17

SCIENCE AND TECHNOLOGY

Irfan Habib

Contents

SCIENCE . . . 464
The space for reason . . . 464
Mathematics and astronomy . . . 467
Medicine . . . 469
TECHNOLOGY . . . 470
Irrigation . . . 471
Water and wind power . . . 472
Craft technology . . . 474
Artillery . . . 477

Part One

SCIENCE

The space for reason

It is widely recognized that in the world of Islam the scholars (^{c}*ulamā*') at the beginning of our period could be divided into three broad segments, viz., the theologians (*fuqahā*; sing. *faqīh*), the mystics (*sūfī*s) and the practitioners of the rational sciences (*hukamā*; sing. *hakīm*). The continuing popularity of Ghazālī (d. 1111) was perhaps partly a reflection of the fact that his reconciliation of the first two trends, and hostility to the third, conformed to the reality on the ground. Both the theologians and the Sufis, while tolerant of such sciences as remained confined to the recording of observations or calculation (e.g. geography, mathematics) or the practice of medicine, were hostile to any questioning of the theological view of the cosmos, to speculative philosophy, and, especially, to any pursuit of reason (^{c}*aql*) as an independent method.

Names to which important scientific achievements can be credited become fewer and fewer in the world of Islam after the twelfth century.[1] This may partly be attributed to the hostility of the religious elements, but also, perhaps, no less to the limits imposed on further progress by the detailed premises of the Hellenistic tradition, from which the thought of the rationalist school largely derived its basic principles. To shake the latter would have required a Scientific Revolution of the kind that early modern Europe witnessed, but the Islamic world never underwent. Nevertheless, it would be too harsh to view the period from the fifteenth to the eighteenth century as one of a 'decline' in scientific learning in absolute, rather than relative terms (i.e. with the European advances in mind). Much was indeed preserved both by way of continuous circulation of the texts of the past, and by translation and commentary; and there was also some elaboration and innovation.

Even the removal of philosophy and reason from a prominent position in intellectual life was by no means a settled matter. At the Mughal emperor Akbar's court (which had its seat at Lahore from 1586 to 1598), there developed a singular ideological trend which made use of Ibn al- ^{c}Arabī's theory of the illusoriness of visible differences to advocate the principle of *sulh-i kul* (Absolute Peace) and to prescribe in its name not only the tolerance of ^{c}*aql* but also its positive protection and promotion. Central in this was thought to be the role of the just sovereign, bathed in 'divine light' – a proposition with clear links to the *ishrāqī* (Illuminationist) school of mysticism (See Chapter 24). Abū'l Fazl (d. 1602) was the major spokesman of this official doctrine. Indeed, in the official history of Akbar's reign (1556–1605), the *Akbar-nāma*, Abū'l Fazl argued that the sovereign ought not to 'seek popular acclaim through opposing reason'. He is said to have been scornful of Ghazālī's condemnation of certain sciences. The officially promoted syllabus for education deliberately excluded theology and only listed sciences (agriculture, surveying, geometry, astronomy, architecture and mathematics, besides ethics, history, government and, regrettably, geomancy).[2]

[1] See *History of Civilizations of Central Asia*, 2000, Vol. IV, Part Two, Chs. 6–10 and 12, for an account of the major achievements of Central Asia in the realm of science within the period 750–1500.

[2] Habib, 1996, pp. 165–9; 1999*a*, pp. 329–40, where the necessary textual references will be found.

The effects of this ideological position led to a new interest in *hikmat* (scientificlearning).[3] There were translations made of scientific works from both Arabic and Sanskrit into Persian, the famous Persian poet Fayzī translating the Sanskrit mathematical text, the *Lilavati*. Science still wrestled with superstition in the study of astronomical phenomena.[4] But it was perhaps in the realm of technology (see below) that Akbar and his circle made the most creditable contributions, with true inventions such as 'prefab' structures, the use of saltpetre to cool water, complex geared devices for water-lift, cart-mill, ship's camel, machine for gun-boring, etc., in some of which there was a distinct precedence over corresponding inventions in Europe.[5]

The intellectual position occupied by Akbar and Abū'l Fazl was undoubtedly based on a reconciliation between Sufi doctrines and the realm of reason, while excluding altogether the entire corpus of Muslim theology. Such a position has remained unique in the whole range of Islamic civilization.[6]

In Persia in the sixteenth century, an attempt was made to achieve a more comprehensive synthesis. Mullā Sadrā (d. 1640) at Isfahan created a system which incorporated all the three elements: theology, Sufism and philosophy.[7] Since Sadrā's ideas exercised considerable influence on his contemporaries and subsequent generations, the rational sciences could gain a place even in the theological seminaries of Persia. Sadrā and his more mystical contemporary, Mīr Abū'l Findiriskī (d. 1640–1), were themselves well-known teachers of the sciences (*hakīmmiyāt*);[8] and Findiriskī's pupil and friend, Kāmrān Shīrāzī (d. 1640–1), was an uncompromising rationalist and sceptic.[9] His beliefs may be deemed a radical deviation, but Mullā Sadrā's more orthodox disciple, Muhsin Fayz (d. 1680–1), also saw a close identification between ᶜ*ilm-i bātin* (mystic science) and *hikmat;*[10] and this despite

[3] This was noted in 1616 by Sir Thomas Roe at the court of Akbar's son, Jahāngīr: 'The molaes of Mahomet know somewhat in philosophy and mathematiques, are great astrologers, and can talke of Aristotle, Euclyde, Averroes and other authors' (Roe, 1926, p. 275).

[4] Moosvi, 1997, pp. 109–20.

[5] Habib, 1997, pp. 129–48. Alvi and Rahman, 1968, urge the claims of Fathullāh Shīrāzī, mathematician and technologist at Akbar's court, to the authorship of some of these inventions.

[6] The uniqueness of this ideological phenomenon is shown by the admission made by Cook, 2000, p. 468*n.*, in his massive survey of Islamic juridical and doctrinal literature, that he was 'not able to find a systematic discussion of the idea' of *sulh-i kul*, as elaborated in Mughal India.

[7] Cf. Nasr, 1986, pp. 678–87.

[8] The originally Jewish scholar Sarmad studied *hakīmmiyāt* under these two scholars (Anon., 1362/1943, Vol. 1, p. 215).

[9] Anon., 1362/1943, Vol. 1, pp. 337–41, for biographical notice and ideas. The author, who knew Kāmrān Shīrāzī personally, quotes the following statement of his: 'I believe in the Godhood of the Creator, in the Prophethood of Reason, in the Imamate of Self, in the Sky being the direction of prayer, and in the Salvation of the Philosophers. I have no use for faiths and creeds' (Anon., 1362/1943, Vol. 1, p. 338).

[10] Arjomand, 1984, p. 150.

the fact that he was a believer in the narrower interpretation (*akhbārī*) of Shiᶜite theology. After the reign of Shāh ᶜAbbās II (1642–66), however, the more orthodox elements became dominant and the 'realm of reason' became more and more restricted in Persia.

So far as one can judge, Transoxania was not affected by either of the ideological trends we have described. On the contrary, the influence of theological orthodoxy and mystic establishments appears to have become dominant to an unprecedented degree.

While it is obvious that science can flourish better where the rational method is given greater scope, it would be a mistake to suppose that what is possible must necessarily follow. Despite the theoretical space secured for *ᶜaql* by the proponents of *sulh-i kul* and the theorists of the Isfahan school, no particularly outstanding scientific achievements were made as a consequence. Here, as we have already suggested, the severe limits imposed on further progress by the axioms of the Graeco-Arab tradition of the past cannot entirely escape responsibility. We can, perhaps, best assure ourselves of this when we look at what happened in the domains of mathematics, astronomy and medicine, three major branches of science at the time.

Mathematics and astronomy

In mathematics, besides the usual textbooks and commentaries on previous books, few advances were made. The Persian translations of the Indian mathematician Bhaskara's (*fl.* 1150) works, the *Lilavati* and the *Bijaganita* (respectively by Fayzī in 1587 and ᶜAtaullāh Rushdī in 1634–5), introduced to the Persian-reading public two texts that represented the most mature stage of the Indian mathematical tradition: here, for example, were methods for integral solutions, held to be 'the finest thing achieved in the theory of numbers before Lagrange'.[11] In Persia itself the most reputed work, as measured by translations and commentaries, was a compendium of arithmetic in Arabic, the *Khulāsat al-hisāb*, by the theologian Bahāu'ddīn al-ᶜAmilī (d. 1622).[12] It preserved much but seemingly marked no great advance.

In astronomy, the observatory established by the Timurid prince Ulugh Beg (1394–1449) at Samarkand, with the distinguished mathematician Jamshīd Ghiyāsu'ddīn al-Kāshī (d. 1429) among its staff, created one of the landmarks in observational recording; and Ulugh Beg's *Zīj-i Sultān-i Gūrkānī* [Astronomical Tables of the Gūrkān Sultān] henceforth became the standard work of reference. Ulugh Beg upheld the view that larger instruments would

[11] Keith, 1920, pp. 525–6.
[12] Described by Storey, 1958, pp. 11–14.

reduce the margin of error and so he built large masonry instruments devised to serve various observational needs. Some of these, like the meridian transit instrument, have survived.

In the latter half of the sixteenth century, at Taqīu'ddīn's observatory in Istanbul, where both metallic and masonry instruments were also used, some of Ulugh Beg's tables were revised. But most Islamic astronomers went on working with astrolabes for their ordinary purposes, while making use of Ulugh Beg's *Zīj* for framing calendars and calculating the moments of astronomical phenomena. A very ambitious scheme was undertaken in the Indian Mughal empire with a view to establishing new astronomical tables on the basis of observations simultaneously made at five different places. With imperial support, Sawāi Jai Singh (d. 1744), a prince himself, established observatories at Delhi, Jaipur, Mathura, Banaras (Varanasi) and Ujjain. His major instruments were on a massive scale, built of masonry, several being of his own devising. He sent a mission with a Christian priest to Europe and obtained instruments as well as the astronomical tables of P. de La Hire (second edition, 1702). He found the latter gave less accurate results than his own, though probably his own refraction table was derived from it. He published his *Zīj* in 1733–4.[13]

Jai Singh's *Zīj* is important because of the improvements he made in the observations, but its inherently conservative character cannot be overlooked. Its text drew heavily upon that of Ulugh Beg's *Zīj*, making certain additions here and there, such as mentioning the sandglass, not known in Ulugh Beg's time. His universe therefore remains entirely Ptolemaic. Even the observation of Venus' lunar phases, made by the telescope at his observatory, finds no mention in the *Zīj;* it was left to a Delhi lexicographer to record the discovery in 1739–40.[14]

Jai Singh's continued allegiance to the Ptolemaic theory and indifference to Copernicus also requires consideration. It may be remembered that even Tycho Brahe (d. 1601), who too worked with large instruments to get better results, had rejected the Copernican system. He held that the firmament (including the sun) revolves around the earth, while only the five planets (the earth not being held to be one) revolve around the sun.[15] Western sources were not, therefore, for a long time so clearly on the side of Copernicus as we may now think. But there might have been another reason for the lack of interest in how the universe really moved. This was astrology.

[13] Jai Singh, 1733–4, MS. For his observatories and their instruments the major survey is still Kaye, 1918.

[14] Tek Chand, 1916, Vol. 1, p. 332.

[15] These ideas of Brahe are summarized in a tract written by a Jesuit, Christofore Borro, and translated into Persian by Pietro della Valle in 1624 for an Iranian astronomer, Maulana Zainuddīn Larī, a copy of which is in the Vatican Library, Vat. Persiano 9. Brahe believed that the earth did not rotate around its axis, and accepted biblical notions on these matters as God-given truths.

When Bābur (1483–1530), swayed by astrological considerations, forced a hurried battle with the Uzbek ruler Shaybānī Khān (1500–10) near Samarkand in 1500–1 and thereby courted disaster, he learnt the lesson the hard way that astrological predictions were 'worth nothing'.[16] Such robust rejection of astrology was, however, rare in our period, and sovereigns and all those who mattered would often look for the astrologically auspicious moment and seek to avoid the inauspicious. It was thus deemed the business of astronomy to determine these moments by the most exact possible observation and calculation. For this task, the Ptolemaic concepts accorded best with how everything in the heavens looks to us from the earth, while the Copernican system was bound to introduce complications which were entirely irrelevant to the astrological purpose. In this sense, not only faith but also a pseudo-science were responsible for the Copernican concepts being ignored.

Medicine

In medicine, the corpus produced in Persian during our period, and still extant, is fairly vast.[17] The texts range from comprehensive compendiums to materia medica, prescriptions for ailments and tracts on particular drugs and diseases. Iranian and Indian contributions predominate, but there are also Transoxanian compilations. One such was Sultān ᶜAlī Khurāsānī's *Dastūru'l ᶜilāj*, 'a detailed manual of therapeutics', completed in 1530–3 under the patronage of the Uzbek rulers of Akhsi. The Janid (Astarkhanid) ruler of Bukhara, Subhān Qulī (1680–1702), wrote a medical work himself, the *Ihyā' al-tibb-i Subhānī*.[18]

The literature on medicine with reference to Safavid Persia has been well explored,[19] though there has been no corresponding work with similar critical apparatus on India. Since, however, Iranian medical practitioners came constantly to India and wrote books there along with their Indian colleagues, it may be assumed that the features of what is known as *tibb-i yūnānī* (Greek medicine) were practically identical in both countries. The Yunani system remained largely unaffected by the Indian Ayurvedic tradition, despite a very well-known Persian text on Ayurveda compiled from Sanskrit sources by Malik Bhuwa in 1512–13.[20]

While there seems to have been little development in anatomy or surgery, the physicians naturally kept track of new diseases and new drugs. Syphilis brought back from the

[16] Bābur, 1995, pp. 130–1; 1922, Vol. 1, p. 139.
[17] For a listing, which could not take account of the more recent finds and library catalogues, see Storey, 1971.
[18] Storey, 1971, pp. 233, 265.
[19] Elgood, 1970.
[20] Bhuwa, 1877.

Americas by Columbus' sailors in 1493, and the discovery of chinaroot, the drug by which it could supposedly be best treated, spawned a small body of literature in the sixteenth century. Written in 1537–8, Nūrullāh ᶜAlā's tract[21] has precedence over Andreas Vesalius' monograph on chinaroot, published at Basle in 1546.

What is surprising is the frequent inability of the physicians to record important popular practices. The practice of smallpox inoculation ('cutaneous scarification') was reported from Turkey in 1717 by Lady Mary Montagu, and from Bengal by R. Coult in 1731.[22] It is probable that it had spread from some area inbetween, perhaps from Transoxania,having been developed from the Chinese method of inoculation by inhalation whichbecame widespread in that country in the sixteenth century.[23] The first English report of thepractice of cutaneous scarification in Kabul and eastern Baluchistan is dated 1839,[24] but it was doubtless present there much earlier as well. It is strange, then, that what really constituted a 'medical epic' of our period, the first human effort at immunization proper, remained unrecorded in the entire range of the region's own medical literature.

Part Two

TECHNOLOGY

It goes without saying that we have a much larger amount of information about technology for our period than for any previous period of Central Asian history.[25] Limitations of space, however, require that we make a selection from the evidence available. In what follows we have kept two particular criteria for selection in view: technological features that were specific to Central Asia and the technological changes that took place here during our period. This means that many aspects, such as agricultural methods (apart from irrigation), means of transport and sericulture, important as these were for economic life, are not discussed. It is hoped, however, that despite its limitations our survey can still be of some use as a provisional effort.

[21] Nūrullāh, 1537–8, MS.
[22] For the latter, see Dharampal (ed.), 1971, pp. 141–2.
[23] Needham, 1969, pp. 58–9; 1970, pp. 375–6.
[24] J. W. Wonchester in: Thomas (ed.), 1979, Vol. 1, pp. 286–7.
[25] See *History of Civilizations of Central Asia*, 2000, Vol. IV, Part 2, Ch. 10, for the period preceding ours.

Irrigation

The major part of Central Asia belongs to the low rainfall zone, in which there are only a few areas in which agriculture can be pursued without artificial irrigation. Bābur, whose experience until late in life was confined to Transoxania and Afghanistan, would, therefore, especially remark on the fact that in India the crops mainly depended on rainfall alone, and so it was not necessary to 'dig canals or build dams (*band*s)'.[26] Since both Transoxania and Afghanistan had snow-fed rivers, canals could be dug the moment the rivers entered broad valleys or plains. Bābur missed in India those artificial 'running waters' (*āqārsū*s) which he remembered from his native land.[27] However, Kashmir, with a geographic situation similar to Ferghana's, had a network of canals cut from the natural streams and rivers from higher levels, and supported by earthen embankments.[28] In the plains, the canals drawn off from the Balkhab river in northern Afghanistan were probably among the best known.[29]

But the canal which could be reckoned a notable engineering feat for its time was constructed in India: Shāh Jahān's (1628–58) 'Royal Canal', running from the point where the Yamuna river enters the plains down to Delhi, 126 km in length, with the channel carried at certain points on massive aqueducts or cut through solid rock.[30] What was lacking in this canal, as in most other canals drawn from rivers of any size, was a stable connection with the parent river, since dams over large bodies of flowing water were seldom built. On smaller streams, though, dams could be built. Thus we read of the Uzbeks, in their war against Shāh Jahān's troops in 1646–7, destroying a dam above Taliqan (Taloqan, northern Afghanistan), thereby diverting the water of the canal running past that town.[31]

In the Iranian plateau and other parts of Central Asia not only is precipitation low, but there are few rivers from which long surface canals can be drawn. From pre-Islamic times this challenge has been met by the remarkable system of underground channels known as *qanāt* in Persia and *kārīz* or *kārez* in Afghanistan and Xinjiang: wells are dug at particular distances to tap underground springs; the wells are then connected by underground channels, sloping downwards, ultimately to emerge in the open on the lower ground, where the

[26] Bābur, 1995, p. 441; 1922, Vol. 2, p. 488.

[27] Bābur, 1995, p. 439; 1922, Vol. 2, p. 486. Bābur speaks of the 'numerous water-channels (*āqār-sū*s)' in the territory of Osh in Ferghana (Bābur, 1995, p. 5; 1922, Vol. 1, p. 4).

[28] Cf. Bernier, 1916, p. 396: Bernier visited Kashmir in 1664. There is a good account of the pre-Mughal and Mughal canals of Kashmir in Khuihamī, 1954, Vol. 1, pp. 138–52.

[29] Sultān Muhammad, *c.* 1660–1, MS, fol. 30a; Balkhī, 1984, Vol. 1 (1), p. 267. The latter work was completed in 1636.

[30] Cf. Singh, 1992, pp. 57–61.

[31] Lāhorī, 1866–72, Vol. 2, pp. 649–50.

water is used for irrigation.[32] Not only is the water thus collected from underground aquifers without need of any lifting mechanism, but much of the water while carried underground is protected from evaporation as well.

Historians of technology have given the name *sāqiya* to an elegant device whose origins go back to the eastern Mediterranean and the early centuries of the Christian era.[33] The device, consisting entirely of wood, rope and clay pots, combines the draw-bar for circular horizontal drive from animal power (ox, camel), pindrum-gearing for converting it into vertical drive, pots borne on a belt ('potgarland') for giving continuous water flow, and a braking lever. Its geography in our period was curious. Bābur, whose marches and wanderings took him over Ferghana, Samarkand, other parts of Transoxania and almost all areas of Afghanistan (including Herat), failed to see it anywhere there and found it a great novelty when he first saw it in Punjab in 1519.[34] In Persia, too, the device was not generally employed – instead, oxen pulling up leather buckets with rope thrown over pulleys was the most common system.[35] Bābur returns to the *sāqiya* in his famous account of India, giving us a description of both the potgarland and the pindrum-gearing employed in it. He also defines the area of its use as Lahore, Dipalpur and Sirhind (that is, mainly Punjab).[36] It was, in fact, also in use in Sind and western Rajasthan,[37] so that the Indus plains formed the area where it was most widely employed.

Water and wind power

While the use of water as a source of power was absent in India's traditional technology, it is quite a common element in that of Central Asia generally, especially in the form of the water-mill (*āsyā*). As described by two notable dictionaries of our period, and by most

[32] A fourteenth-century lexicographer, Qawwās, 1974, p. 25, describes the *kārīz* aptly as 'a stream, with its head concealed which they excavate in a line of wells'. For Chardin's enthusiastic description based on his travels in Iran down to 1677, see Chardin, 1927, p. 252. The *qanāt/kārīz* system has been frequently described by more recent observers: see, e.g., Elphinstone, 1839, Vol. 1, pp. 396–98; Wulff, 1966, pp. 249–54. For *kāriz* in the Turfan depression in Xinjiang, see Stein, 1981, Vol. 2, pp. 568–9, 586: Stein believes that the *kārīz* only began to be excavated in the Turfan area in the eighteenth century.

[33] Schioler, 1973, is the best single study of the history of the mechanism so far. See also D. R. Hill in *History of Civilizations of Central Asia*, 2000, Vol. IV, Part Two, pp. 268–9, but there is an obvious fault in Fig. 7 on p. 268: the channel taking out water can never come through the wheel, which would then have to be spokeless!

[34] Bābur, 1995, p. 360; 1922, Vol. 1, p. 388. This was at Bhera on the Jhelum river.

[35] Cf. Wulff, 1966, pp. 256–60. He says, however, that the device is used in Khuzistan (southwestern Iran) (p. 259). Yet in India, in English usage, the mechanism is called 'Persian wheel'! For the use of the pulley-device, see Chardin, 1927, pp. 252–3.

[36] Bābur, 1995, pp. 439–40; 1922, Vol. 2, p. 486.

[37] Habib, 1999*b*, p. 28 and note.

modern observers, the ordinary water-mill in Persia and other parts of Central Asia was of the ungeared type with a horizontal waterwheel (i.e. with a vertical shaft, the so-called ‘Norse mill’). The lexicographers of our period tell us of a *tanūra*, or masonry tower, constructed with its top open to receive stream-water, and a hole at the bottom to lead the water into a trough (*gāv*), with sufficient velocity to strike the scooped blades (*parra*s) of the mill wheel. So struck, the wheel rotated to work the mill placed above it on the same shaft.[38] This is how the water-mills of Afghanistan (and those of ‘Persia and Toorkistan’) are reported to have worked in the early nineteenth century.[39] The same kind of mill was in use in the Tibetan cultural area and in the Himalayas.[40]

While the Vitruvian type of mill, with vertical water-wheel and horizontal shaft, is not apparently described by the sources of our period, there was no technological reason why this mill should not have existed, since pindrumgearing necessary for converting vertical into horizontal motion was otherwise known. In fact, it has been found in modern Iran wherever larger streams have offered ‘more water at a lower head’.[41]

Given the multiple purposes for which water power was used in Chinese technology, Chinese influence may be responsible for certain water-driven devices in the proximity of the Xinjiang region. The hydraulic trip-hammer, traced in China to the third and fourth centuries A.D. and illustrated from 1300 onwards,[42] is undoubtedly the ultimate source of the *pekoh*, the water-driven rice mill in the Hazara district of northern Pakistan: here ‘by an ingenious contrivance a large wooden hammer is lifted [by force of water] and let fall in a quick succession of strokes on the grain that lies in a trough below’.[43]

Sistan, shared between Iran and Afghanistan, has a notable place in the history of wind-mills, going back to the tenth century, when we have accounts of it in Istakhrī and Ibn Hawqal.[44] In our period both poets and lexicographers were familiar with the *bād-ās* or *āsyā-i bād* (windmill).[45] The mills, as attested by their remains and modern descriptions of

[38] Inju, 1876, p. 112; Tek Chand, 1916, Vol. 1, pp. 30–1, 261. Inju completed his dictionary in 1608–9 and Tek Chand in 1739–40. Cf. Wulff, 1966, p. 280.

[39] Elphinstone, 1839, Vol. 1, p. 401.

[40] See Buchanan, 1819, p. 221, for the water-mills of Nepal that he saw in 1802–3. Francisco de Azevedo saw water-mills in use in Leh (Ladakh) in 1631 (Wessels, 1924, p. 108; cf. Moorcroft and Trebeck, 1837, pp. 239–40).

[41] Wulff, 1966, pp. 280–3.

[42] Needham, 1954–, Vol. 4 (2), pp. 390–2.

[43] Watson, 1908, p. 60, with a photograph of the device.

[44] See the masterly summary of the early history of Sistan wind-mills in Needham, 1954–, Vol. 4 (2), pp. 555–8. For a more detailed treatment see Wulff, 1966, pp. 284–9.

[45] See especially Tek Chand, 1916, Vol. 1, pp. 30–1, quoting (in 1739–40) the seventeenth-century poets Mullā Hātif and Mīrzā Sa’ib for *āsyā-i bād*. These poets ignore the warning made in 1608–9 by Inju, 1876, pp. 67–8, that *bād-ās* is the correct form!

those in operation, were horizontal, the wind being led to the sails of the mill by shield-walls.[46] The mills were used to grind grain as well as lift water;[47] in the latter case a geared device must have been added. In all descriptions from the nineteenth century, the mill-stones are shown as placed below the wind-driven sails, which seems the more convenient arrangement. One has to rely heavily on Dimashqī (d. 1326) to suppose that earlier the quern was placed on the shaft above the sails, compelling thereby a roofing of the windmill.[48] This would be an inconvenient and clumsy method. Probably the analogy of the 'Norse' water-mill, where the quern is placed above the mill wheel, influenced the description by Dimashqī or his informant. But if Dimashqī was accurate in his report, we must infer that a crucial improvement took place in the device within our period, greatly simplifying it and making it more cost-effective.

Craft technology

We have already observed the presence of pindrum-gears (a form of rightangle gearing) in water-lifting wheels and water-mills. The device was central to a large number of technological innovations authored or patronized by the Indian Mughal emperor, Akbar. These included not only methods of lifting water to considerable heights, but also a cart-mill and a common drive for wheels boring the barrels of a number of muskets at the same time.[49] Though important in the history of technological ideas, these probably had no sequel in the realm of actual production technology.

An interesting marriage of two gearing devices of different origins appears to have occurred in the rural technology of Punjab, where pindrumgearing was combined with worm-geared rollers (of Indian origin).[50] The latter had given India upright rollersfor crushing sugar cane; in Punjab more efficient horizontal rollers were set to work byinstalling pindrum-gears to convert the horizontal drive from animal power into vertical motion.[51] In eastern Baluchistan, the same result was obtained by having similar wormgeared rollers worked by (presumably vertical) water-driven wheels.[52]

[46] Wailes, 1967–8, pp. 138–9, for modern reports; also the reports of Elphinstone, 1839, Vol. 1, pp. 400–1; Bellew, 1874, pp. 234–5; Tate, 1910, pp. 250–3.

[47] Captain Christies' journal, 1810, in: Pottinger, 1986, p. 409.

[48] Cf. Needham, 1954–, Vol. 4 (2), pp. 557–8; Wulff, 1966, pp. 284, 289.

[49] Habib, 1997, pp. 136–41.

[50] Cf. Habib, 1985, pp. 213–14. See, however, Daniels and Daniels, 1988, where the Indian origin of worm-gearing is doubted on rather unconvincing grounds.

[51] This was seen at work north-west of Lahore in 1831 (Burnes, 1834, Vol. 1, p. 44).

[52] Observed in 1810: Pottinger, 1986, pp. 25–6.

It is curious, however, that worm-gearing should have ended in the vicinity of the Indian subcontinent. It is entirely missing in Iranian traditional technology, as described by Wulff. Even the cotton-gin, which in India is depicted in an Ajanta fresco of the sixth century,[53] had a very complex counterpart in Persia, where rollers moved only through the pressure exerted on the free roller by the rotating roller being wedged closely to it.[54] In sugar-cane milling, where it would be difficult to have the rollers rotate only by pressure, the mill had to have both the recumbent rollers rotate with pindrum-gears in the most complicated manner, as is shown by the Egyptian sugar-cane mill figured at the end of the eighteenth century.[55]

As Lynn White pointed out long ago, two important principles of belt-drive and flywheel are embedded in the simple-looking spinning-wheel.[56] It is now certain that its origins lay in China in the early centuries of the Christian era, but its worldwide diffusion occurred only in the half-millennium preceding 1500.[57] Under the name *charkha*, its presence in Central Asia by the twelfth century is attested by its mention, as ‘the old woman’s instrument’, by Anwarī (*fl.* 1138–9) and Nizāmī (d. *c.* 1200), and later by Sa^c^dī (*fl.* 1257); and in India the first textual reference (fairly explicit) is of 1350.[58] One would have felt, then, that the use of the belt-drive as a means of speeding up motion should have become general in Central Asian technology during our period. But this is surprisingly not the case. In the Iranian gem-cutter’s craft the classical bowstring drill continued to be used, whereas a belt-driven drill would have been far more effective.[59]

It is quite possible that this inability to make good use of the belt-drive, despite the presence of the spinning-wheel in practically every poor home, was due to the late-coming of the crank in Central Asian technology. The crank, we may remind ourselves, is a rimless spoke set on the same shaft as the wheel, the spoke turning in a right-angled direction at its outer end so as to provide a handle. The crank is especially suited to the belt-drive since if it is set to the large wheel, it can greatly quicken the flywheel’s motion. Yet early paintings of the spinning-wheel from the region tend to show it without a crank, or even a peg fixed on

[53] On this see Alam, 1986, pp. 130–1.
[54] Wulff, 1966, pp. 179–80.
[55] Anon., 1817, Vol. 2, Pl. VII: the drawing was made by French artists during the French occupation of Egypt, 1798–1801.
[56] White, 1960, p. 517.
[57] Needham, 1954–, Vol. 4 (2), pp. 102–7, 266–8.
[58] Habib, 1985, pp. 203–4.
[59] Wulff, 1966, p. 39. Cf. Chardin, 1927, for the bow used by Iranian lapidaries in the seventeenth century. The use of the belt-drive for cutting diamonds in the Deccan and at Surat in India in the latter half of the seventeenth century (Tavernier, 1925, Vol. 2, pp. 44–5; Fryer, 1909, Vol. 1, p. 285) probably owed something to European influence.

the main wheel.[60] Wulff, however, found that in the traditional rural carpentry of Persia of the nineteenth century, the crank was a prominent feature of the spinning-wheel.[61] In India too it begins to appear as an appendage of the spinning-wheel in the seventeenth century.[62] It is, therefore, a permissible inference that our period saw the adoption of the crank in at least some areas of craft technology, although its full potential remained unrealized.

While China and Europe could both be sources of the crank at this late period, the screw as a means of joining pieces of metal was of definitely European ancestry. But its use in European metalcraft itself was a late one, probably no older than about 1500.[63] The earliest reference to the metallic screw in India comes from Thevenot, who reported in 1666 that the'Indians of Dehly cannot make a Screw as our locksmiths do.'[64] That is, they could not cut grooves into the metal, but merely soldered iron, copper or silver wire on both [male and female] parts. It is likely that Persian craftsmen had a similar screw, since, according to Jean Chardin, Persian gunsmiths rejected the screws on the ground that they would not withstand the pressure of gunpowder exploding within the barrel.[65] This would naturally have been the case if the screws had soldered wire and not grooved threads.

Printing, which China had adopted from an earlier age and Europe since the fifteenth century, evoked practically no response in Central Asia. Chardin claims that in 1676 he was engaged by the Persian court to help establish a printing press, but 'all was broke off'.[66] Yet printing of another sort, namely, cloth printing, was well established in Persia in the sixteenth century. The influence here was that of India. Thevenot (1665) noted that the printed textiles were called 'Indian cloths' because most of them came from India; yet'many are also made in Persia, and the flowers and other paints are stamped upon them with a mould besmeared with colours'.[67] The term *chīt*, or chintz (from the Hindi*chhīnt*),

[60] See the earliest drawing of the spinning-wheel that I can trace in India, in Shadiābādī, 1468– 9; MS, fol. 94b, a Persian dictionary from Central India, illustrated in the early sixteenth century; the spinning-wheel in an Isfahan painting of 1578 (Blochet, 1929, Pl. cxxxvii); and three Turkic women using a spinning-wheel shown in a painting from Emperor Jahāngīr's album (Kuhnel and Goetz, 1926, Pl. 1).

[61] Cf. Wulff, 1966, pp. 186–8, with two photographs on p. 187.

[62] See seventeenth-century Mughal paintings in Stchoukine, 1929, Pl. XLIV, and Martin, 1912, Pl. 207(a); and an eighteenth-century Kangra painting in Hajek, 1960, Pls. 48–9.

[63] Cf. Singer et al., 1954–8, Vol. 2, p. 242*n*; Vol. 3, p. 629; Needham, 1954–, Vol. 4 (2), p. 121.

[64] Thevenot, 1949, p. 65. The Indian screw, he adds, was turned left-to-right, not right-to-left, to open: this, however, was an inconsequential difference, though it may help us to trace the particular tradition of screw-making on which the Delhi locksmiths drew.

[65] Chardin, 1927, p. 271.

[66] Ibid., p. 249.

[67] Quoted in Baker, 1921, p. 37.

for printed cloth was used by poets of the time like Mullā Tughrā and Tāhir Wahid; the latter wrote specifically of the *chīt*-makers of Isfahan.[68]

The evidence by no means suggests, then, that ours was a period of stagnation in the craft skills in Central Asia. The diffusion and adoption of some new devices can clearly be traced or inferred. But there is no doubt that, compared with Europe's development of technology prior to its Industrial Revolution, the pace of change in Central Asia was demonstrably slow. Chardin's judgement made about Iranians could, perhaps, apply to all the peoples of Central Asia: 'they are not desirous of new Inventions and Discoveries, – choosing rather to buy Goods from Strangers, than to learn the Art of making them'. He gives the examples of watches, which were bought but not made; of printing, which we have already touched upon; and of guns, to which we now turn.[69]

Artillery

Owing to a lacuna much lamented by historians, Bābur's memoirs lack any narrative of the period 1508–19. It is obvious that a notable advance in the adoption of artillery was made during these very 11 years, as one can judge by comparing Bābur's narration of his own military operations in Transoxania and Afghanistan before 1508 and in Afghanistan and India after 1519. It is true that he mentions the use of a cannon (*qazān*) by the Timurid ruler Sultān Husayn Mīrzā of Herat, while besieging Hisar in 1495–6.[70] Indeed, it is possible that gunpowder devices, including Chinese mortar (*huochong*), had reached Central Asia through the Mongols as early as the thirteenth century.[71] Yet the potential remained unexploited; even Sultān Husayn's use of cannon may have had Ottoman inspiration. In any case, neither Bābur nor his opponents made use of either cannon or muskets in any battle up to 1508, when the first part of his memoirs closes. When in 1500–1 Bābur was defending Samarkand against Shaybānī Khān, his own weapon was a *nāwak* (crossbow).[72]

The battle of Chaldiran (1514), at which the Ottoman sultan Selim I (1512–20) overthrew the Safavid Shāh Ismā^{c}īl I (1501–24), undoubtedly established the efficacy of artillery:

68 Quotations in Tek Chand, 1916, Vol. 1, p. 150; Vol. 2, p. 260. The term is still in use (Wulff, 1966, p. 225).

69 Chardin, 1927, p. 249. He says again, on pp. 276–7, that the art of watch-making was unknown among the Persians.

70 Bābur, 1995, p. 51; 1922, Vol. 1, p. 59 (the reference to catapults in this translation of both the passages where the word *qazān* occurs seems unjustified). The term *qazān* occurs later in Bābur's memoirs indisputably for cannon (e.g. Bābur, 1995, p. 531; 1922, Vol. 2, p. 588, where we are told that a *qazān* exploded while firing a stone, a piece of it killing eight people).

71 Khan, 1996, pp. 27–39.

72 Bābur, 1995, p. 135; 1922, Vol. 1, pp. 142–3.

guns (presumably both cannon and muskets) placed behind carts, chained to each other, had shattered the Safavid charge.[73] Twelve years later we find Bābur, now himself possessed of muskets and cannon, consciously copying the Ottoman tactics at his own battle of Panipat (1526), which won him northern India.[74]

There seems little doubt that these cannon-pieces and muskets were both made according to Ottoman prototypes and techniques. The Ottomans cast their bronze gun-barrels whole, as they did at the siege of Constantinople in 1453.[75] An anonymous Italian merchant describes the casting of a bronze cannon, 'in the Turkish manner – all in one piece', in northern Iran, between 1511 and 1514.[76] This was how Bābur's gun master Ustād ᶜAlī Qulī also cast cannon.[77] But muskets (*tufak*s) had to be differently made from wrought iron. There was apparently an earlier *ᶜajamī* (Persian) tradition, producing a musket with a small barrel, with a lock ('a contrivance locked on to the stock').[78] But the occurrence of the term *farangī* (foreign) in relation to muskets in Bābur's memoirs suggests that European influence at that early date cannot be excluded.[79] His muskets, therefore, could have been true matchlocks.

One matter which needs investigation is the late intrusion of artillery into Transoxania. Haydar Dughlāt (1499–1511), despite his detailed narratives of warfare in Transoxania and Xinjiang until 1536, makes no mention of artillery until he comes to describe military operations in India.[80] As late as 1558 the English merchant Anthony Jenkinson found 'four handguns' a sufficient protection against large bands of men who were only archers, when he and his companions journeyed from Urgench to Bukhara.[81]

As against this, however, artillery received considerable attention in both Safavid Persia and Mughal India. In *c*. 1571 d'Alessandri held that Persian arms, including muskets ('harquebuses'), were 'superior and better tempered than those of any other nation'.[82] Abū'l Fazl in his *Ā'īn-i Akbarī* (1595) gives a detailed account of Akbar's innovations in musketry and gunnery, and these enable us to understand how far manufacture of these weapons had

[73] Sarwar, 1939, pp. 78–82.
[74] Bābur, 1995, pp. 423–4; 1922, Vol. 2, pp. 468–9. Bābur himself says here that these preparations were made *Rūm-dastūrī*, 'in the Ottoman fashion'.
[75] A. R. Hall in: Singer et al., 1954–8, Vol. 3, p. 363.
[76] Grey (ed.), 1873, p. 153.
[77] Bābur's description of a successful casting in 1526, despite some miscalculation: Bābur, 1995, pp. 487–8; 1922, Vol. 2, pp. 536–7.
[78] See the account of the anonymous Italian merchant already quoted, Grey (ed.), 1873, p. 153.
[79] Bābur, 1995, pp. 342, 428; 1922, Vol. 1, p. 369; Vol. 2, p. 473.
[80] Haydar Dughlāt, 1898, p. 474.
[81] Jenkinson, 1906, p. 19.
[82] Grey (ed.), 1873, p. 227.

proceeded at Akbar's court. Matchlock was the general form of musket, but Akbar had invented one where the musket fired without a match, with just a movement of the cock – thus indicating a wheel-lock, perhaps, or an early anticipation of the flintlock. His musket barrels were made by twisting iron strips continuously heated to fold round and round; the strip then had its inside bored and smoothed by a wheel-drill. As has been noted, Akbar was credited with having invented an ox-powered machine, which, through pindrum-gearing, drove wheel-drills that could bore 16 muskets at one time. In cannon-pieces, Akbar's main achievement seems to have been to try to solve the problem of transport by making gun parts separately, which could be reassembled later. This was possibly inspired by the system of *kārīz*-pipes, for there is no proof that screws were employed.[83]

These efforts show a high sense of the importance of artillery. But during the next (seventeenth) century, the level of manufacture failed to keep pace with that of Europe. For one thing, the basic form of the matchlock, as illustrated in the Persian (and Mughal) miniatures of the sixteenth and seventeenth centuries, remained unchanged: 'a rather straight stock, and narrow butt, the match-lock being attached to the neck of the butt'.[84] Writing on the basis of his observations until 1677, Chardin gave credit to the Persian workmen for making their barrels strong, and boring and scouring them 'with a Wheel, as we do'. But, though they shot 'further and straight', the muskets were heavy; and, without screws and lacking (spiral-)springs, their locks were inferior.[85] And the Persians had only matchlocks, not using flint at all.[86]

Flintlocks had appeared on the Indian coasts in the hands of Europeans by the early 1620s.[87] Yet Asian armies persisted with the matchlock well into the nineteenth century. This was true even of so modernized an army as that of Ranjit Singh (d. 1839), the ruler of Punjab.[88] While the matchlocks were not without some advantage,[89] it is clear that it was not this advantage but the difficulty in the use of simple devices like screws and spiral springs that made the shift to flintlock so difficult.

In cannon, the large-scale iron-casting, with use of blast furnaces, made all the difference, especially during the seventeenth century when cast-iron European guns established their advantage mainly in respect of cheapness. The superior drilling techniques and

[83] For the text see Blochmann (ed.), 1867–77, pp. 124–6; for analysis, Habib, 1997, pp. 139–44.
[84] H. Stocklein in: Pope and Ackerman, 1964, Vol. 6, p. 2584; Chardin, 1927, Vol. 2, p. 271.
[85] Chardin, 1927, Vol. 2, p. 271.
[86] Ibid., p. 164.
[87] Valle, 1892, Vol. 2, pp. 371–2.
[88] As reported in 1836 by Hugel, 1972, p. 301.
[89] It was noticed in 1840 in Sind (Eastwick, 1973, p. 145) that the matchlock had a longer range than the 'musket' of the East India Company's sepoys, which was probably no longer a flintlock but had percussion-caps in its discharges.

achievement of greater precision and standardization also counted. When Hormuz fell to the Persians in 1622, the Portuguese guns that they found there won the victors' unstinted admiration: each was 'an achievement of the expert masters and unique gun-makers of Europe'.[90] Such recognition of the superiority of European craftsmanship in gun-making was all the more significant, since of all the powers in Central Asia, it was Persia that continued to have the best artillery. Nādir Shāh's spectacular successes against the Mughals in India and the Uzbeks in Transoxania in his short reign (1736–47) would demonstrate this truth in the eighteenth century. But Persia itself, as we have seen, was now a long way behind Europe in all essential areas of development.

[90] Iskandar Munshī, 1896–7, Vol. 2, p. 691.