04-S1) David Goodman, "[Spanish] Science: Navigation, Empire and Counter-Reformation"¹

The Scientific Traditions of the Oriental Minorities

Spain in the fifteenth century stood out from the rest of Europe because of its distinctive social composition. Nowhere else in Christendom were there to be found large oriental minorities, of different race and religion, the Jews and Moorish Muslims living in close contact with the Christian majority. The Jews had first arrived some time after the Roman destruction of Jerusalem, part of that diaspora which resulted in Jewish settlements throughout Europe. And Spain’s Jewish communities increased during the early middle ages through further migrations from Africa. The Moors had come as conquerors in the eighth century, the westernmost thrust of that remarkable expansion of the forces of Islam. Crossing the Straits from North Africa, the invading Moors, Muslim and Arabic-speaking, soon succeeded in conquering practically the entire Iberian peninsula; only a fringe in the extreme north remained in Christian hands. From that small area began the reconquista, that gradual Christian reconquest which would take seven centuries to complete. Christians, Moors and Jews therefore lived at various times under Christian or Moorish rule.

For centuries the three communities had lived side by side in relative harmony; periods of peaceful coexistence and mutual admiration. There had been much intermarriage; Jews had married into the highest levels of Christian society—Ferdinand, king of Castile and Aragon, was descended from the Jewish Enriquez family. In the

fourteenth century the Christian ruler of Seville, Pedro I, had built a Moorish-style palace using Moorish craftsmen loaned by the Muslim king of Granada. And at the same time in Muslim Granada a building of the Alhambra was painted with scenes depicting Christians and Moors playing chess together, hunting together and engaged in chivalrous battle. Henry IV of Castile (r. 1454-74), the brother of Isabella, ate like a Moor, dressed like a Moor and retained a Moorish guard. Under Christian rule Muslim craftsmen had produced the beautifully ornate interiors of mediaeval synagogues which still survive in Toledo; and later generations of Muslim craftsmen of the fifteenth century assisted in the construction of churches in Aragon, and were even permitted to complete their work with the inscription: ‘There is no God but Allah’.

This intimate interaction of different peoples enriched Spanish culture, bringing oriental influences in architecture; ceramics; patterns on embroidered garments; cooking; and the Castilian language, which permanently adopted numerous Jewish words and an estimated 4,000 words from Arabic. And the character of Spanish science was also deeply affected by the presence within the peninsula of well-developed Jewish and Arabic traditions. In mediaeval Toledo scholars—Jewish, Muslim and Christian—had collaborated in the translation into Latin of Arabic and Hebrew scientific texts; that had been a process of importance not just for the development of Iberian science, but for the whole of Western science (see Chapter 1).

The continuing stimulus of the Arabic scientific tradition in Spain is clearly seen in the so-called ‘Alfonsine Tables’, astronomical tables compiled by Arab scholars and translated into the vernacular Castilian through the patronage of Alfonso X, king of Castile and Leon (1221—84). Based on Ptolemy’s *Almagest*, they allowed the positions of the Sun, Moon and planets to be calculated for particular years or days; also the duration of lunar and solar eclipses. Circulating first in manuscript and then in modified printed editions (Venice, 1483 and 1492; Nuremberg, 1536 and 1542), the *Alfonsine Tables* remained the basis of all astronomical almanacs in Spain and throughout the West until the mid-sixteenth century. Copernicus, during his studies at Cracow, had
bought a copy of the second printed edition of the *Tables*. At the Castilian university of Salamanca, students in the 1560s and 1570s who attended the lectures of Hernando Aguilera, professor of astrology, heard him discuss the same *Tables*.

But by the sixteenth century Arabic science no longer had the esteem it once enjoyed. It is too strong to speak of a decline; more correctly there was an ambiguous attitude to Arabic science. There were two reasons for this. First there was the spread to Spain of Renaissance humanism from Italy and the Netherlands. That scholarly movement, inspired by admiration of the literature of ancient Greece and Rome, sought to recover classical texts purified from mediaeval accretions; and that often meant eliminating alterations and additions introduced by Arabic commentaries. In various European universities a tension arose, notably in the medical faculties, between scholars who wished to retain established teaching texts derived from Arabic intermediaries, and a younger generation who insisted on using the original Greek texts of Hippocrates and Galen. In sixteenth-century England Thomas Linacre and John Caius were the most active of these medical humanists. In Spain the same goals were sought at the new humanist university of Alcala de Henares, founded in 1508 by Cardinal Cisneros, archbishop of Toledo and later regent of Spain. During the 1560s the victory of humanism over Arabic at Alcala secured the abandonment of the most famous text of Arabic medicine, Avicenna’s *Canon*; it was replaced by the direct study of Greek and Latin texts.

But this humanist opposition to Arabic literature did not prevail throughout Spain. There is evidence that Avicenna’s *Canon* continued to be taught at the University of Salamanca in the seventeenth century. And when Philip II built up the great library—it was intended to be accessible to scholars—in his palace of the Escorial fifty kilometres north-west of Madrid, the collections included a rich holding of mediaeval Arabic books, predominantly medical and pharmaceutical. The king brought to his palace Diego de Urrea, a professor of Arabic, to teach the language to resident monks. The purpose was in part to benefit from this concentrated stock of Arabic medical wisdom; but also to
train Arabic-speaking missionaries to extirpate Mohammedanism in the peninsula.

That brings us to the second reason for the ambiguous status of Arabic science in Spain: its association with the world of Islam, a religion now regarded as heretical, corrupt and a dangerous threat to the Christian West through the might of Spain’s formidable enemy, the Ottoman Turks. The last vestige of Moorish rule in the peninsula, the kingdom of Granada, had finally been conquered in 1492. After their marriage which had united the crowns of Castile and Aragon, Ferdinand and Isabella had decided to complete the centuries-old internal crusade against the Moor. As a reward for the recovery of Granada for Christendom the pope had bestowed on the victorious king and queen the title of ‘The Catholic Monarchs’. But the subjugated Moors soon found they had cause for complaint. In the last stage of battle Ferdinand and Isabella had called on the city of Granada to surrender in exchange for offers of religious toleration. The offer was accepted but the promise broken. Isabella authorized Archbishop Cisneros to begin the compulsory conversion of these new subjects—some 200,000 out of Spain’s six million. By 1500 Cisneros had converted all Granada’s mosques into churches and, although a patron of learning at Alcala, he organized the burning of Arabic books except for those dealing with medicine and philosophy, another sign of residual respect for classical Arabic science. The Moors were forcibly baptized.

Forced conversion, persecution and expulsion would also be imposed on Spain’s other oriental community, the Jews. The reputation of Jews in Spanish society as artful magicians and possessors of knowledge secret and powerful generated both fear and admiration. Spurious texts attributed to Solomon, the Jewish prince of wisdom, circulated in the peninsula. The Clavicula Salomonis (Solomon’s Key), purporting to be Solomon’s legacy to his son

Rehoboam, gave instructions for conjuring spirits; information on the marvellous properties of herbs and stones; and revealed secret geometrical diagrams inscribed with Hebrew letters supposed to have magical powers in overcoming disease. Although
the Old Testament prohibited sorcery and divination, other Jewish texts encouraged occult science. The mystical Kabbalah promised control over nature by meditation of secret script representing the signs of the zodiac; the Talmud recorded some rabbinical beliefs in the effectiveness of amulets in fighting disease and of the influence of the constellations on individuals at the time of their birth.

Probably through a combination of skill and expectations of wonder-working, the Jews became so prominent as physicians that they dominated medicine in Spain, achieving the highest positions as court physicians. But their elevated social position was made insecure by prevailing Christian beliefs that Jews had a tendency to apply their knowledge to evil ends. When Henry III of Castile (1377—1406), struggling to restore order after the massacres of Jews, died very young, his Jewish physicians were accused of poisoning him; the myth still fanned resentment in the sixteenth century. When in 1509 López de Villalobos, a convert and son of a Jewish doctor, was appointed court physician to Ferdinand the Catholic, he was imprisoned by the Inquisition on a charge of achieving his exalted position by black magic; he was later exonerated and released.

The forced conversions of the 1390s and the subsequent voluntary conversions for reasons of insurance against further persecution created a new class in Spanish society, known officially as New Christians or conversos (‘converts’) and amongst the populace as marranos (‘swine’). Some of them or their offspring became sincere Christians (Teresa of Avila; St John of the Cross; Diego Lainez, the successor to Ignatius Loyola as general of the Jesuits). Others were Catholic only in name and to varying degrees retained secret loyalties to Judaism. And it was specifically to investigate and correct this continuing attachment of conversos to Jewish beliefs that Ferdinand and Isabella established the notorious Spanish Inquisition in 1480. The Inquisition had no powers over unbaptized Jews; but converted Jews were arrested, subjected to torture to secure confessions of Jewish observance, or delivered to civil authorities for execution at the stake. In the first terrible decade of its functioning the
Inquisition punished an estimated 17,000 victims; some 2,000 *conversos* were burned at the stake. And the Inquisition declared that the descendants of the condemned should be ineligible to hold public office, so reinforcing ideas of racial purity. But there were still many unconverted Jews in the peninsula and there is some evidence supporting the crown’s concern that they were encouraging the converted to remain faithful to Judaism. The belief that Jews were hindering the full assimilation of the *conversos* into a wholly Catholic Spanish society motivated Ferdinand and Isabella to deport the Jews from their places of maximum concentration in Andalucia to other regions of Spain; and when that didn’t work to issue the edict of 1492 forcing unconverted Jews to accept baptism or be thrown out of Spain; any who returned would be sentenced to death. So ended the centuries of Jewish communal life in Spain.

Today Spanish historians commonly blame the persecution and expulsion of the Jews for Spain’s scientific stagnation from the late sixteenth and seventeenth centuries, the very period when other parts of Europe were experiencing the scientific revolution. It is alleged that the arrest, murder or expulsion of Jews deprived Spain of her best scientists; and further that scientific decline followed the destruction of Spain’s Jewish merchant community, because ‘there is no science without the financing of science, without artisans, mechanics and merchants; yet these were the groups who were systematically eliminated’ (Marquez, 1986, pp.75—6). What truth is there in this? The wider point depends on the dubious assumption that the vacuum left by departing Jewish traders and artisans was left unfilled by others who could take their place; also there is the debatable assertion that science can only flourish where there are merchants and craftsmen. But there is no doubt that through persecution Spain lost the services of distinguished scientists. The expulsion order of 1492 caused the departure of the astronomer Abraham Zacut and his expertise now benefited Portuguese navigation. Lluis Alcanyis, an enterprising physician, remained in Spain as a *converso*. He had taught in the school for surgeons which he had helped to establish (1462) in the city of
Valencia. His treatise on the plague (c. 1490), written to combat the outbreak in the city, was the first medical text to be printed in Valencia. In 1499 he was appointed the first professor of medicine at the new university of Valencia. But in 1504 he was arrested by the Inquisition for observance of Jewish rites, imprisoned for three years and then burned alive.

But other converso physicians continued to practice in Spain and did well despite the risks of persecution and the obstacles of prejudice. In the cities, colleges of apothecaries exploited old fears of poisoning to exclude those of Jewish descent and secure the profession of pharmacy as a preserve for untainted Old Christians. In 1564 Philip II reaffirmed royal approval of the constitution of Valencia’s college of apothecaries which prohibited conversos from preparing medicines,owning a pharmacy or admission to the qualifying examination in pharmacy. Similarly in Barcelona the college which supervised the practice of pharmacy there required intending pharmacists to present documents establishing a pure genealogy unspoilt by Jewish blood. And the same racial discrimination was prescribed at Zaragoza and Seville explicitly to protect the populations of those cities from converso poisoners.

But it is one thing to enact a strict regulation and another to enforce it. It is questionable if these regulations were effective. Genealogies were frequently forged at a price, and regulations of this type not always enforced. It is established that, despite similar statutes of purity preventing conversos from holding office in the tribunal of the Inquisition in Toledo, its cathedral and its municipal council, all of these in fact had converso members. And many conversos, one way or another, managed to settle in Spanish America even though that was strictly forbidden. There may have been enough Old Christian pharmacists in Spain to exclude the conversos. But that was not true of medical practitioners, and this explains the continued reliance on converso physicians. There are even some indications that Spaniards of Old Christian stock were shunning the medical profession to avoid suspicion of Jewish descent, so strongly established had the Jewish connection with medicine become. In his treatise on nobility
of 1595 the Benedictine Juan Guardiola sympathized with efforts to purify the medical profession from conversos, but conceded that it was permissible to employ them, as Philip II did, because of their talent. When in the 1570s the tribunal of the Inquisition at Logrono needed the services of a physician, they were unable to find one of pure race. Doctor Belez was available but he was a converso; could he be employed? The central office of the Inquisition in Madrid gave permission to consult him but only if his title went unrecognized. However begrudging, Spanish society in the sixteenth century could not do without its converso physicians.

The Spanish monarchs did not need conversos for navigation. Spanish historians used to allege that Columbus may well have been of Spanish Jewish descent. That is now dismissed; there is no reason to suppose he was anything other than the son of a Catholic family from Genoa. Nor does it seem that the crew who sailed with him to America in 1492 had as many conversos as was once supposed; but Columbus did take a converso interpreter, Luis de Torres, because his fluency in Arabic was thought to be invaluable for communicating with the people of China, the landfall Columbus expected to achieve by sailing west across the Atlantic. His assurance that this sea route would give access to the wealth of Asia failed to persuade the Portuguese monarch Joao II; but then he turned to Ferdinand and Isabella and after six years’ persistence they finally agreed to support a project which many of their councillors and geographers had thought crazy, partly because they believed that the western ocean was immense and not navigable by the relatively short crossing Columbus promised.

Despite the repeated assertions that scientific knowledge was essential to Columbus’ discovery of America, there is little evidence to support this. What seems to have been important were Columbus’ persistence, his confidence based on a considerable underestimate of the extent of the western ocean, and above all his uncanny seamanship—not any astronomical expertise nor even occasional reliance on astronomical observations, but an intuitive mastery of winds, currents, charts and the magnetic compass which continues today to bring admiration from sea-dogs.
This absence of science may not be true for the final phase of the Iberian voyages of discovery: the expedition of 1564 Philip II sent from Mexico to the isles of the Pacific in search of spices, and which resulted in the Spanish colonization of the Philippines. The king wanted an experienced navigator skilled in geography and astronomy to guide the expedition. Andres de Urdaneta was commissioned. He had sailed to the Moluccas before becoming an Augustinian friar. Now resuming navigation he organized the equipping of the expedition with astronomical instruments: astrolabes and cross-staves. It is not known how much use was made of these scientific instruments for the voyage because there is no record of observations. Urdaneta’s achievement, one of the feats of sixteenth-century navigation, was to discover the elusive favorable winds at the high latitude of 42°N for the return journey east to the coast of Mexico. That discovery which established the route of Spain’s galleons to Manila for the next two centuries owed much to Urdaneta’s experience of currents and winds; it is unclear if the remarkable return journey of five months at sea without touching land was in any way assisted by his astronomical expertise.

The Spanish settlements in the Pacific had led to conflicts with Portuguese monarchs who complained they were infringements of their preserve specified by the demarcation line agreed at Tordesillas. For years the Moluccas with their valuable spices had been contested; there were battles in that remote region. Peace had come in 1529 when Charles V sold the island to the Portuguese monarch for 350,000 ducats. And now doubts were raised on the legitimacy of Spanish occupation of other islands in the same part of the world—the Philippines. It all depended on a precise determination of the agreed demarcation lines, in fact lines of longitude. And in Philip II’s reign this was a matter of political as well as scientific importance. Philip had commissioned a royal cosmographer, Alonso de Santa Cruz, to survey the various methods available for determining longitude.

His resulting account is especially interesting for the clear recognition of the obstacles which prevented a contemporary solution to the problem of longitude. In
theory astronomical observations could provide the answer; as Santa Cruz said, the ancient Greeks had known this. For observers stationed at different locations on earth the same lunar eclipse occurred at different times. That was because the earth took twenty-four hours for its rotation through 360 degrees. If the recorded times of observation of the eclipse differed by six hours, the two observers were in positions separated by 90 degrees of longitude. But in practice this collaboration was far from simple. Santa Cruz commented that a lunar eclipse could last for hours and the two separated observers would have to be sure they were timing the same phase of the eclipse. A greater difficulty ruled the method out; an accurate timekeeper was essential—even a few minutes error on the clock would result in significant errors in longitude; but Santa Cruz said the available clocks usually gained or lost as much as half an hour a day making them useless for even approximate determinations of longitude.

The same instrumental inadequacy nullified the solution recently proposed in 1522 by Gemma Frisius of Louvain, a cosmographer of the Spanish Netherlands. If a clock set at a port of departure was taken on board ship, the longitude traversed during a voyage could be found by determining local time at sea from observation of the sun; from the difference with the time on the carried clock, position in longitude relative to the port of departure could be calculated. But although he regarded this as the most promising method Santa Cruz pointed to sources of error apart from the existing inaccuracies in clocks: the variation in temperature and humidity which affected clocks and the disturbance in the clock’s smooth running caused by the motion of the ship. These difficulties would not be eliminated until the eighteenth century with the invention in England of Harrison’s marine chronometer.

Meanwhile the longitude data demanded by Philip II produced results far from the truth, the inevitable consequence of imprecise clocks. From recorded observations of lunar eclipses taken in Panama in 1581 it was calculated that Panama City was 49 degrees 15 minutes west of the Canary Isles; the actual difference in longitude is 61
degrees, an error of 11 degrees 45 minutes, or about 700 miles. And in the Philippines where Urdaneta had asked a fellow Augustinian, Martin de Rada, to take astronomical observations for calculations of longitude, the results indicated that the Philippine town of Cebu was 215 degrees 15 minutes west of Toledo; the correct figure is 232 degrees, a large error of just under 1,000 miles.

Navigation and the competition for territory were clearly stimulating enquiries into longitude and astronomical observation in sixteenth-century Spain. And the urgency felt by the crown for a reliable method of determining longitude is revealed by the large monetary prize of thousands of ducats offered at the beginning of Philip III’s reign (1598) to anyone who could solve the problem.

The close connections between Spanish navigation, science and the crown were most apparent at the Casa de la Contratación (House of Trade) established by the Catholic Monarchs in Seville in 1503. It had been created to supervise Spain’s shipping and trade with the American possessions. From 1508 it became increasingly important as a centre of scientific and technical expertise covering the whole range of knowledge required for the art of navigation. A small technical staff employed by the crown supervised the manufacture of nautical instruments, the preparation of nautical charts and the maintenance of a standard chart of the Indies continually updated as new information came in. Crown officials also taught formal courses to pilots and examined them.

In addition to these ‘pilot-majors’ and ‘cosmographer-majors’, Philip II created ‘a chair of the art of navigation and cosmography’ (1552). It was intended to rectify the lack of training of masters and pilots. The appointed professor was Jeronimo de Chaves, the author of works on the calendar and a commentary on Sacrobosco’s Sphere, the standard introduction to Ptolemaic astronomy. He was instructed to teach from that elementary manual; to explain the technique of setting a ship’s course by the use of marine charts; the rules for determining latitude from observation of the sun and pole star; the use of clocks; the times of tides; and the theory and practice of nautical
instruments ‘so that errors in them can be detected’. Before any pilot or master was licensed to operate on the Indies route this course would have to be studied and an examination passed.

All of this activity greatly impressed Stephen Borough, the English navigator who visited the Casa in 1558. He soon called for a comparable institution to be established in England. In fact Philip’s repeated interventions and complaints reveal that inefficiency and corruption were affecting all aspects of the Casa’s scientific work (Goodman, 1988, pp.76-78). Nevertheless Seville had become the world centre of navigational expertise. And the teaching manuals based on teaching at the Casa were translated into several languages—one of the most widely read was the Arte de navegar (Valladolid, 1545) of Pedro de Medina, teacher of pilots at the Casa. Spanish naval historians have some basis for their claim that other European nations learned their navigation ‘from us’.

The Stimulus of Empire

By the 1530s Spain had acquired an empire far more extensive than Portugal’s and differing from it in the possession of huge land areas populated by millions of new subjects, the subjugated Amerindian empires of the Aztecs and Incas. The crown was determined to amass detailed information about these new territories in order to secure complete control of government and full exploitation of resources. And some of the Spaniards who came to the New World were so amazed by their remarkable environment that they were led to challenge long-held opinions and generate radically new ideas. In these two ways the experience of empire stimulated Spanish science and led to real advances in knowledge. This is particularly noticeable in the middle of Philip II’s reign, during the 1570s.

The Royal Council of the Indies was the central authority responsible for everything concerning Spain’s overseas possessions, except finance (transferred at the beginning of Philip II’s reign to the Council of Finance) and the maintenance of Catholic
orthodoxy (the responsibility of the Inquisition). Created in 1524, this consultative Council met regularly in Madrid and on the basis of its advice the monarch took the decisions of government which were then executed by his viceroys in the Indies. The Council consisted of lawyers, but in 1571 Philip added to it a new scientific officer, Juan López de Velasco, the ‘cosmographer-chronicler’, to remedy the lack of basic knowledge of the overseas territories.

His comprehensive duties, spelled out in the king’s instructions, reveal the crown’s desire for precise scientific information. He was required to compile accurate geographical tables of data on the longitude and latitude of places and their distances apart. That entailed the organization of astronomical observation in the Indies and the collection of results in Madrid. The royal cosmographer was instructed to arrange for the observation of lunar eclipses in the Indies. He was to write to royal officials out there communicating the times when these were to be observed, send instructions on how to make simple instruments—a type of sundial made from paper circles with wooden or metal gnomons, and explain the technique to be employed—marking the points on the dial where the shadow of the moon crossed it at the beginning and end of the eclipse. The other essential datum for a determination of longitude with reference to Madrid was provided by Lopez de Velasco himself: the recording of the time of the same eclipse as it occurred in Madrid. The surviving record of observations made in Panama in 1581 shows that these instructions were complied with.

In addition López de Velasco had to collect as much information as possible on the flora and fauna of the Indies. This along with other information was solicited and secured by the sending out of printed questionnaires to government officials in localities throughout the Indies, with a request for the return of completed forms to the Council in Madrid ‘as quickly as possible’. Many were completed, supplying the government then and historians today with valuable descriptive information on Spanish America.

More impressive work was achieved at the same time by the crown’s scientific expedition to the Indies. In 1570 Philip sent a Portuguese cosmographer, Francisco
Dominguez, to conduct a full geographical survey of New Spain (Mexico); with him went Francisco Hernandez, one of Philip's numerous court physicians, now appointed 'protomedico general of our Indies'. Hernandez's task was to find out all he could about the medicinal plants of the Indies. The marvelous virtues of exotic American plants had for decades raised hopes in Europe that genuine panaceas were now within reach; the newly discovered guaiacum was being employed in central Europe in the 1510s and for centuries after to treat syphilis, though its effectiveness was imaginary.

The sale of American medicinal plants had already become a profitable commercial venture and perhaps the search for greater profits was one motive behind the royal expedition. Hernandez was instructed to accumulate reliable information by consulting Indian herbalists on the places where medicinal plants could be found and their supposed virtues. Then he was to test the information by observations and experiments. Viceroy's were instructed to supply local artists to provide illustrations of the plants. For five years Hernandez traveled by mule over the vast territory of New Spain accompanied by artists, plant-hunters and an interpreter. At various hospitals he experimented on the sick with extracts from plants he had never seen before. His own health suffered and he was never able to complete his mission with a botanical survey of Peru. But the description of thousands of species of Mexican Flora which he sent to Madrid has never been superseded. The manuscripts were deposited in the Escorial; the fine illustrations were used to decorate Philip’s living rooms; and sacks of seeds and tubs of plants were transplanted in the gardens of the royal palace in Seville.

Hernandez’s reactions were revealing. Here were plants of great medicinal power which had never been seen in Europe. He therefore wrote to the king that he had surpassed Dioscorides, the long-established authority on medicinal plants; progress had been achieved far beyond the Greeks, because they had no inkling of this American floral treasure. And he was sure that if Alexander the Great had won fame from his patronage of Aristotle’s natural history, how much greater glory would come to Philip from this expedition!
But his manuscripts were not published until the seventeenth century. And Europeans became acquainted with American medicinal plants chiefly through the *Historia medicinal* (1565—74) of Nicolas Monardes, physician of Seville, who acquired shipped specimens as part of his business ventures in the Indies. His book familiarized Europeans with Peru balm, Tolu balm, sarsaparilla and tobacco—then regarded as a medicine. In the seventeenth century American flora gave Europeans ipecacuanha and quinine; these were not imaginary panaceas but important new medicines.

The peculiar fauna of America—the iguanas, armadillos, llamas, turkeys and parrots—amazed Europeans who saw them for the first time. Some were surprised to find any form of life in equatorial America because they had learned from Aristotle and other ancient authorities that nothing could live in the scorching heat of the tropics. When the Jesuit missionary Jose de Acosta arrived in Peru in 1571 his ingrained trust in Aristotle, nurtured by the education of his religious order, weakened under the severe blows produced by experience of a wholly new environment. In his widely read *Historia natural y moral de las Indias* (Seville, 1590) he confessed to mocking Aristotle’s philosophy because ‘while his doctrine predicted everything to be ablaze I and all my companions were cold’. Acosta was experiencing the chill of the Andes, a further refutation of Aristotle who supposed that the upper atmosphere became increasingly fiery. Huge rivers and lakes falsified the Ancients’ assertion that the tropics must be parched; and the presence everywhere of Indians exposed the belief in the impossibility of life in the tropics as nonsense.

But the most interesting of Acosta’s reactions were his acute theoretical reflections on the origin of life in the New World. How had the Indians and animals arrived in America? His explanation began from the conviction that all humans and beasts had been generated from the mating pairs in Noah’s Ark, and then liberated after the Flood’s retreat on Mount Ararat where the Ark had come to rest. But that was in Asia Minor in the Old World. He rejected the idea of a separate divine creation of life in America because that would imply incompleteness in God’s original creation and reduce
the importance of Noah’s Ark. So the Amerindians and American beasts must have crossed from the Old World. But an ocean passage seemed incredible:

the Amerindians knew nothing of the magnetic compass; in fact they had been astonished at the sight of Spanish ships. Acosta therefore concluded that Amerindians and beasts had crossed from the Old World to the New by land. His prediction that future exploration would show the two continents to be joined or very close would be confirmed by the eighteenth-century exploration of the Siberian Kamchatka peninsula (no more than 56 miles of the Bering Straits separates Siberia from Alaska). As for the distinctive fauna of the New World, Acosta speculated that they had walked from the Ark to various regions of the earth, but were able to survive only in the New World. But he was left with an unresolved difficulty: why had these animals never been observed in the Old World? No answer could be given to this until the theories of evolution centuries later.

Of all American natural resources none provided the Spanish with greater wealth than the precious metals. Silver had since antiquity been important in Europe’s economy for trade with the Far East. In recent centuries the chief centers of production had been the mines of central Europe (the Harz mountains, Saxony, Bohemia, the Tyrol and Hungary). All of that changed with the discovery in the 1540s of Spanish America’s rich silver deposits (Zacatecas, New Spain; and the great silver mountain of Potosí, Peru). The European mines declined; they could not compete with the American scale of production and the lower price of silver. Mexico and Peru became the principal suppliers of Europe’s silver, assisting the Spanish monarchy’s hugely expensive military campaigns and bringing wealth to financiers in Genoa. The operation of the American mines was left in the hands of the settlers, but the crown took its share: one tenth of the yield in New Spain; one fifth in the more lucrative Peru. Viceroyds departing from Spain to take up office in Mexico City or Lima were left in no doubt by the king’s instructions that the fostering of American mining was to be given the highest priority.

All of this gave a strong stimulus to Spanish metallurgy. It was technological
innovation which caused the silver boom in America. At first the silver had been extracted by smelting the ore; but the fuel costs were high and attempts were made to process silver ore ‘without fire’. A settler from Seville, Bartolome de Medina, successfully applied a new method of extracting the silver by mixing the crushed ore with mercury. In a slow chemical process in the cold, mercury alloyed with the precious metal to form silver amalgam. This was then heated—the only part of the process requiring fuel—and the amalgam decomposed; the mercury vaporized leaving the silver. The idea is thought to have come from Germany, but there was real achievement in Medina’s successful implementation of the technique with American ores. The considerable saving in fuel was offset by additional expenses for salt, an essential ingredient, and mercury, supplied by the king’s peninsular mine of Almaden and the Peruvian mine at Huancavelica. The great advantage of the amalgamation process was that it permitted the economic exploitation of the low-grade silver ore of Potosi, where production increased seven-fold in 1572—92, reaching a peak in 1592 of 900,000 marks of silver, 200 tons.

Spaniards in the peninsula and America worked on various designs of furnaces and methods of ventilation both to boost production and improve the dreadful working conditions of the Indian labor force. And a way was also discovered of accelerating the amalgamation process and reducing the consumption of mercury: in Potosi it was discovered that this could be achieved by the addition of iron filings. No one understood why this worked—twentieth-century text-books still present the amalgamation process as full of the complications that chemists call ‘side-reactions’. But it did work and this addition of a metallic reagent—later a copper salt was used—remained standard practice in the twentieth century.

**Monarch, Cities, Church and Science**

Power, political and financial, affected the development of science in peninsular Spain. No individual had as much power as the monarch but, contrary to what is
usually assumed, the power of the Spanish monarch was not absolute. In the crown of Castile, the largest and most populous part of the peninsula, the king’s power was limited by the cortes, the parliament of the realm. That was no democratic institution but a gathering of elite representatives of the oligarchies, moneyed and aristocratic, which governed the cities. Nor did the cortes meet regularly; but it was not the lame duck historians have until recently supposed it to be—its ability to withhold taxes from the crown until local grievances were satisfied seriously curtailed the king’s power. There were other cortes in the crowns of Aragon (Aragon, Catalonia, Valencia), and in Navarre. And in these regions, as well as the Basque lands, the king’s power was greatly reduced by the existence of jealously guarded regional liberties. When in the sixteenth century monarchs sent protomedicos, royal physicians, to examine, license and control medical and pharmaceutical practice in Navarre, Aragon and Catalonia, there was in all cases resistance to what was seen as centralizing control from Castile, and the crown was forced to back down.

The extent to which an interested monarch could influence scientific development in Spain became clearer with the accession of Philip II (r. 1556-98), a dilettante. His strong interests in medicinal plants led him to establish a botanic garden at his palace of Aranjuez, south of Madrid, where distillers were regularly employed to extract plant essences. At the other great palace of the Escorial, an entire suite of rooms was devoted to the chemical preparation of medicines from plants and minerals. The elaborate apparatus included a giant brass distillation tower, 20 feet high, fitted with 120 glass alembics (vessels carrying distilled liquors to a receiver) which was said to produce 180 pounds of distilled essences in 24 hours. Those employed included Diego de Santiago, who designed apparatus and wrote an alchemical treatise revealing the influence of Paracelsus (see Chapter 6), and Richard Stanyhurst, a Catholic exile from Elizabethan England. The medicines prepared were stored in the associated pharmacy and dispensed to patients in the adjoining infirmary, and to the royal family. The same attraction to alchemical medicine induced Philip to bring to Madrid Leonardo Fioravanti,
an Italian Paracelsian physician employed by the viceroy of Philip’s kingdom of Naples. Fioravanti had written to Philip offering to prepare more effective alchemical medicines for the king’s soldiers; he worked in Spain in 1576-7 disseminating Paracelsian alchemical medicine, unorthodox medical doctrine which challenged the established Galenism of university medical faculties.

Within the confines of his court Philip could establish scientific institutions, but more ambitious plans to extend them throughout Castile were less successful. That can be seen in the outcome of the planned Academy of Mathematics. Suggested by Philip’s architect Juan de Herrera, and motivated by the desire to provide the kingdom with ‘men proficient in mathematics, architecture and other related sciences and skills’, Philip announced its establishment in Madrid in 1582. The king purchased premises, and soon nobles and military officers were attending lectures on a wide range of scientific subjects, including demonstrations with scientific instruments. The lecturers included foreign experts: Joao Lavanha, a Portuguese, taught geography and navigation; Giuliano Firuffino of Milan taught military engineering. But there were also Spanish lecturers: Herrera on architecture, and Cristobal de Rojas, who gave a geometrical treatment of fortification. Apart from lectures, the staff prepared vernacular translations of classical scientific texts like Euclid’s *Optics*; that was very much in keeping with the king’s policy of making Castilian a dominant world language.

Philip was delighted with his new Academy and in 1587 sought to diffuse its curriculum by ordering the *cortes* of Castile to set up similar institutions in the cities. But he had neither the money nor the power to enforce this. And when several of the cities refused to provide the necessary finance, the project collapsed. In Madrid Philip’s Academy continued to function until 1625, and then its scientific instruments and books were inherited by the Colegio Imperial, a Jesuit college which taught mathematical science and natural philosophy.

The cities’ power was sometimes used positively to promote scientific developments. Barcelona was no longer the thriving port it had been in the thirteenth
and fourteenth centuries when it was the centre of Aragon’s Mediterranean empire. But it was still something of a city-state ruled by moneyed nobility and powerful guilds. Its College of Apothecaries continued to resist royal interference; in 1511 it had supervised the publication of an official pharmacopoeia, the first in Spain—only one other had yet been published in Europe (Florence, 1498). In Valencia rich merchants controlled the city and its university. Public health was well developed and the university unusual for the dominant position of medicine. It was here that Spain’s first chairs of anatomy, surgery and medical botany were created (1501). And here also that innovating teaching was introduced—Vesalian anatomy from the 1540s and, unique in Europe, a short-lived university chair in alchemical medicine (1591) given to the Valencian physician Llorenç Cocar, a follower of Paracelsus (Lopez Piñero, 1973, pp.125—6; 1977; and 1979, pp.98—9).

What influence did Spanish religious institutions have on the development of science in the peninsula? From the sixteenth century the effective head of the Catholic Church in Spain and Spanish America was not the pope but the monarch. It was a serious offence to publish papal bulls in Spain without prior authorization by the crown. And Philip II delayed publication of the decrees of the Council of Trent until his lawyers had scrutinized them; they were then permitted to be published on the understanding that the king’s power was unaffected. The Spanish Inquisition may only have been established (1480) after permission had been given by the pope; but thereafter it functioned as a royal Council directed not from Rome but by the crown. Nor is the idea tenable of a solid Catholic affiance between the popes and Spain; during the sixteenth century relations often reached breaking point for political reasons: in 1527 the troops of Charles V, emperor and king of Castile, sacked Rome and imprisoned the pope; and in the next reign Philip II’s relations with Rome were embittered for years. In Spain the pope’s importance was chiefly that of a paymaster—a source of badly needed revenue for the Monarchy’s military campaigns. And in those campaigns of Ferdinand and Isabella against the Moors, and of Charles V and Philip II against Islam and
Protestantism, the Spanish monarchs saw themselves as the divinely appointed champions of Catholicism, responsible for the protection of the Holy Faith within Spain and its overseas territories, and the overthrow of diabolical Islam and heretical Protestantism.

Since the late fifteenth century the courts of Spanish monarchs had begun to be affected by currents of Italian and Dutch humanism, widening horizons in religion and literature, influencing science, painting and architecture. In the 1520s the ideas of the Dutch humanist Erasmus spread to the court of Charles V, bringing challenging religious ideas, and in the 1530s a humanist Honorato Juan played some part in Philip II’s education. But then came the reaction of the 1530s against these new currents of European thought; the intellectual atmosphere had changed and there was a return to traditional doctrines, secular and religious. The reason was the spread of the German Reformation. Spanish monarchs now became the leaders of Counter-Reformation. When he prepared Philip to succeed him, Charles V urged him to use the strongest measures to keep Spain free of the Protestant infection. Accordingly in 1559 Philip II introduced a general ban on university study to prevent contact with European Protestants; his subjects were permitted to enroll only in Spanish universities and the designated, safe, Catholic universities at Naples, Rome and Bologna.

In 1558 while Philip was in the Netherlands his sister Juana, now regent, had introduced stricter censorship laws with the death penalty for printing or importing heretical literature. The crown sent agents to inspect bookshops and universities; at Salamanca the rector and masters of the university were instructed to report to the Inquisition students in possession of suspect works or professors who taught Lutheran doctrines. And in 1 559 Fernando Valdes, Inquisitor General, issued the first Index of the Spanish Inquisition The prohibited books included the zoological treatise of Conrad Gesner, and the pioneering illustrated botanical works of Leonhart Fuchs and Otto Brunfels—all banned simply because these German authors were Protestants. The much enlarged Indices of 1583—4 issued by the Inquisitor General Gaspar de Quiroga
prohibited the works of the German astronomers Peurbach and Reinhold; parts of Paracelsus' work and of his followers like Toxites and Fioravanti—Paracelsian ideas were regarded as infected with Lutheranism even though Paracelsus remained Catholic. The seventeenth-century Spanish Indices became still larger, that of 1632 listed as many as 2,500 authors, and now prohibited practically the whole of Paracelsus' work. But the astronomy of Copernicus was not prohibited until after the trial of Galileo (1633).

What was the effect of these repressive measures on Spanish science? Did they completely cut Spain off from European science and therefore cause that seventeenth-century stagnation which left Spain untouched by the scientific revolution? The evidence shows that the ban on university study abroad was imposed: at the university of Montpellier, where Aragonese students had traditionally come to study medicine, some 248 Spanish students matriculated in 1510—59; after the ban of 1559 the figure for 1560—99 is just twelve. The assessment of the general effect on Spanish science depends on one’s view of the quality of university science; Spanish historians have argued that Spanish students were not missing much because the most flourishing science in Europe was produced outside the universities, which were conservative. The effects of the Inquisition on Spanish science are not easily discussed with any precision. The effectiveness of the Indices is problematic because of loopholes—the occasional official permission granted to consult forbidden works—and the impossibility of complete control; the clandestine circulation of prohibited literature is another imponderable. The Inquisition had first targeted conversos and Moriscos, and then concentrated on the sexual morality of Old Christians. But fear of the Inquisition may have inhibited innovatory ideas; perhaps that accounts for the marked fall in publication of scientific works in the seventeenth century (Lopez Pinero, 1979, pp.374-5). The Spanish Inquisition was not abolished until 1834, by which time it had become moribund. But during the eighteenth century it could still spring into action after periods of dormancy, arresting scientists like the mathematician Benito Bails for consulting prohibited works
or the physician Diego Zapata on a charge of Judaizing. And as late as 1790 a Spanish
Index expurgated a sentence from the Castilian translation of Nordberg’s History of
Charles XII in which Copernicus was described as ‘the discoverer of the true system of
the world’ (Domergue, 1986, p.107).

Yet Spain was not completely cut off from European developments. Vesalian
anatomy was taught in peninsular universities; so for a while was Paracelsian
alchemical medicine. But in the seventeenth century innovation had ceased. Not until
the 1680s was a concerted effort made to modernize Spanish science with the
introduction of doctrines like Harvey’s circulation of the blood and corpuscular
philosophy. The innovators were small groups of individuals operating outside of the
universities, patronized by enlightened noblemen. The most important centres of their
activity were Zaragoza, Madrid, Valencia, and Seville where in 1700 was created
Spain’s first modern scientific institution, the Regia Sociedad de Medicina y demas
Ciencias, strongly inspired by Cartesian influence (Cenal, 1945; Lopez Pinero, 1979,
pp.371—455).