteenth century, and though some of his observations were only worked out in detail much later, they certainly must

have contributed to a nourishing atmosphere for the pursuit of biology in Scandinavia. His careful study of plant reproduction, his pioneering work in pollination and hybridization, and his understanding that there were environmental habitats and climatic zones that describe plant distributions— all point in the direction of nineteenth-century botany and twentieth-century ecology. Although it has been suggested that the very success of Linnaeus's crusade to establish *his* methods—with their emphasis on taxonomy and nomenclature—discouraged an ultimately more fruitful development of botany, especially in Sweden, there can be no doubt that Linnaeus introduced many students to careful field work and that his concise rules for classification drew many amateurs into the service of science.

Scientific Academies

As important as Linnaeus is as a symbol of Sweden's scientific culture, the institution he helped found, the Royal Swedish Academy of Sciences, is of far greater importance to the development of science in Sweden. The Swedish Academy of Sciences merits special attention not only because it has had a seminal role in supporting scientific research and contact between Sweden's scientists and the greater international scientific community, but also because it exemplifies a key theme of this survey—the importance of Enlightenment attitudes in supporting science in the Nordic world.

Scientific societies and academies evolved in part from the secret societies and reform-minded coteries of the seventeenth century, which usually were met with alarm and opposition by religious and political authorities. The treatises and charters of some of those groups (such as the Rosicrucians), as well as the utopian literature of the time (such as Bacon's *New Atlantis*, 1624), portray model societies in which the contemporary sciences play the key role: science is applied for the betterment of society, which in turn is ruled by, or on the advice of, a scientific priesthood. The crucial element was the idea that science is useful and connected with public good. Such an ideal is sometimes called "Baconian utilitarianism," because of the importance of Francis Bacon's codification of the new scientific ideology.

The Royal Society of London, founded in 1660, was the first enduring scientific society, and it has survived to this day. Although heir to some of the ideals of secret societies, the Royal Society suppressed overt political programs and focused on scientific problems in a spirit of religious tolerance. That was necessary when it was founded, in the wake of the English Civil War. Instead of basing a methodology on a particular view of the universe, the Royal Society took up Baconian science, which called for gathering data and systematically ordering it and analyzing it. The actual program for research

Pehr Kalm

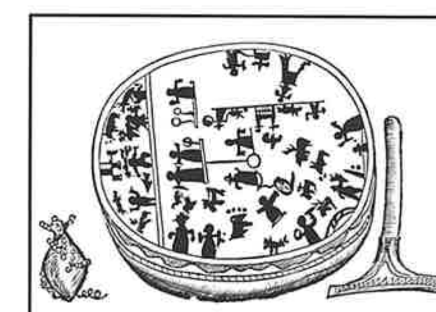
One of Linnaeus's most able students was a Swedish-born Finn named Pehr Kalm. He defended a thesis at Uppsala under Linnaeus in 1744 and was elected to the Swedish Academy of Sciences the following year. He was a leading proponent of utilitarian science, his botanical research reflected the spirit of the Swedish Enlightenment, and he exemplifies the program of agricultural innovation envisioned by Linnaeus and the Academy: Kalm was always looking for plants with pharmacological uses or as possible sources for vegetable dyes that could decrease Sweden's dependence on imports. In 1747 he was appointed professor of "economy" at Åbo University in Finland, which at that time referred to scientific agriculture and animal husbandry, but he immediately undertook a three-year survey of eastern Canada and New England on behalf of the Swedish Academy of Sciences. Besides collecting seeds of plants that might be profitably adapted to Swedish conditions, Kalm carefully described New World flora, noted the daily temperatures—which he measured with the new Swedish centigrade (Celsius) thermometer—and recorded historical, agricultural, and ethnographical details of the indigenous and immigrant peoples he encountered. He was quite naturally interested in the Swedes and Finns who had settled in New Sweden along the Delaware River, and he interviewed those who remembered something of the early years. Cut off from an increasingly disinterested Sweden, the colonists were politically assimilated by the dominant Dutch and English colonies. Therefore Kalm's observations have particular significance to historians of New Sweden. A precise observer and able naturalist of the Linnaean stamp, Pehr Kalm identified 90 plants that are included in Linnaeus's *Species plantarum*, 60 of which were previously unknown to European botany. He returned to Finland in 1751.

Illustration of Cuvier's Kinglet taken from Audubon's *Birds of America* (1840). The bird is sitting on a branch of *Kalmia latifolia*: like Linnaeus, Pehr Kalm had a plant named for him.

Urban Hiärne and Johan Wallerius: Chemical Philosophy and Practical Chemistry

The rational, practical chemistry of the Enlightenment grew from mystical roots in alchemy and Paracelsian chemical philosophy. In Denmark the first chemists were Paracelsians, ever searching for spiritual essences that gave drugs and poisons their powers. So, too, the man who laid the foundations for a brilliant tradition of Swedish chemistry was a Paracelsian. As a student at Uppsala, Urban Hiärne (1641-1724) was a proponent of Cartesian mechanical philosophy but became attracted to Paracelsian ideas while studying medicine and chemistry in France. After returning to Sweden he practiced medicine, eventually became a royal physician, and was appointed to the Board of Mines. Hiärne prepared medicines and analyzed mineral waters in his personal laboratory until 1683, when he was placed in charge of the government chemical laboratory in Stockholm, one of Europe's best equipped laboratories. There he established a tradition of seeking practical chemical means to improve mining and medicine.

It was not until 1750 that a chair in chemistry, metallurgy, and pharmacy was created at the University of Uppsala; it was initially held by Johan Gottschalk Wallerius (1709-85). Previously, as a lecturer in medicine, he had taught his students medical chemistry and mineral assaying in his private laboratory, but with the new chair he secured funding to build a university laboratory. Wallerius continued in the Hiärne tradition of practical analysis coupled with a somewhat Paracelsian theory of nature. As a mineralogist he urged the classification of minerals on the basis of their chemical properties as well as external appearances. His Swedish *Mineralogia* (1747) and Latin *Systema mineralogicum* (1772-75) were translated into several European languages and widely used. For urging the comparative chemical analysis of plants and soils in which they grow, he is considered the founder of Swedish agricultural chemistry. His *Agriculturae fundamenta chemica* (Chemical Foundations of Agriculture) was translated and used as a textbook throughout Europe. Thus, by the second half of the eighteenth century, the time of Bergman and Scheele, chemistry was well established at the Stockholm laboratory and in the University of Uppsala, in large part through the pioneering efforts of Hiärne and Wallerius.



Among artifacts collected by Ole Worm (see p. 4), some, like this Sami shaman's drum, reveal 17th-century scientists' increasing interest in national history and ethnography. From Ole Worm, *Museum Wormianum* (1655)

described by Bacon was unworkable, but the basic idea persisted that science was a collective effort that flourished on the contributions of many field observers.

Unlike less formally organized predecessors, the Royal Society survived, despite the poor state of its finances. Although called "royal," it was not funded by the crown, but supported internally. It succeeded for two basic reasons. On the one hand, it provided a forum for scientific exchange, the posing of critical scientific questions, and the communication of observations made by both domestic and foreign members. The reports and journals of the Royal Society were written in English, rather than the Latin of the universities, thereby permitting a wider class of active members, not just those with a university education. On the other hand, the Royal Society and those institutions patterned after it served to legitimize science. This may seem unimportant today, when science has tremendous authority as well as legitimacy, but in early modern Europe science had no professional status (outside of the medical profession and the universities), and formal scientific education was still a part of philosophy and therefore linked to metaphysics and ethics. The pursuit of science still depended largely on patronage and hobbyists. By legitimizing science as a corporate activity, scientific societies like the Royal Society could encourage amateurs and draw on their practical experience and field observations. That encouragement made Baconian science possible.

The hundred years following the founding of the Royal Society in London witnessed the establishment in all the major European nations of similar scientific societies, supported in varying degrees by their governments. Sweden was the first of the Scandinavian countries to establish a national scientific society, the Royal Swedish Academy of Sciences, at Stockholm in 1739, and Denmark quickly followed, in 1742. Even in Norway, ruled by Denmark until 1814, a learned society was founded in Trondheim in 1760. Such was the importance of public science to national prestige and enlightened society.

The Swedish Academy of Sciences was linked from its inception to mercantilist politics and the Baconian ideal of useful science. Sweden was governed by a national assembly (Riksdag) rather than the monarchy for much of the eighteenth century, during what in Sweden is called the "Age of Freedom" (1718-72). When the mercantilists won control of the Riksdag in 1739, the founding of a scientific academy soon followed as part of their party's political vision.

The Swedish mercantilists aimed to stimulate national growth by increasing manufacturing, agricultural production, and export—for the good of the nation at large, as well as for their own pocketbooks. Baconian utilitarian science was to be an instrument of that strategy, and the early Swedish Academy supported research that would enhance animal husbandry, increase soil fertility, find suitable new crops to increase agricultural output, devise new machinery and organization for manufacturing, find new sources and uses for minerals, and so on.

The founding members of the Swedish Academy reflect this progressive fusion of utilitarian science and Enlightenment politics: Carl Linnaeus was a botanist, Mårten Triewald an engineer, Jonas Alström a factory owner, Sten Carl Bielke a politician and amateur botanist, and both Anders Johan von Höpken and Carl Wilhelm Cederhjelm were politicians. Those men modeled the Swedish Academy on the Royal Society (London) and favored autonomy from the government and crown. And like its foreign counterparts, the Swedish Academy served both as a forum for national science and as a window opening onto the international community. All reports were written in Swedish, to permit the widest possible dissemination of information to those who could best use it—farmers, craftsmen, manufacturers, miners, and merchants. They, in turn, could report the success or failure of new crops and techniques, instruments, and so on. The Academy also supported a library and subscribed to the reports and transactions of other scientific societies, chiefly those in London, Paris, Berlin, and St. Petersburg. Foreign scientific articles of particular importance were translated into Swedish and reprinted by the Swedish Academy.

The Swedish Academy of Sciences, like many of the institutions of the Enlightenment, occupied a middle position between private interests and the public good. Its members represented both and formed a bridge between politics and commerce. Its scientific mission was also twofold. On the one hand, the academy needed to support research, to fund specific projects beyond the means of individuals and projects that were esoteric in nature and of interest to the scientific elite. Such funding was accomplished by specific grants and through the creation of special laboratories, institutes, and research stations, such as the Astronomical Observatory (opened 1753), the Institute of Physics (1849-1922), and the Vassijaure Scientific Research Station for subarctic research (opened 1902), to name but three examples. On the other hand, the Academy had a distinctly public function, namely, to disseminate useful information to all levels of society and to drum up public interest and support for science.

The Academy's reports were available for all to read, but it was the almanac that reached the widest audience. Almost every small community in Sweden received at least one almanac, which provided information about new crops and techniques, as well as the traditional seasonal lore. The Swedish Academy of Sciences had the sole rights to produce and sell the almanac, which was an important source of money for the Academy's projects.

Another way the Academy was able to reach the public was through its exhibits at the Swedish Museum of Natural History. One does not often think of museums as key parts of national science, but they house collections that are to be used for research and, just as importantly, serve to inform and entertain the public and gain its general support for science by linking science with the broader culture and with national prestige. The museum grew out of the many collections of natural specimens that the Swedish Academy of Sciences

Leprosy in the North

Under the climatic and economic conditions of nineteenth-century Scandinavia, where intimate familial contact was maintained from generation to generation, leprosy, the dread medieval scourge, prospered after it had all but disappeared from the rest of Europe. Leprosy in northern communities afflicted families, leading Daniel Cornelius Danielssen and C. W. Boeck, physicians at the leprosy hospital in Bergen, Norway, to suppose that the disease was hereditary. On the basis of their research they published a major study on leprosy in 1847, and Bergen became an international center for leprosy research. In 1868 Danielssen hired Gerhard Henrik Armauer Hansen (1841-1912), who concluded from epidemiological studies that leprosy was not hereditary, but rather caused by a specific, communicable agent. Hansen traveled to Austria and Germany to learn the latest methods of the new science of bacteriology, and, after returning to Bergen, he discovered in 1873 the rod-shaped bacillus that is popularly called "Hansen's Bacillus" (*Mycobacterium Leprae*). To prove that a microorganism is the cause of a particular disease requires that the agent be isolated from a sick individual, replicated, and introduced into a healthy individual to see if the host then contracts the disease. When Hansen failed to cultivate the bacillus *in vitro*, he secretly cultured it in the eye of a patient already suffering from an alternate form of the disease. This breach of medical ethics resulted in his dismissal from his post at the hospital. However, he was permitted to remain a leprosy medical officer in Norway, and in that position he was able to bring about changes in the state's methods for isolating victims of the disease from their families; thus, he broke the sequence of infection. Leprosy subsequently declined sharply in Norway.

gradually acquired in the eighteenth century. Some of the material was sent home to Sweden by Linnaeus's traveling students, but much more came from the elaborate "wonder rooms" and private collections of wealthy benefactors. Peter Jonas Bergius, for example, donated an herbarium of 16,000 species in 1784.

At first the wonders and curiosities of nature were simply accumulated at the Academy, much as in the collections of seventeenth-century princes, but in 1779 a curator was hired, and the collection was organized and opened to the public. It became an actual museum in 1819, after receiving a couple of large private collections of animals, mostly insects, that required special care and better facilities than their owners could afford. The National Museum remained the responsibility of the Academy but began receiving state support as early as 1820. In 1841 it was renamed the Swedish Museum of Natural History, given increased funding, and expanded. An emphasis at the museum on collecting gradually gave way to research, as curatorships were created to support active scientists, such as the famous Swedish explorers Sven Lovén and Adolf E. Nordenskiöld. During the second half of the nineteenth century the National Museum was the center of Swedish biological research and a stronghold of support for Darwin's theory of evolution.

Scandinavian Science in the Romantic Period

The nineteenth century produced many scientists of international standing, such as the Norwegian mathematician Niels Henrik Abel (1802-29), the Swedish astronomer and physicist Anders Ångström (1814-74), for whom the "Angstrom" (a common unit for measuring radiation wavelengths) is named, and the Norwegian geologist Waldemar Brøgger (1851-1940), who made important contributions to tectonics, stratigraphy, and paleontology. In medical science there were also important advances, the most notable of which was the work of the Norwegian Armauer Hansen (1841-1912) in isolating the bacillus responsible for causing leprosy. But probably the best-known Nordic scientists of the nineteenth century came from the romantic era at the beginning of the century: the Swedish chemist Jöns Jacob Berzelius and the Danish physicist Hans Christian Ørsted.

Jöns Berzelius (1779-1848) developed an interest in natural science while still in his early teens, when, like so many hobbyists in the wake of Linnaeus, he began collecting and classifying Swedish plants and insects. Academic pursuit of the life sciences at that time meant studying medicine, so Berzelius moved to Uppsala. There, just before the turn of the century, Berzelius was introduced to the latest ideas in chemistry, which had recently been reformulated by the French chemist Antoine Lavoisier.

Swedish chemists, most notably Torbern Bergman (1735-84) and Carl Scheele (1742-86), had been very active in the analysis of minerals and attempts to systematize chemistry, traditions that left their mark on Berzelius's work, too, which began in earnest after he met the wealthy mine owner and chemical enthusiast Wilhelm Hisinger. As a medical student Berzelius had become acquainted with the recently invented Voltaic Pile, a primitive battery used as a current-source for medical experiments at the beginning of the century. Through Hisinger's connections, Berzelius was able to use the largest Voltaic Pile in Sweden at the time; it belonged to the Galvanic Society, and he immediately began studying the effects of electrical currents on solutions of sodium, potassium, ammonium, and calcium salts. The results of those experiments were published in 1803, and they convinced Berzelius that the force that bound chemical elements together was electrical.

In 1807 Berzelius was appointed Professor of Medicine and Pharmacy at Stockholm's College of Medicine (later the Karolinska Institute), where he had a laboratory at his disposal and money to support his research. During the ensuing years Berzelius learned of Dalton's atomic theory, which fit well with what he had learned from his study of electrochemistry, namely, that elements combine in fixed proportions or weight ratios. This led him to the determination of the relative atomic weights of 39 of the 49 elements then known, findings that he published in 1818 along with the data that had been determined by his students for six more elements. Included with this table of atomic weights were the chemical compositions for nearly 2000 compounds. Also in 1818, Berzelius was elected Permanent Secretary of the Swedish Academy of Sciences, a post he held for the next thirty years. The Academy provided him with a better laboratory, where he and his students discovered a number of new elements, including selenium, thorium, lithium, and vanadium.

Berzelius's studies of the electrical decomposition of salts revealed that some were more readily separated than others, and he was able to rank elements according to how strongly "electronegative" they were, a method that helped explain their relative affinities. For that work and for his determination of relative atomic weights, he is considered to be one of the founders of modern chemistry.

Berzelius had greatly advanced inorganic chemistry. The next major achievements were to come in organic chemistry, chiefly from laboratories in Germany and France. Berzelius did not manage to accommodate organic chemistry, since it did not yield experimental results wholly compatible with his theories. He believed that the chemical activity of living organisms was categorically distinct from that of salts, metals, and minerals. Like many scientists and philosophers of the romantic era, Berzelius was a "vitalist"; he believed that living beings were governed by some special life-force that was absent from dead objects.

Hans Christian Ørsted (1777-1851) also became interested in chemistry, the fundamentals of which he learned while working in his father's pharmacy.

Carl Wilhelm Scheele

The recognition of the place of oxygen in combustion was one of the most important developments in the history of chemistry. Once combustion was understood, the role of gases in organic and inorganic processes was determined, and new theories of composition decisively replaced ancient notions of matter theory. The work of Carl Scheele (1742-86), the first person known to have identified and isolated oxygen, exemplifies the tremendous challenges faced by chemists in the eighteenth century and the great changes they wrought—they destroyed old theories, discovered new substances, and developed laboratory techniques that were crucial to the modern breakthrough associated with the work of Antoine Lavoisier, John Dalton, and Jöns Berzelius.

Credit for the discovery of oxygen initially went to Joseph Priestley, whose work was quickly publicized on the Continent. But historians have shown that Scheele not only isolated the gas, but also communicated that knowledge privately to Lavoisier and others. Although Scheele was led on his path by his rejection of previous assumptions about combustion, he failed to develop his ideas fully, leaving it to Lavoisier to exploit the chemical significance of oxygen. Like many early chemists, Scheele was trained as a pharmacist. He remained outside the university his entire life but enjoyed personal contact with leading academic chemists in Sweden and abroad and was elected to the Swedish Academy of Sciences. His discovery of chlorine and various organic acids confirmed his reputation as a first-rate analytical chemist.

A photo portrait of H. C. Ørsted, taken in the late 1840s

Berzelius and Scientific Method

The later eighteenth-century French Revolution and subsequent Reign of Terror and the Napoleonic Wars that wracked Europe in the early 1800s nurtured a German reaction (*Naturphilosophie*) to the ideas of the French Enlightenment, ushering in an age of romanticism. The German romantic philosophers, with Friedrich Schelling perhaps foremost among them, violently opposed the radical materialism and perceived atheism of the Enlightenment and proposed a view of the world in which spirit dominated. Philosophers and poets, the interpreters of the new doctrines, were exalted over practical scientists, who worked with mere things rather than with abstract principles. Romanticism's goal for education was the development and perfection of the individual human intellect, which would naturally lead civilization forward. That goal contrasted with the emphasis on applied science and the training of specialists for the progressive betterment of society that typified the Enlightenment.

In 1794 Ørsted began to study for a degree in pharmacy at the University of Copenhagen, where he became quite interested in the philosophy of Immanuel Kant. After completing his degree in pharmacy and taking a Ph.D. in 1799, Ørsted learned of the new Voltaic Pile (1800) and visited several laboratories in Germany, where he became interested in the relationship between electricity and the chemical affinities of the elements—about the same time Berzelius was undertaking his first experiments running currents through salt solutions. But Ørsted's commitment to the ideas of Kant and the German *Naturphilosophie*, which was such a powerful influence on the intellectuals of the romantic era, led him in a different direction, to the discovery that electricity and magnetism are related phenomena.

Ørsted understood Kant to have said that the human mind imposes certain patterns on the perceptions it receives from the senses and that these patterns are what we call scientific laws. These laws are reliable because the human mind was created as an image of the divine mind, and therefore the imposed patterns correspond to God's ordering of nature—a philosophical position much more sophisticated than Linnaeus's natural theology, but similarly motivated.

Kant had written that humans do not actually perceive matter, but only attraction and repulsion, the "basic forces" that cause matter to cohere in bodies and yet give it solidity and impenetrability. All perceived phenomena—light, heat, electricity, magnetism, gravity—were manifestations of attraction and repulsion. That belief in the underlying duality of all phenomena permitted Ørsted to look for a relationship between electricity and magnetism that the traditional natural philosophy of Newton and Descartes did not embrace.

Although Ørsted had predicted as early as 1813 that an electrical current would produce a magnetic effect, his understanding of how it should work prevented him from empirically "discovering" it until 1820. During a public demonstration of electricity and magnetism, Ørsted observed that an electrical current forced through a thin wire noticeably moved the magnetized needle of a compass placed underneath it. Further investigation revealed that the current created a circular magnetic field around the wire, an observation that had eluded him in his earlier attempts. Ørsted reported the electromagnetic effect in 1820, and the experiments of Ampere and Faraday that demonstrated the basic properties of electromagnetic fields soon followed. Application of these principles made possible telegraphs and telephones, generators and motors, which have all revolutionized technology and altered our culture.

One thing that Berzelius and Ørsted had in common was their interest in scientific subjects that were poorly supported by their universities, namely, the new chemistry of Lavoisier and the recently discovered Voltaic Pile. Both scientists were educated at universities, but in the end both were supported outside them: Berzelius by the Medical College in Stockholm and the Swedish Academy of Sciences, and Ørsted by the Polytechnical Institute in Copenhagen. Both depended for intellectual support on scientific societies, such as the Galvanic Society in Sweden and the Society for the Promotion of Natural Science, which Ørsted helped found in 1824. Increasingly in the nineteenth century scientific innovators required patronage and institutional support outside the universities.

Jöns Berzelius, who had studied animal magnetism in Germany and familiarized himself with the metaphysical speculations of Schelling and his kind, rejected *Naturphilosophie* as a scientifically useless doctrine. Berzelius, while not a radical materialist, argued that science must be based on experiment and experience, not created from *a priori* principles. A science built on metaphysics is doomed to error, since the power of the human imagination to fabricate principles will lead to empty conclusions. For Berzelius, nature is the source of truths that mankind must learn from experience and apply for its betterment. Thus, the scientist should not be cloistered in universities, but active in both nature's laboratory and civic affairs. As permanent secretary of the Swedish Academy of Sciences from 1818, Berzelius was in a position to resist the incursion of German speculations about spiritual activity (dynamism) into Swedish science. The profundity of the impression that the Enlightenment had made on Swedish science is exemplified by Berzelius's friend Carl Adolph Agard (1785-1859), professor of botany at the University of Lund. For, even though Agard was greatly influenced by Schelling's philosophy, he did not permit his metaphysics to determine the content of his science, which still rested on observation and experiment. Although they argued over philosophy of science, Berzelius and Agard both promoted the increase of the sciences in the academic curriculum and advocated the introduction of natural science into the schools as well, a half century before T. H. Huxley would be urging similar reforms in Britain.

Foundations and Scientific Institutes: The Role of Philanthropy

One feature that has made the use of institutes particularly well suited to the Nordic cultural area is the ability of the autonomous or semi-autonomous scientific institute to channel private money into areas of research needing special initiatives. Some of Scandinavia's best-known scientific achievements have been funded privately, through foundations, which provided research "venture capital" when university or governmental agencies were unwilling or unable to provide the necessary funds. The following examples of the interdependence of autonomous institutes and private sources of support will illustrate the central role of philanthropy in promoting advanced scientific research.

One of the earliest such arrangements in Scandinavia was the Bergius Foundation, which supported a horticultural school and research garden under the auspices of the Swedish Academy of Sciences. All of this was the bequest of Peter Jonas Bergius, who, with his brother Bengt, had turned the family estate into a private botanical institute, complete with a large library, 15,000-sheet herbarium, and both herbal and botanical gardens. *Bergielund*, as it was called, was left to the Academy in 1791, and it was to be maintained by the Bergius Foundation, which also paid for a Bergius Professor to be attached to the institute. Eventually *Bergielund* was sold and the horticultural school closed, but the Bergius Garden and Bergius Institute were relocated and have remained in Stockholm. The garden has since been transferred to Stockholm University, but it is still under the director of the Bergius Institute and serves to illustrate one of the many cooperative links between the Academy's institutes and various public and private sector organizations.

In Denmark, the history of the Carlsberg Laboratory and the Carlsberg Foundation provides another example of private-sector initiative on behalf of public science. In 1847 J. C. Jacobsen, a Danish brewer, sought to improve beer making in Denmark by importing the brewing and lagering techniques that had made German beer world famous for its quality. But Jacobsen's achievement went beyond state-of-the-art brewing; he applied scientific principles and created a high-technology industry, driven by research and development, out of what had traditionally been an art. The Carlsberg Brewery, as Jacobsen called it, soon became a model brewery, in which new technologies could be readily tested and applied to production. In 1871

Niels Henrik Abel

The brief career of Niels Henrik Abel (1802-29) aptly illustrates the difficulty Nordic scientists once faced in obtaining financial support both at home and abroad. His mathematical genius was recognized while he was still a high school student in Oslo, but when he entered the new University of Oslo in 1821, no fellowships were available, and he was forced to get on by donations from members of the faculty. Eventually the Norwegian government awarded him a travel stipend to study in Germany and France. In Paris he presented an important paper on elliptical integrals to the Academy of Sciences, hoping to gain an international reputation with its acceptance. However, the referees neglected the work, which only surfaced after Abel's death. The culmination of his work on integrals of transcendental functions was a paper published in 1827-28; this area of mathematical research was popular for the remainder of the century. While Abel was abroad, he was passed over for a professorship at the University of Oslo, and when he returned to Norway, he was obliged to support himself by tutoring school boys in mathematics. Despite pleas to the King of Sweden and Norway from French and German academicians requesting that a position be created for the young mathematician, no job was forthcoming. Abel died of tuberculosis in 1829, just days before an invitation to join the faculty in Berlin arrived. Although Abel's case is extreme, it shows the difficulty that the paucity of academic positions and fellowships created for Nordic scientists wishing to participate in international science before the modern system of prizes, grants, and scientific institutions was created.

Jacobsen established a private laboratory, later named the Carlsberg Laboratory, for research related to beer making.

In 1876 Jacobsen set up the Carlsberg Foundation, both to guarantee that the Carlsberg Laboratory had sufficient operating funds and to finance the sciences in general, which for him meant the natural sciences, mathematics, philosophy, linguistics, and history. When he died in 1887, J. C. Jacobsen left the Carlsberg Brewery to the Carlsberg Foundation to ensure that it continued to produce both beer and funds for research. Jacobsen's son, Carl Jacobsen, had started his own brewery in 1880-83, and in 1901 he followed his father's example and deeded New Carlsberg to the foundation.

The motives behind the Carlsberg Laboratory and Carlsberg Foundation exemplify the view that the successful businessman not only should return some of his wealth to society—an ideal found elsewhere in the history of Scandinavian philanthropy—but could also combine love of nation with the pursuit of scientific excellence. To be sure, Jacobsen sought to secure the future of his brewery by establishing a foundation and laboratory to finance its work and maintain its scientific principles, but he also did so because he viewed the brewery as a national treasure of sorts. That much is clear from his testament (trans. from *Salmonsens Konversations Leksikon*, q.v.):

> The continuous purpose of this operation will be to develop the production to the greatest possible perfection, without regard for immediate profit, so that the brewery and its products will always be a model, and to see to it by their example that the brewing of beer in this country is maintained at a high and honest standard.

But, as was later the case with the Swedish philanthropist Alfred Nobel, Jacobsen's goal was not only to improve national science, but also to advance *public* science. His intent is evident from his establishment of the Carlsberg Laboratory. Although he principally built it to further research of use to the brewery—for example, the investigation of yeasts, hops, and enzymes—Jacobsen explicitly stated that no result of the Institute's work that has theoretical or practical significance should be kept secret.

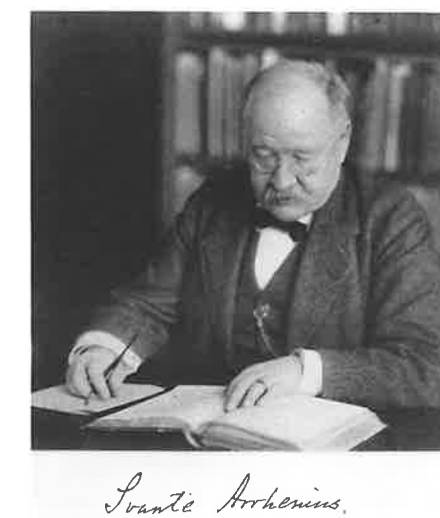
The Carlsberg Foundation today is a major supporter of the sciences and humanities, financing projects and the publication of results. The Carlsberg Laboratory continues to promote research into grains, enzymes, and other matters related to beer making. Three of the Foundation's five-member board of directors also administer the Laboratory, and all five are selected by the Royal Danish Society of Scientists from its own membership. Thus, what started as a private company—a brewery—has become a private foundation and research laboratory under the administration of an autonomous scientific society. A similar relationship exists between the Swedish Academy of Sciences and the Nobel Foundation and its institutes.

The modern world's highest scientific honors are the Nobel prizes conferred each year in chemistry, physics, and medicine. These prizes, which carry a large sum of money, were the legacy of Alfred Nobel and were left not only to the people of Scandinavia, but to those who, regardless of nationaity, would have conferred the greatest benefit on mankind during the preceding year. Nobel had made a fortune in industrial chemistry, and when he died in 1896, he left thirty million *kronor* as capital to finance five annual prizes and the institutes to support a cadre of "in-house" experts to evaluate the achievements of nominees. That was a tremendous sum at the turn of the century. Although the prizes were clearly intended to be international, they and the institutes that were eventually established with Nobel's money have been used to legitimize certain kinds of science and promote Swedish science, too. The creation of the first Nobel Institute is a case in point.

Alfred Nobel in his laboratory, painted by E. Österman

The disposition of Alfred Nobel's estate, despite his testament, was not a simple, straightforward process. Even after the claims made by the Nobel family were legally satisfied, the mechanisms for carrying out Nobel's will had to be established, and various alternative plans for exploiting the new-found wealth for Swedish science were suggested. The Technical College in Stockholm, for example, sought Nobel funding to help it compete with the universities by establishing one or more institutes there. The money the college was awarded permitted the expansion of its scientific faculty and the employment of Svante Arrhenius (1859-1927), a chemist of international fame.

At first, Svante Arrhenius's pioneering work in electrochemistry was poorly received by the university establishment at Uppsala, where his doctoral dissertation and defense (1884) were given rather low marks. His theory that salts disassociate into ions in solutions to form electrolytes ran counter to prevailing concepts, which made academic progress difficult for him. Eventually he was offered a professorship in physics at Stockholm Technical College, where he remained from 1895 to 1905. During those years his work was well received abroad, and he was also appointed to the Swedish Academy of Sciences. In 1903 he received the Nobel Prize for chemistry.



Arrhenius understood personally the difficulties—both bureaucratic and financial—that Sweden faced in acquiring and maintaining first-rate scientific minds. The scientific establishment did not know what to do with Arrhenius's work, which did not seem to the physicists to be really physics and did not seem to the chemists to be really chemistry. That gap was bridged in 1905 when a Nobel Institute for Physical Chemistry was created, and Svante Arrhenius, who had just been offered a professorship at the prestigious University of Berlin, was appointed as director and remained in Sweden.

The earlier barriers to Arrhenius were not just financial but arose in part because of the established system at the universities, where the idea of a discipline like physical chemistry ran afoul of both the physicists and the chemists, who sought to protect their disciplinary boundaries. Just as the patronage offered to Tycho Brahe in sixteenth-century Denmark permitted him to create a research institute for chemistry and astronomy, which were not

A. I. Virtanen

In the 1920s the Finnish biochemist Artturi Ilmari Virtanen (1895-1973) began to examine the role of enzymes and bacterial fermentations in organic reactions, work that led him to scrutinize the process by which nitrogen is fixed in soluble compounds in the root nodules of legumes. Working with cattle fodder, he realized that nitrogenous material, which includes the proteins, carotene, and vitamin C that are essential to effective dairy cattle nutrition, are lost during storage. He discovered that acid retarded the breakdown of these nitrogen compounds and developed a method of treating raw silage with dilute hydrochloric and sulphuric acids to slow the degradation of the fodder. This procedure is called the A. I. V. method, after his initials. It was introduced into Finnish agriculture in 1929, and its use spread quickly to other north European nations, where milk production is an important part of the agricultural economy. Virtanen received the Nobel Prize in chemistry in 1945 for his work.

The Carlsberg Laboratory of 1897

recognized as autonomous disciplines at the University of Copenhagen, the private funds made available by the Nobel Foundation enabled Arrhenius to establish an institute for a new field on the scientific frontier, which would not have been possible within the existing Swedish academic structure.

The Nobel Foundation continued to function in this capacity by founding (or refounding) Nobel institutes for research in areas at the forefront of science. Thus, when theoretical physics was at the cutting edge of the European scientific world, the Nobel Institute for Theoretical Physics replaced the Institute for Physical Chemistry (1933). As experimental physics became the exciting new research area in prewar Europe, the Institute for Experimental Physics was established in 1937, with partial support from the Nobel Foundation. In 1943, when organic chemistry was again an active new research field, the Laboratory of Organic Chemistry was opened. In 1951 it became the Nobel Institute, Department of Chemistry. Today there are Nobel institutes for both physics and chemistry in Sweden.

The Nobel Prizes were also used to encourage research in areas that fell between disciplinary boundaries or were otherwise unsupported (or undersupported) by the universities or governments. For example, Theodore Svedberg (1884-1971) was awarded a Nobel Prize in 1926 for his research in colloidal chemistry. This field was not recognized as proper chemistry by the Swedish academics, and Svedberg would likely have left Sweden for the United States if he had not received official recognition. Receiving a Nobel Prize not only provided the scientist with research funds, but also gave his work legitimacy and opened the doors of opportunity at home.

The Nobel and Carlsberg Foundations are two conspicuous examples of private-sector foundations supporting institutes and scientific initiatives, but there are others, created by diverse means and for various purposes. The Knut and Alice Wallenberg Foundation, for example, was established in Sweden in 1917 specifically to finance research grants to be administered by the Swedish Academy of Sciences and various institutes. Eighty percent of the income from the fund's capital is used to start museums, establish laboratories at the universities, and promote scientific research in a variety of ways—often in conjunction with the Nobel Foundation, the Swedish government, and other granting agencies.

The Fridtjof Nansen Fund for the Advancement of Science is an example of another kind of foundation that channels private-sector donations for the promotion of public scientific efforts. The Nansen Fund differs from those previously mentioned in that it did not originate as a gift or legacy of a wealthy philanthropist but was set up by a scientific society to receive private donations to further its work.

Fridtjof Nansen (1861-1930) was a world-famous Norwegian explorer and arctic scientist whose daring spirit and physical endurance captured the minds of the Norwegian people. Nansen was met as a national hero on his return to Oslo in 1896, after his heroic attempt to reach the North Pole on skis. The secretary of the Norwegian Academy of Science, Waldemar Brøgger, used that occasion, when the nation was excited by the success of Nansen's scientific explorations, to create a fund to solicit donations for the advancement of science. Today the fund is administratively linked to thirty-three independent funds and administered by a committee consisting of members of the Norwegian parliament, the Academy of Science, the universities, and Norsk Hydro—a chemical and energy corporation that donates large sums to support science in Norway.

Unlike the Wallenberg Foundation, which is autonomous but in part supports the Swedish Academy of Sciences and Swedish research, and the Nansen Fund, which was created by the Norwegian Academy to attract funding for Norwegian research, the Mittag-Leffler Foundation was created specifically for the Swedish Academy of Sciences to support research in all the Nordic countries. Gösta Mittag-Leffler (1846-1927) was a professor of mathematics at Stockholm University and the founder of a leading journal for mathematics (*Acta mathematica*). Through marriage he became very wealthy, and in 1919 he merged his villa, his library, the journal, and a large sum of money into the Mittag-Leffler Institute for Mathematics. The institute was then donated to the Swedish Academy of Sciences, but he remained as its director until he died. Mittag-Leffler's expressed aim was to maintain and advance *Nordic* mathematics, not just that of Sweden, and the board of directors includes members from other Nordic countries, in addition to those from the Swedish Academy of Sciences. Over the years the institute has attracted outside funding and has served as an international center for advanced mathematical study.

Modern scientific research in many fields demands ever-larger budgets to build and staff more sophisticated laboratories and larger, more expensive apparatus: Tycho Brahe's work demanded carefully crafted and therefore costly instruments for measuring the angles between celestial bodies; subsequent observatories required expensive telescopes and mounts; the extensive taxonomic effort of the Linnaeans required scientific expeditions to the far corners of the earth. In our own century astronomy still demands large instruments, which capture public attention, such as the Space Telescope and the large radio-telescopic arrays, but for much of the twentieth century it has been the field of high-energy physics that has been most conspicuous for its grand apparatus and experiments. Such tools as the cyclotron, bubble chamber, and the nuclear reactor figure prominently in the public perception of twentieth-century science. Debate over the cost of supporting ever-larger particle accelerators, such as the "supercollider," has brought the cost-effectiveness of scientific research into the public forum. "Big science," as these ultraexpensive research efforts are collectively termed, requires big budgets. Small countries—even those with strong economies, like the Nordic states—have difficulty justifying them. They have responded to the cost problem by sending scientists abroad to participate in the large laboratories established in

Fridtjof Nansen—explorer, scientist, humanitarian—was also a fine artist. The vignette above is from one of his illustrated books.

Photograph of Fridtjof Nansen, taken 1922 in Sofia, Bulgaria

[The Bohr-Einstein debate] was one of the great scientific debates in the history of physics, comparable, perhaps, only to the Newton-Leibniz controversy of the early eighteenth century. In both cases it was a clash of diametrically opposed philosophical views about fundamental problems in physics; in both cases it was a clash between two of the greatest minds of their time.

Max Jammer, *The Philosophy of Quantum Mechanics* (1974)

Bohr is the most profound of the four [Planck, Rutherford, Einstein, Bohr] and probably the one whose influence has been largest. He is always questioning, never certain of his answers.

D. ter Haar, 1959

countries like Britain and Germany and merging resources in a supranational collective effort. A case study of the Danish physicist Niels Bohr and the Bohr Institute sheds light on both these alternatives.

Niels Bohr (1885-1962) is probably the best-known twentieth-century Scandinavian scientist, ranking with his contemporary Albert Einstein in laying the foundations for modern atomic physics. Bohr's early articles on the structure of the atom rejected the earlier "planetary" model, in which electrons were assumed to orbit the atomic nucleus according to the laws of classical physics that describe our solar system. His work attracted international attention as early as 1913. There was, however, no support for his research at the University of Copenhagen, so he went to England to work with J. J. Thomson at Cambridge and then with Ernest Rutherford at Manchester, in one of England's best-equipped physics laboratories. Finally a professorship in theoretical physics was created for him in Copenhagen in 1916, but he still needed research facilities. To encourage him to remain in Denmark, his friends donated money to buy land for a research institute. Construction began in 1918, and the Institute of Theoretical Physics, later commonly called the Bohr Institute, was finished in 1921.

The prestige of Bohr and his institute increased in 1922 when he was awarded the Nobel Prize in physics. His atomic model, familiar to all first-year students of physics today, provided theoretical explanation for the observed correlation between the atomic structure of the elements and their ordering in the periodic table. That same year element number 72, named Hafnium—after the Latin name for Copenhagen (*Hafnia*)—was discovered at the institute.

The Bohr Institute was one of the foremost laboratories for atomic physics in the years before World War II. In 1938 Europe's first cyclotron for accelerating subatomic particles was put into operation at the Bohr Institute. World War II and the occupation of Denmark by the Germans disrupted international cooperative research, but the Germans were understandably interested in the institute's work and kept it open. In 1943 Niels Bohr was tipped off that he was to be arrested and taken to Germany, and he permitted himself to be smuggled to Sweden and then flown to England and the U.S.

Since the war, Bohr's institute has continued to support research in high-energy physics and in its early years even housed the theoretical division of the Center for European Nuclear Research (CERN; now in Geneva, Switzerland). In 1963 the Institute for Theoretical Physics was officially renamed the Niels Bohr Institute in recognition of Bohr's lifelong work.

The history of the Bohr Institute shows a pattern similar to that of the institutes and foundations already mentioned: when Bohr's accomplishment and fame exceeded the resources of his university and he was forced to look abroad for patronage to continue his work, private donations provided a stimulus for the creation of an institute. In this case the donations were not initially from one of the large foundations, as was the case with the Nobel

institutes, for example, but rather from his own friends. Once established, the Bohr Institute attracted additional finances from both the public and private sectors. The role of private donations to support public science has proven important for retaining scientific leaders and national research initiative in the small to medium economies of the Nordic countries.

NORDIC SCIENCE

Modern science is for the most part a collective effort. The physicist working at the Bohr Institute is in regular contact with colleagues in Sweden and anywhere else that similar or complementary work is being carried out. Nevertheless, it is possible to consider a scientific initiative to be national in as much as nations must choose how to spend research money, and this necessity leads to research policies that favor some areas of work over others, namely, those considered to be in the national interest. Applied science—that is, scientific research for industrial applications, as opposed to "pure" science, which is undertaken for intellectual reasons—is of national interest because it impinges directly on the economy. To the extent that neighboring countries cooperate and coordinate their research policies, it may be possible to speak of regional science.

The Nordic countries, because of traditions that grew out of the Enlightenment and a concern for public welfare, engage in a great deal of planning at all levels of government, as well as at the national and pan-Nordic levels; science policy is an important element of that overall planning. Science policy involves control and direction of science by means of funding and regulation in accordance with the social and economic goals set by the government. There are various aspects of how such policy is formulated and accomplished, but we will focus here on strategies for choosing research areas, the role of scientific institutes in mediating policy, governmental funding and control of research, and the attempt to maximize a small nation's resources through cooperation.

Research Strategies: Niches and Desirable Goals

A nation or group of nations cannot fully support scientific research in every possible area owing to limitations in money, trained scientists, and facilities. All scientists, research groups, and governments must therefore decide how best to focus available resources on research that will either convey a special scientific advantage or achieve some socially desirable end, such

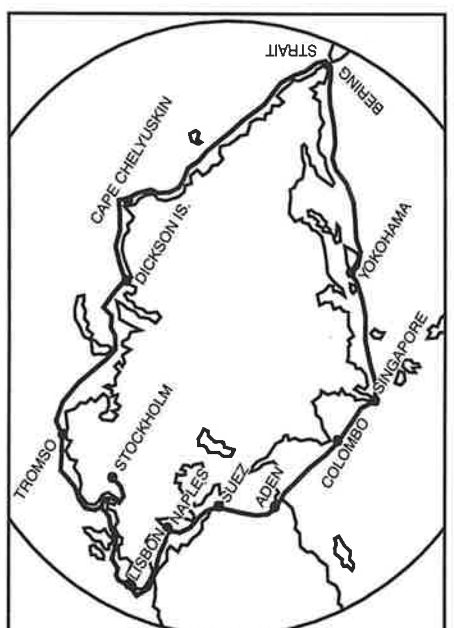
Kristineberg Marine Biological Station

Gullmarsfjorden on Sweden's west coast was recognized by the Swedish zoologist Bengt Fries (1799-1839) in 1835 as a unique environment for biological research. Located between the North Sea and the Baltic, the deep fjord nurtures a wide variety of marine life because of its varied salinity and protected waters. Fries, the noted arctic zoologists Sven Lovén and Otto Torell, and other biologists from the universities of Uppsala and Lund regularly visited the fjord on summer excursions during the middle of the century and realized the value of establishing a permanent research station with an aquarium as a locus for continuing study. In 1876 Anders Regnell made a donation to the Swedish Academy of Sciences specifically for that purpose, and the Kristineberg site at the fjord's mouth was purchased and developed. Donations from other philanthropists in the 1880s enabled the building of additional facilities, including a winter laboratory, which permitted the station to be used year round. Today Kristineberg continuously maintains between 60 and 80 researchers and embraces every aspect of marine biological, geological, and hydrological study.

Anders Celsius, painted as a young man. In 1742 Celsius invented the centigrade (or Celsius) thermometer.

as national defense or clean water. A special scientific advantage might be international leadership in a particular field of pure science, such as marine biology, or it might entail a strong research-and-development program for a particular industry, for example, that of semiconductors.

Individual researchers, as well as scientific institutions, achieve the greatest success, whether measured in technological advantage, revenues, or professional status, when they find a research area in which they can excel and which they can dominate. A concept drawn from evolutionary biology, which shares such ideas as competition and survival of the fit with industrial economics, is instructive. In biology a variant of a species may successfully compete with other populations for available food by finding a particular place or *niche* in the environment. If it is better adapted to that niche than its direct competitors, it will thrive as a population by dominating its niche. In the world of scientific research this has happened historically, and it is also a conscious research strategy today—one achieves most if one does what one is best suited for. Past success, in turn, provides a basis for future scientific initiatives. Two examples of scientific research that have been dominated by Scandinavians in the past will illustrate this concept of *dominance of niche.* We will consider first the ways in which Nordic countries have capitalized on their geography and dominated arctic science and then how they have sought to take and maintain leadership in environmental science.



Map showing Nordenskiöld's voyage through the Northeast Passage with the S/S *Vega*, June 1878 to April 1880

Arctic Exploration and Science

Nordic prominence in arctic science—that is, arctic geology, meteorology, oceanography, biology, archaeology, and so forth—is rooted in a strong tradition of arctic exploration. Many Scandinavian explorers were primarily adventurers (and scientists only incidentally) but their ventures were usually supported for political and economic reasons, which often entailed the scientific mapping and assessment of resources. Sometimes, however, purely theoretical questions were the driving forces behind arctic missions. For example, in order to test Isaac Newton's hypothesis that the Earth was not a perfect sphere but was flattened somewhat at the poles, it was necessary to compare measurements of the Earth's surface corresponding to a one-degree change in latitude along a meridian; if the length proved to be smaller in the far north than it was near the equator, Newton's prediction would be supported by observation. That experiment was one of several touchstones that would help decide whether Newtonian physics was superior to that of the followers of René Descartes. To resolve that purely theoretical question, the famous French scientist Pierre Louis Moreau de Maupertuis conducted an expedition in 1736-37 to Torneå, which is today part of Finland. Although the expedition

was not a Scandinavian initiative, Maupertuis needed someone with expertise in astronomy and chose a Swedish astronomer named Anders Celsius (1701-44) to assist with the measurements. Celsius is best remembered today for his standardization of the thermometric scale, but he had studied astronomy, mathematics, and physics at the University of Uppsala, where he was appointed professor of astronomy in 1730. In the years that followed, he traveled in Europe, met Maupertuis, and purchased the instruments needed for the precise astronomical measurements at Torneå. Returning to Uppsala from Torneå, he reinvigorated the teaching of astronomy at the university, where a new observatory was completed in 1742. Celsius worked on various scientific problems in his short life, including the causes of the apparent dropping of the level of the Baltic Sea, which had been a matter of scientific discussion since the 1690s. But satisfactory solutions to that problem had to await the arctic expeditions of the nineteenth century.

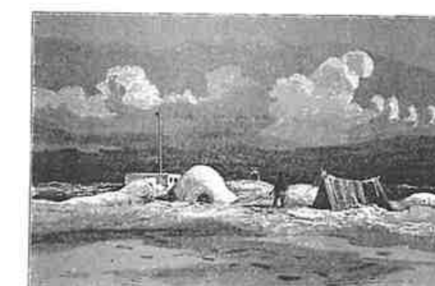
In 1837 Louis Agassiz (1807-73) argued that the Baltic Sea was not actually falling, but that the Scandinavian land mass was rising. He theorized that for a long time the land had been depressed by the weight of massive glaciers that covered Scandinavia during an "ice age" and that the land had begun rising after they melted. Agassiz's theory of glaciation explained much of the geology of northern regions as coming from the scouring action of primeval ice masses as they slowly moved across the rock. The water from melting glaciers carved out rivers and left fields of rounded boulders and gravel beds, features not well explained by earlier geological theories. Such a far-reaching and novel theory required field observations to support it, and that is where Scandinavian experience with arctic and subarctic research came into play.

In 1837, the year that Agassiz announced his theory of glaciation, Sven Lovén (1809-95) joined an expedition to Spitzbergen (now Svalbard), far to the northwest of the Norwegian mainland. Lovén, considered a pioneer in polar exploration, observed the glaciers and studied the animal life on and around Spitzbergen. Many of the snails and mussels he found there—species that were limited to northern arctic regions—corresponded to fossil specimens he had seen in Sweden. From those observations, Lovén concluded that Sweden had had an arctic climate in a previous age, when much of the land was covered by an icy sea. Lovén's hypothesis fit well with Agassiz's theory of glaciation, but further research was needed.

Otto Torell (1828-1900), a student of Sven Lovén, shared his mentor's speculation that the Scandinavian peninsula had once been covered by a large ice sheet, and he traveled to Switzerland to examine an existing glacier environment first hand. From that experience he became convinced that glaciers had in fact produced the characteristic marks on the Scandinavian landscape. There was much opposition to the glacial theory among geologists, however, and more fieldwork was needed in order to construct a convincing case.

Torell next traveled to Iceland, where he spent half a year leading a research team back and forth across the island's ice-covered interior. The

A. E. Nordenskiöld, painted 1886 by Georg von Rosen (1843-1923)



One of several illustrations in Nordenskiöld's *The Voyage of the Vega* (1881) following year (1858), Torell organized an expedition to Spitzbergen, where he spent the summer examining its plant and animal life, glaciers, and glacial deposits. Accompanying him were a zoologist and the famous Swedish-Finnish explorer Adolf E. Nordenskiöld (1832-1901). In 1859—the year Charles Darwin published *On the Origin of Species*—Torell published a dissertation on the mollusks of Spitzbergen, a work that also contained the first general treatment of glaciation in Scandinavia and its relationship to the arctic climatic zone during a previous ice age. The work firmly established Agassiz's theory that northern geology had been largely created not by some sort of great flooding, but by the scouring and erosive action of glaciers and their runoff.

Torell had personally financed most of his expeditions to Iceland, Spitzbergen, and Greenland (1859), but the planned, future expeditions required greater resources than he could muster. The Swedish Academy of Sciences stepped in, made polar exploration a national concern, and raised enough money for Torell and Nordenskiöld to lead a two-ship expedition in 1861 to Spitzbergen and the sea north of it. The resulting reports and specimens further strengthened the theory of a previous ice age.

The 1861 expedition and Nordenskiöld's follow-up voyage in 1864 were organized by the Swedish Academy of Sciences and funded from both private and public sources, including the Swedish Crown and the National Assembly (*Riksdag*). Those primarily scientific ventures had resulted in many studies of arctic biology, geology, paleontology, magnetism, and geography. But polar exploration, once it entered the national consciousness, also became a matter of politics and an emblem of national achievement, and the goal of reaching ever further northward, the nineteenth-century equivalent of the twentieth-century race to put humans in space, vied with purely scientific ends.

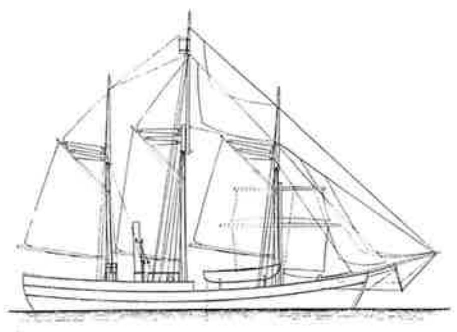
Nordenskiöld's next expedition, in 1868, was funded privately and reached 81° 42′ north latitude, a record by ship, before returning to Sweden with scientific specimens and reports. Nordenskiöld realized that it would be impossible to go much farther north by ship, so he began planning a longer expedition. After the failure of the 1872-73 expedition, Nordenskiöld and the Academy turned their attention eastward, to find a "Northeast Passage" over Russia to the Pacific Ocean.

After several preparatory expeditions in the mid-1870s, Nordenskiöld set out from northern Norway in 1878. His ship reached the northern entrance to the Bering Strait before being stopped by the winter ice. There he camped and continued to the Pacific when the ice pack broke up the following July. The success of the expedition aroused national pride, and Nordenskiöld, having returned to Sweden a national hero, was made a baron.

Those expensive expeditions were financed privately for the most part, and much of that money came from a Swedish merchant and lumber baron named Oscar Dickson (1823-97). No doubt Dickson had genuine admiration for Swedish scientific and exploratory missions, but it is also true that he benefited socially (and perhaps financially) from his patronage. His extensive timber cutting, some of which was illegal, had earned him a shady reputation, which he was able to overcome by social advancement. Dickson had funded large portions of the 1868 polar voyage, several Siberian expeditions, and—jointly with a rich Russian mine owner—Nordenskiöld's search for the Northeast Passage. All in all, he financed six Swedish and Norwegian expeditions, in return for which he was granted membership in the Swedish Academy of Sciences, made an aristocrat, awarded an honorary Ph.D. at Uppsala, and admitted to several foreign learned societies.

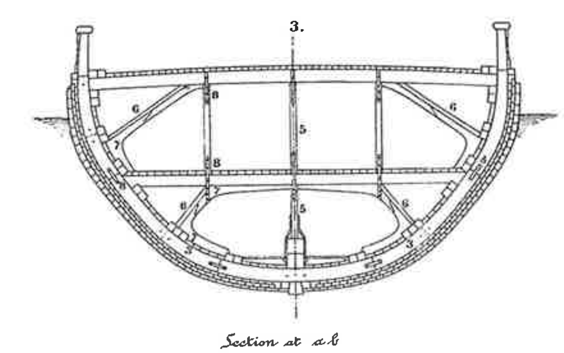
The expeditions organized by the Swedish Academy of Sciences and funded by a mixture of government grants and private donations initiated a long period of arctic exploration that was dominated by the Scandinavians. By 1910, thirty-five Swedish expeditions had set out to investigate arctic areas. These expeditions were usually cartographic and scientific missions, which were also attempts to find mineral deposits and maintain international leadership in arctic exploration. One of the most famous polar explorers of all time, however, was not a Swede, but a Norwegian. Inspired by Nordenskiöld's efforts, Fridtjof Nansen (1861-1930) undertook an investigation of the interior of Greenland in 1888 to find out whether it was ice, snow, or perhaps—as some believed—a warmer area than the coast. Adverse currents and ice floes along the east coast delayed his landing for nearly a month, and then it took another month and a half for him and his four companions to ski across Greenland's interior and make careful records of the weather. They reached the west coast too late in the fall to meet the ship back to Norway and had to spend the winter. Their circumstances provided them with plenty of time to learn about the climate and region.

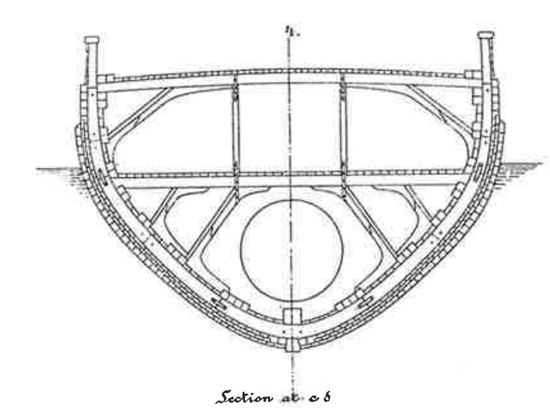
Identifying driftwood and ship wreckage found in Greenland as having originated in Siberia, Nansen postulated that ocean currents carry arctic ice and drifting wood across the pole. Consequently, he designed a special polar exploration ship, the *Fram*, to withstand the pressure exerted by the ice; it could be frozen into the ice pack and thereby drift along with it. The *Fram* set sail in early summer 1893 and traveled north and east until the ice closed in at 78° 50′ north latitude, over Siberia. After drifting with the ice for a year and a half, Nansen realized that their course would take them no farther than 85° 55′ north, their position at that time. He and F. Hjalmar Johansen then left the ship, hoping to reach 90°—the pole itself—on skis, pulling their provisions on sleds. They reached 86° 14′ north, within 268 miles of their goal, before they had to turn back because of equipment failure and a faulty map. For nine months they lived on walrus and polar bear meat, before being rescued by an English polar expedition. Meanwhile, the *Fram* continued to drift with the ice to north of Norway and headed home when the ice broke up in May 1896, picking up Nansen en route.



Fram

Foresight and willingness to adapt to the environment rather than fight against it enabled Nordic explorers to succeed where others failed. The design of the *Fram*, the ship used by Nansen and Amundsen, exemplifies the special care and preparation that lay behind those expeditions. *Fram* was constructed to enable a relatively small crew to survive, trapped in the arctic ice floes, for five years. Ice tends to crush long, steep-sided sea-going vessels, and experience had shown that small, more rounded boats tended to float up on the ice and avoid destruction. In view of those findings, the *Fram* was built short and wide, with a rounded cross section. The hull was built of two layers of oak planking with an ice shield fastened on the outside. Unlike whalers and other previous arctic ships, *Fram* was reinforced on the broadsides rather than on the prow, since it would be squeezed in the ice pack rather than breaking a path through it. Woods were selected for each part according to their desirable characteristics: the keel was American elm; the support frames, grown to the proper shape, were Norwegian oak; the knees joining them to the planking were white pine, giving the ship an elasticity impossible to achieve with iron fittings. To control heat and humidity in the living spaces, the hull side of each cabin was panelled in three layers, with dead air space and cork, felt, and reindeer hair insulation in between. Door sills were raised to obstruct the flow of cold air along the decks. A skylight in the upper deck let light into the salon through three layers of glass. Even the rudder and propeller were designed to be removable so that they would not be damaged by the pressure of the ice. The rigging was simplified to enable the ship, when under sail, to be run by two men. The result was a vessel ideal to the task. The shipbuilder, Colin Archer, reported that after Nansen's expedition (1893-96) only one fitting needed replacement before the *Fram* was again ready for exploration. It would shortly be Amundsen's turn to rely on this superior Norwegian technology, in the Antarctic.





Amundsen and Scott

For Roald Amundsen (1872-1928), attaining the pole would attract the funds needed for scientific exploration of the Arctic and would help establish the national identity of Norway, which had recently won independence after a half millennium of rule by Denmark and Sweden. For Robert F. Scott (1868-1912) and his backers, reaching the pole was assurance that British willpower and determination still ruled, when the decline of the empire was everywhere manifest. However, if the goal was not purely scientific, the means employed certainly were—for Amundsen. As an heir to a tradition of Nordic polar exploration, and with the moral support of Fridtjof Nansen, Amundsen studied all the literature and gleaned all the experience of those who had gone before him. He calculated his food requirements to endure the worst weather, redesigned his garments, skis, sleds, dog-harnesses, fuel containers, etc., to correct for previous inadequacies. He ordered the best sled dogs to be had—from Greenland—and found experienced handlers to manage them. He refitted *Fram* with a newly invented diesel engine and brought a factory mechanic along with him to maintain it. He left nothing to chance in the way of planning, equipment, or training. Every gram was measured and recorded. His team was carefully chosen to have redundant specialties, so that the loss of one member would not imperil the rest. Key instruments were brought in duplicate. Safety factors were built in at every level. Scott's expedition, by contrast, lacked advance planning, coordinated training, and adequate transportation. Scott belittled the use of skis and sled dogs, against the best advice offered him, even by Nansen. Instead, his party started for the pole with a collection of prototype motor sledges, ponies, and dogs. The sledges soon broke down, the ponies died, and the dogs were sent back, leaving Scott to proceed to the pole on foot and on skis (Scott had ordered one of his men to leave his skis behind). The British clothing and footgear was inadequate, and supplies were insufficient. Poor planning left Scott's party to struggle home from the South Pole too late in the season and long after Amundsen had come and gone. Scott's men suffered vitamin deficiencies, lack of fuel, and lack of stamina. They did not make it. Scott had chosen to pit British endurance against the elements, to fight nature. Amundsen, the scientific explorer, had studied nature and adapted to it.

Nansen's expedition, although failing to reach the pole, produced new scientific data that helped the Scandinavians maintain leadership in arctic studies. Nansen had observed that there was no polar land mass and that the ice pack did drift, but not in the direction of the wind, as supposed. That observation led to a new model for the movement of ocean currents, one that took into account the rotation of the earth. Nansen had developed new instruments for measuring varying temperatures and salinities of the sea at different depths, devices for sampling bottom sediments, and an accurate meter for measuring ocean currents. Mathematical study and mapping of all such data fit well with the pioneering work of fellow Norwegian Vilhelm Bjerknes (1862-1951), who created the weather-front model. The result was a new understanding of the fluid dynamics of the atmosphere and hydrosphere.

Scandinavian polar exploration and research has continued into the twentieth century. Otto Nordenskiöld, a nephew of Adolf, explored glaciers in southern Chile and, in 1902-03, led a Swedish expedition to Antarctica, one that failed when the ship ran aground. The party was rescued and Otto Nordenskiöld returned to Sweden and made extensive plans to establish a permanent Swedish base on Antarctica. World War I intervened and the plans were abandoned.

In the meantime another Scandinavian, Roald Amundsen (1872-1928), reached the South Pole. Nansen's expeditions had awakened a sense of adventure in the young Roald Amundsen. Amundsen is best remembered today for his race with Robert F. Scott to be the first to reach the South Pole, but in fact he was a scientifically trained explorer who led several polar expeditions to collect data, particularly concerning the Earth's magnetic field, and his race to the pole was motivated as much by the need to arouse public interest in funding arctic research as by personal competitiveness.

Amundsen's first polar experience was as first mate on a Belgian ship that set out to determine the location of the south magnetic pole (1897-99). The ship lay frozen in the ice for thirteen months, during which Amundsen learned how to take measurements of the terrestrial magnetic field. When he returned to Europe, he decided to become a scientist-explorer, and he formally studied magnetism both in Norway and in Germany. His aim was to undertake a voyage to locate precisely and to study the northern magnetic pole.

With the encouragement and support of Nansen, Amundsen was able to secure a suitable boat and enough private and state funding for a three-year exploration of the Northwest Passage over Canada. Amundsen's boat anchored in Petersen's Bay, near the magnetic pole, for nineteen months, while he made the necessary magnetic measurements, before continuing—first by inland waterways, then over Alaska, and finally south along the North American coast—to San Francisco, which he reached in October 1906. His expedition was the first to sail the entire Northwest Passage, and it returned with a large quantity of physical and ethnographic data, as well as a large collection of artifacts from previously unknown arctic peoples.

Amundsen wished to continue Nansen's arctic research, but when the American explorer Robert Peary reached the North Pole in 1909, Norwegian financing for polar exploration largely disappeared. Amundsen clearly understood that another "first" would be needed to reawaken the public's interest and support for polar science, so when he had put together another expeditionary boat and crew, he set his sights on a new goal—in secret.

Before sailing from Madeira in November 1910, Amundsen revealed to his crew that he intended to be the first to reach the South Pole. When the crew agreed, he sent telegrams to the expedition's committee in Norway and to his rival, Scott, who was still in New Zealand.

Amundsen reached Antarctica and set up his winter base on the Ross Barrier early in 1911. He then provisioned depots at 80°, 81°, and 82° south latitude, all of which would be used as stepping stones to the pole and back. Toward the end of October, Amundsen and four companions set out with four sleds, fifty-two dogs, and supplies for four months. He reached the general area of the pole on 14 December 1911. For four days they made astronomical measurements, which showed they were within three to six kilometers of the geographic pole, and they therefore explored the area in a radius of eight kilometers to make sure they actually "reached" the South Pole. When the ill-fated Scott expedition arrived 17 January 1912, they found the Norwegian flag already there, but Amundsen was gone. Besides winning the race to the pole, Amundsen's expedition returned with a year's worth of meteorological measurements made at the base camp and a mass of other geographic and oceanographic data, which were analyzed and published in Oslo.

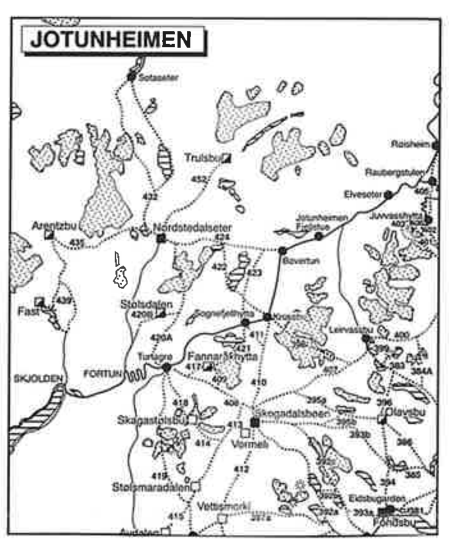
Scientific exploration continued after the First World War, and further studies were made of the glaciers in Norway, Iceland, Greenland, and Spitzbergen, where a permanent station for meteorological and magnetic studies was set up in 1932-33. After the Second World War, a joint Swedish-Norwegian-British expedition explored Queen Maud Land (Antarctica) between 1949 and 1952. In 1957-58, designated as the "International Geophysical Year," a multidisciplinary scientific survey of Spitzbergen was again undertaken.

To mark the one-hundredth anniversary of Adolf Nordenskiöld's voyage through the Northeast Passage, a special arctic research team comprising one hundred scientists from nine countries was organized by a consortium of Swedish and Norwegian scientific societies and institutes, with support from the Swedish Government and Navy. The research team boarded the *Ymer*, a Swedish icebreaker, and from 1978 to 1980 made a chemical, meteorological, oceanographic, biological, geological, and geographic survey of the arctic regions between Spitzbergen and Greenland. Arctic research continues to be an important part of Nordic scientific expenditure, as the significance of polar geophysics in environmental pollution and the fragility of arctic ecosystems are becoming apparent. The prominence that Scandinavian scientists still hold

Map of the South Pole, showing Amundsen's route (starting from Bay of Whales) and Scott's (starting from Ross Island). Amundsen reached the pole on 14 December 1911; Scott on 18 January 1912.

The national parks of Norway

Not until one hundred years after the establishment of Yellowstone National Park in Wyoming (1872) did Norway get its first national parks. Nevertheless, outdoor life has been very popular in Norway since the mid-nineteenth century, when marked trails and overnight accommodation were first provided. Today the Norwegian Tourist Association has 160,000 members; it operates 310 mountain cabins and maintains 12,000 miles of marked trails. The map below shows the lakes, fjords, and glaciers of the Jotunheimen area, as well as trails and cabins (staffed or unstaffed), which existed long before Jotunheimen became a national park in 1980.



in this field is based on over a century of experience with arctic conditions and a tradition of designing equipment and training men to cope with them.

Environmental Science

For several reasons environmental studies, arctic and otherwise, is another niche in which Nordic science has flourished: geographic location, governmental priorities and initiatives, and a long scientific tradition in biology. In the late nineteenth century it became evident to many Scandinavians that their natural regions—marshes, lakes, and large tracts of forest—were rapidly disappearing. The primary cause was the uncontrolled extension of agriculture, which steadily encroached on marginal soils, such as the sands and wetlands of Western Jutland in Denmark. Draining of marshes to make them arable destroyed wildlife habitats. Heavy logging was destroying the forests of Norway and Sweden at a rate that had already caused alarm in the eighteenth century, for lumber was a vital export commodity. By the 1870s people began to worry about protecting natural areas. In response, Adolf Nordenskiöld, who had attained national prominence as an explorer, proposed that protected national parks be established in the Nordic countries. In the next decades the protection of specific areas of Sweden from commercial exploitation gained support from scientists who were concerned that natural evolutionary processes available for study were becoming rare, from agriculturalists who worried that declining habitats would fail to support insect-eating birds, and from outdoorsmen of all sorts. Furthermore, the tourist associations, which had been organized in Norway in 1868 and in Sweden in 1885, spoke in favor of maintaining natural areas for visitors. The Nordic peoples have always associated themselves with nature, and recreation in natural areas is an important part of their leisure life. Even economists were concerned that unrestricted growth would destroy future natural resources, such as timber, and they favored protective legislation.

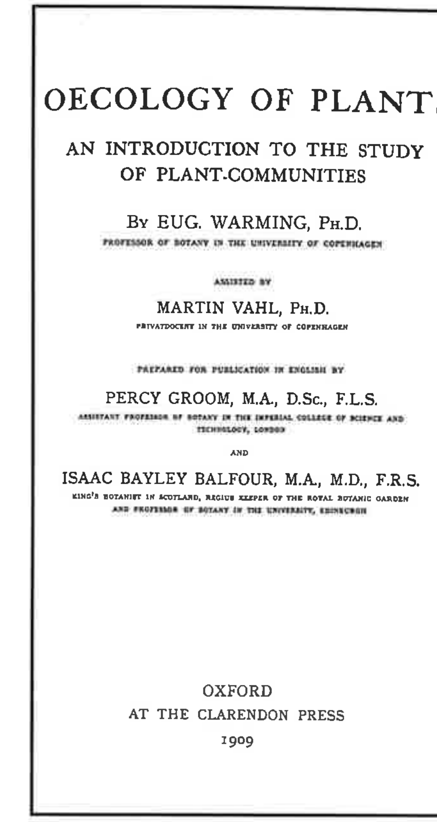
Of course, Sweden was not the first country to be concerned about preservation; the first national parks were established in North America, and elsewhere in Europe the importance of environmental conservation was becoming evident. But Sweden did not lag behind, and in 1904 the Committee for the Protection of Nature was established by the Swedish Academy of Sciences to come up with proposals. They eventually included a national landmarks law protecting specific landscape features and a national park law protecting park areas, both enacted in 1909.

The drive to preserve natural areas had begun in the late nineteenth century from a concern to protect nature *from* people, so that part of it might remain pristine. In the early twentieth century, scientists began to think in terms of protecting nature *for* people, inasmuch as humans were now being viewed as a part of that nature and dependent on it. Attention was shifting to the whole environment and toward the wise use of resources and the control of pollution, rather than just the isolation and preservation of natural parks. The interdependence of the various links in the web of life is an idea that in Scandinavian science may be traced back to Linnaeus. Even though Linnaeus maintained the old notion that God had created a fixed number of immutable species, an idea antithetical to modern biology, he understood that there was a complex interdependency among creatures, that a balance was maintained by birds of prey feeding on small birds, which fed on the insects that kept plant populations in check.

Ecology in the modern sense was to develop later, the term itself having been coined by the German evolutionist Ernst Haeckel in 1866. A Dane, however, made plant ecology a popular subfield of botany. Eugene Warming (1841-1924) grew up on Jutland's Atlantic coast, with its fragile environment of marshes and dunes, where he studied the plant life closely. After becoming an evolutionist, he set out to determine not only why certain plants were found in certain ecological niches, but also why plants seem to congregate in definable plant communities. His book on the subject, *Plant Communities* (1895), drew attention to the relationship between plant communities and ecological environments such as meadows.

The strong tradition of biological studies, coupled with the twentieth-century commitment to regulate industries in the public interest, has led to an increasing involvement of Nordic scientists in regulatory activities. Again Sweden serves as an example. Through the Swedish Academy of Sciences' Committee for the Protection of Nature, the Government's Board of Crown Forests and Lands, and similar agencies, scientists have acted as consultants in issuing permits for hydroelectric dams, draining lakes and marshlands, and other environmental issues, especially since World War II.

Direct government involvement in environmental matters was quite limited until the 1960s, when the National Environmental Protection Commission was enacted (1962) and a state commission for the control of air pollution was established (1964). In 1967 these agencies were merged to form the National Environmental Protection Board, moving protection of the environment out of the Swedish Academy of Sciences' control and placing it wholly under governmental auspices. Freed from regulatory duties, the Academy turned to global scientific studies of pollution and energy use. In 1972, the Academy launched a special journal of environmental research called *Ambio*, and, in 1977, thanks to a private donation from Kjell and Märta Beijer, opened the Beijer Institute to concentrate on ecological problems. Since then the institute has been reorganized as the International Institute for Energy, Resources, and the Human Environment, with an international board of directors appointed by the Swedish Academy of Sciences. It is supported by the Beijer Foundation and grants from the Swedish government.



OECOLOGY OF PLANTS

AN INTRODUCTION TO THE STUDY
OF PLANT-COMMUNITIES

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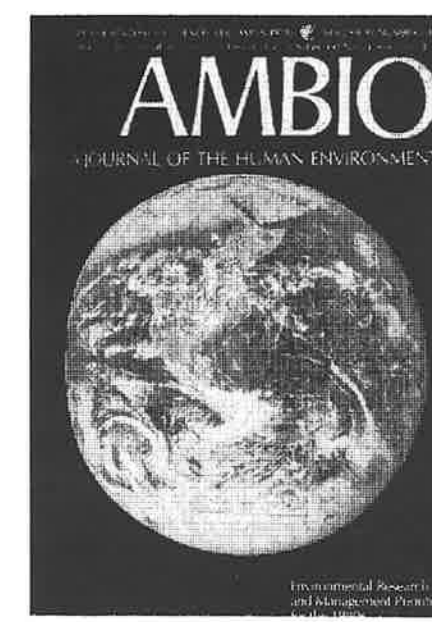
OXFORD
AT THE CLARENDON PRESS
1909

Title page of Eugene Warming's *Plant Communities,* in the first English edition of 1909



Cover of the journal *Ambio,* published since 1972 by the Swedish Academy of Sciences

Vilhelm Bjerknes

The career of Vilhelm Bjerknes, a pioneer in modern meteorological study, illustrates both the historical importance of private philanthropy to Nordic scientific effort and the usefulness of cultivating scientific specialties to dominate well-defined niches. Bjerknes's education was strongly influenced by his father's attempt to unify the theories that explained the behavior of fluids (hydrodynamics) and electromagnetic fields (electrodynamics). With the help of a state grant, Vilhelm Bjerknes studied on the Continent, where he began to apply hydrodynamic theory to evaluate the movements of the atmosphere and hydrosphere. His work held out the prospect of creating long-term weather forecasting, for which he received an annual stipend from the American Carnegie Foundation from 1905-41. Although he secured a chair at the University of Christiania (Oslo) in 1907, he left for the University of Leipzig in 1912, where he was given a greater opportunity for research as professor of geophysics and chairman of the Geophysical Institute. When Fridtjof Nansen brought him an offer to start his own geophysical institute in Norway, Bjerknes returned to his native land to accept a professorship at the University of Bergen in 1917. Bjerknes's application of classical hydrodynamics and thermodynamics to the motions of the air and water produced the weather-front models, based on the movement of high and low-pressure vortices, that are still in use. By making a strategic choice to focus the work of the "Bergen school" on weather analysis and modeling, Bjerknes was able to dominate a scientific niche that was vital to military and shipping interests.

Collective Nordic Efforts

Twentieth-century Nordic cooperation has taken the official, political form of the Nordic Council, a supranational council composed of members of the five governments of the Nordic countries. Collective research and development is one of the council's aims. In the years following World War II the Nordic Council decided to support research in physics. Plans for a Nordic physics institute were being made in Sweden already by 1953, but it was decided to involve the Bohr Institute and thus take advantage of Niels Bohr's leadership and international reputation, and to do that it was necessary to wait until 1957, when the theoretical physics unit of CERN moved from Copenhagen to Geneva. In that year the Nordic Institute for Theoretical Physics (NORDITA) was established and funded by the Nordic Council for research in astrophysics and atomic, nuclear, subatomic, and solid-state physics.

More recently a joint Nordic council for applied research, called Nordforsk, was created to focus collective funding on common problems. Since 1987 its research functions have been absorbed by the Nordic Fund for Technology and Industrial Development (est. 1973). This inter-Nordic fund is intended to do for Norden collectively what the research institutes have done for the individual countries, namely, to enhance Nordic industrial competitiveness globally through automation and information technology and by the development and domination of particular industrial niches. Since 1980 Nordic Council policy has been to promote R & D in computer software, high-performance Gallium-Arsenide semiconductors, computer-aided radiation therapy, technology for disabled persons, development of health services, and computer-aided education. In 1983 a special Nordic Council for Science Policy was created, and by 1984 forty percent of its budget was directed to R & D, with a stress on industrial technology.

The Nordic Council has also undertaken research on the environment. A program proposed in 1991 by the Nordic Council of Ministers calls for a five-year joint research program covering climatic change, studies of the Baltic region, and ways of integrating environmental policies into the existing social, economic, and political framework of society. The proposal notes that the Nordic countries already spend a great deal of money on environmental research, but that much more can be done more efficiently if their resources and efforts are pooled.

Conclusions and Generalizations

Although the Nordic countries lie on Europe's northern frontier and have at times been marginalized in the history of European civilization, many of the contributions made by Nordic scientists have been central to the development of international science. From the sixteenth century to the present, from Tycho Brahe and Carl Linnaeus to Fridtjof Nansen and Niels Bohr, Nordic scientists have pioneered in exploring and investigating the natural world. The political maturation of the Scandinavian countries during the late seventeenth and eighteenth centuries and their rapid economic development from resource-rich wildernesses to modern industrial societies in the late nineteenth and twentieth centuries have instilled a scientific culture and high standard of technology in Norden.

The willingness to seek scientific solutions to social and economic problems and the desire to approach these problems collectively are legacies of the Enlightenment that have become characteristic of the Nordic mentality. The scientific institutions that have evolved in the Nordic countries reflect this mentality: they are diverse in form and function but generally serve to channel both public and private-sector funding to research-and-development programs that will benefit several firms or are in the general public interest. The importance of this combination of resources is evident from the fact that the Nordic countries have a very high relative expenditure on research and development. The amount of the R & D funded by the governments, however, is small compared to that offered by the major industrial economies. As has been pointed out, private sources of funding are often less burdened than are universities and government agencies with the conservatism that often dogs public bureaucratic organizations and slows their responses to new problems. Thus, the Nordic system of institutes offers the innovative spirit that comes with private funding, the efficiency that comes with small size and diversity, and the accountability that comes with government control. The success of collective R & D has permitted small and medium companies within the individual Nordic countries to compete against larger firms. Furthermore, that action has been carried over into a cooperation between the Nordic countries that will help Nordic firms compete globally with much larger international companies and maintain a high technological standard.

Sigurður Thórarinsson and Surtsey

In the 1950s it was discovered that Iceland lies astride the mid-atlantic rift, where crustal material wells up and forces apart the giant tectonic plates that make up the earth's surface. Here the rift can be studied from land, making Iceland a unique volcanic geological laboratory. Nearly every type of terrestrial volcano is represented on Iceland, so it is not surprising that vulcanology is a well-established specialty there. Sigurður Thórarinsson (1912-87), professor of geology at the University of Iceland, has conducted careful research on Iceland's geology through much of the present century, keeping detailed accounts of the eruptions of Mount Hekla on Iceland's mainland (1947-48), Helgafell on Heimaey (1973), and the volcanic creation of a new island, Surtsey (1963). Thórarinsson pioneered the study of volcanic history by means of analysis of soil profiles, called tephrochronology. Tephra is the term collectively applied to the ash, cinders, lava, scoriae, pumice, and other rocks thrown out in volcanic eruptions. By comparing strata samples from various locations with historical accounts of eruptions, Thórarinsson was able to reconstruct the chronology of Hekla's development. Surtsey also provided a unique opportunity for scientists to study rare geological processes up close: the eruptions, ash and lava deposits, erosion by wind and waves, and eventual colonization by plants and animals. Thórarinsson, who chronicled Surtsey's evolution from the first day smoke was observed boiling up from the ocean, has published scientific and popular accounts.

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