

Al-Bīrūnī (or Bêrūnī), Abū Rayḥān (or Abu'l-Rayḥān) Muḥammad Ibn Aḥmad

(b. Khwārazm [now Kara-Kalpakskaya A.S.S.R.], 4 September 973; d. Ghazna [?] [now Ghazni, Afghanistan], after 1050), *astronomy, mathematics, geography, history*.

Bīrūnī was born and grew up in the region south of the Aral Sea, known in ancient and medieval times as Khwārazm. The town of his birth now bears his name. The site was in the environs (*bīrūn*, hence his appellation) of Kāth, then one of the two principal cities of the region, located (in the modern Kara-Kalpakskaya A.S.S.R.) on the right bank of the Amu Dar'ya (the ancient Oxus) and northeast of Khīva. The second capital city of Khwārazm was Jurjāniyya (modern Kunya-Urgench, Turkmen S.S.R.), on the opposite side of the river and northwest of Khīva. There also Abū Rayḥān spent a good deal of time during the early part of his life. About his ancestry and childhood nothing is known. In verses ridiculing a certain poet (*Yāqūt*, p. 189; trans., *Beiträge*, LX, p. 62) he claims ignorance of his own father's identity, but the statement may have been rhetorical. He very early commenced scientific studies and was taught by the eminent Khwārazmian astronomer and mathematician Abū Naṣr Maṣṣūr. At the age of seventeen he used a ring graduated in halves of a degree to observe the meridian solar altitude at Kāth, thus inferring its terrestrial latitude (*Taḥdīd*, 249:7). Four years later he had made plans to carry out a series of such determinations and had prepared a ring fifteen cubits in diameter, together with supplementary equipment. There was, however, time only for an observation of the summer solstice of 995, made at a village south of Kāth and across the Oxus from it. At this time, civil war broke out. Bīrūnī went into hiding and shortly had to flee the country (*Taḥdīd*, 87:3, 109:6-110:11). "After I had barely settled down for a few years," he writes, "I was permitted by the Lord of Time to go back home, but I was compelled to participate in worldly affairs, which excited the envy of fools, but which made the wise pity me."

Since these "worldly affairs" essentially affected not only Bīrūnī's personal well-being but also his scientific work, it is necessary to introduce the names of six princely dynasties with which he became directly involved.

(1) The ancient title of Khwārazmshāh had long been held by the lord of Kāth, a member of the Banū 'Irāq. Abū Naṣr was a prince of this house (Krause, p. 3). In 995, however, the emir of Jurjāniyya attacked his suzerain,

captured and killed him, and seized the title for himself (*Chahār Maqāla*, p. 241). It was this disturbance that caused Bīrūnī's flight.

(2) For well over a century the Khwārazmshāhs had been dominated by the Sāmānids, a royal house of Zoroastrian origin but early converted to Islam. The Sāmānid capital was in Bukhara, about two hundred miles southeast of Khīva, from whence the dynasty ruled in its heyday an area comprising roughly all of present Afghanistan, Transoxiana, and Iran. In Bīrūnī's youth this empire was rapidly breaking up. Nevertheless, in a poem written much later (*Yāqūt*, p. 187; trans., *Beiträge*, LX, p. 61) he names as his first patron Maṣṣūr II, almost the last of the Sāmānid line, who reigned from 997 to 999.

(3) Much farther to the west flourished the Buwayhid dynasty, which had originated in the highlands south of the Caspian and extended its domain south to the Persian Gulf and, by 945, west over Mesopotamia.

(4) Set precariously between the Sāmānids and the Buwayhids was the Ziyārid state, based in Gurgān, a city just back of the southeast corner of the Caspian shore.

(5) All these competing dynasties were menaced, and eventually absorbed, by the swift expansion of another kingdom, that of the Ghaznavids, named from Ghazna, their base in east-central Afghanistan. Sultan Maḥmūd, son of a Turkish slave and the second and greatest of the line, was two years older than Bīrūnī. By 1020 he had carved out a realm extending a thousand miles north and south, and twice as far east and west.

(6) Over these kaleidoscopic shifts there presided at Baghdad the spectral figure of the Abbasid caliph, retaining only the shadow of power over these fragments of his ancestors' empire. Playing a role somewhat analogous to that of the medieval popes, he was accorded a strange religious respect by the temporal princes of Islam. Upon them the successive caliphs conferred prestige by investing them with honorific titles and robes of honor.

To which or from which of these kingdoms Bīrūnī fled in 995 is now uncertain. It may have been then that he went to Rayy, near modern Teheran. In the *Chronology* (p. 338) he quotes a ribald poem on the tribulations of penury, and to illustrate it states that he was once in Rayy, bereft of a royal patron and in miserable circumstances. A local astrologer chose to ridicule his views on some technical matter because of his poverty. Later, when his circumstances improved, the same man became friendly.

At the command of the Buwayhid prince, Fakhr al-Dawla, the astronomer al-Khujandī built a large mural sextant on a mountain above Rayy. With this

Fakhrī sextant, named for the ruler, he observed meridian transits during 994. Bīrūnī wrote a treatise describing this instrument (*Sextant*) and a detailed account of the observations (*Tahḍīd*, 101:20-108: 19). Part of his information was obtained from al-Khujandī in person, and since the latter died about 1000 (*Suter*, p. 74), the conversation between the two cannot have been long after the observations.

There is some reason for thinking that Abū Rayḥān also was in the Caspian province of Gīlān about this time. He dedicated a book (RG 7) to the Ispahbad (Persian for “ruler,” or “commander”) of Gīlān, Marzubān ibn Rustam, who was connected with the Ziyārids. In the *Chronology*, completed about 1000 (trans., pp. 47, 191), he mentions having been in the presence of this individual, perhaps the same Ispahbad who sheltered Firdawsī, the epic poet of Iran, from the wrath of Sulṭān Maḥmūd (*Browne*, pp. 79, 135).

Regardless of where he had been, Bīrūnī was back in Kāth by 997, for on 24 May of that year he observed a lunar eclipse there (Oppolzer 3403), having previously arranged with Abu’l-Wafā’ that the latter should simultaneously observe the same event from Baghdad (*Tahḍīd* 250: 11, gives only the year; but Oppolzer 3404, on 17 November 997, was invisible from both cities). The time difference so obtained enabled them to calculate the difference in longitude between the two stations.

This year saw the beginning of the short reign of the Sāmānid Mansūr II. If Bīrūnī ever resided at his court in Bukhara (as Bīrūnī’s poem mentioned above may imply), it probably was at this time. Meantime, the ruler of Gurgān, the Ziyārid Qābūs, had been expelled from his lands, and at Bukhara he sought support for a return to power. He succeeded in reestablishing himself at Gurgān and Bīrūnī either accompanied him or followed almost immediately thereafter, for about 1000 Bīrūnī dedicated to Qābūs his earliest extant major work, the *Chronology* (text, p. xxiv). This was by no means his first book, for in it he refers incidentally to seven others already completed, none of which are extant. Their titles indicate that he had already broken ground in the fields he later continued to cultivate, for one (RG 34) is on decimal computation, one (RG 46) on the astrolabe, one (RG 146) on astronomical observations, three (RG 42, 99, 148) on astrology, and two (RG 161, 162) are histories. By this time he also had engaged in an acrimonious correspondence with the brilliant Bukharan philosopher and physician Avicenna on the nature and transmission of heat and light. Bīrūnī refers to him (*Chronology*, text, p.257) as “the youth” The appellation, coming from

an individual still in his twenties, may seem less condescending when it is realized that the precocious Avicenna was still in his teens.

In the *Tahdīd* (214:15-215:3), after describing the measurement of a degree along a terrestrial meridian made at the direction of the Caliph Ma'mūn, Bīrūnī writes of his own abortive project to repeat the operation. A suitable tract of land was chosen between Gurgān and the land of the Oghuz Turks (in the deserts east of the Caspian?), but the patron, presumably Qābūs, lost interest.

The end of Abū Rayḥān's sojourn at the Ziyārid court can be fixed within precise limits, for in 1003 he observed two lunar eclipses from Gurgān, one on 19 February and the other on 14 August. On 4 June of the following year he observed a third lunar eclipse (*Canon*, pp. 740, 741), but this one from Jurjāniyya. Hence, sometime in the interim he had returned to his homeland, high in favor with the reigning Khwārazmshāh. This was now a certain Abu'l-<sup>c</sup>Abbās Ma'mūn, a son of the usurper to the title mentioned above. Both Ma'mūn and a brother who preceded him on the throne had married sisters of the ever more powerful and truculent Sultan Maḥmūd of Ghazna.

The bounty of the shah enabled Bīrūnī to set up at Jurjāniyya an instrument, apparently a large ring fixed in the meridian plane, which in gratitude he called the Shāhiyya ring (*Canon*, 612:5). He reports in various places in the *Tahdīd* and the *Canon* some fifteen solar meridian transit observations at Jurjāniyya, the first the summer solstice of 7 June 1016, the last on 7 December of the same year. It was probably during this interlude of prosperity and royal favor that he had a hemisphere constructed, ten cubits in diameter, to be used as a plotting device for the graphical solution of geodetic problems (*Tahdīd*, 38:6).

Meanwhile, Khwārazmian political affairs, in which Bīrūnī was closely involved, had been building up to a climax. The Caliph Qādir conferred upon Ma'mūn an honorific title and dispatched an envoy bearing the insignia of the award. The shah was frightened lest Maḥmūd take offense at his accepting the honor conferred directly and not through Maḥmūd as implied overlord. Ma'mūn therefore sent Bīrūnī west into the desert to intercept the embassy, take delivery of the objects, and thus forestall a public investiture.

In 1014 Maḥmūd let it be understood to Ma'mūn that he wanted his own name inserted into the *khutba*, the Friday prayer for the faithful and for the reigning monarch. Ma'mūn convened an assembly of the notables, proposing that he accede to this demand, but the chiefs refused to allow him to do so,

realizing that it meant the end of the region's autonomy. Ma'mūn then sent to them Bīrūnī, who, "with tongue of silver and of gold," convinced them that their liege was only testing them by his request and that the *khutba* would not be changed. At this, Maḥmūd dispatched an insulting ultimatum to the shah, demanding that he keep his nobles in line, or he, Maḥmūd, would do it himself. The hapless Maḥmūd introduced the sultan's name into the *khutba* in the provincial mosques, but not those of Jurjāniyya and Kath. Thereupon the Khwārazmian army revolted and killed Ma'mūn. This was all Maḥmūd needed. He marched into Khwārazm with ample forces, obtained the delivery of his sister, the Khwārazmshāh's widow, took Kāth, on 3 July 1017, cruelly executed the insurgent leaders, and set one of his officers on the throne. The surviving princes of the local dynasty were carried off to imprisonment in various parts of his domain (*Barthold*, pp. 275-279).

Much of our knowledge of these events is from Bīrūnī's extensive history of his native land, a work that has been lost except for fragments incorporated into other histories. As for Abū Rayḥān himself, he also was led off by the conqueror, partly, no doubt, to grace the sultan's court but also to remove an active partisan of the native rulers from the scene. He is next heard of in a village near Kabul, depressed and in miserable circumstances, but hard at work on the *Taḥdīd* (119:1-12). On 14 October 1018 he wanted to take the solar altitude, but had no instrument. He therefore laid out a graduated arc on the back of a calculating board (*takht*) and, with a plumb line, used it as an improvised quadrant. On the basis of the results obtained, he calculated the latitude of the locality.

The next firm date at our disposal is 8 April 1019, when he observed a solar eclipse from Lamghān (modern Laghman?), north of Kabul. He uses this, and the lunar eclipse mentioned below, to comment sarcastically upon the ignorance of the local astronomers.

Sachau has shown (*India*, trans., I, xi) that Bīrūnī's relations with Maḥmūd were never good, although the stories in the *Chahār Maqāla* (text, pp. 57-59) alleging cruel and arbitrary treatment of the savant by the sultan are doubtless apocryphal. It is evident that Abū Rayḥān received some sort of official support for his work, for in the *Canon* (p. 609) he writes of having determined the latitude of Ghazna by a series of observations carried out between 1018 and 1020 with an instrument he calls the *Yamīnī* ring. A title bestowed upon Sultan Maḥmūd by the caliph was *Yamīn al-Dawla* ("Right Hand of the State"). No doubt this ring was a monumental installation named, as was the custom, for the ruler patron.

It is also clear that Bīrūnī's interests in Sanskrit and in Indian civilization are due to his having become an involuntary resident of an empire that had by then expanded well into the Indian subcontinent. Already in 1002 Maḥmūd had conquered the district of Waihand, on the Indus east of Ghazna. By 1010 he had subjugated Multan and Bhatinda, the latter 300 miles east of the Indus. Twice repulsed (in 1015 and 1021) from the borders of Kashmir, by 1022 he had penetrated and subdued the Ganges valley to a point not far west of Benares. In 1026 Maḥmūd led a raid due south from Ghazna all the way to the Indian Ocean. From Somnāth, at the tip of the Kathiawar Peninsula, he carried off immensely valuable booty, as well as fragments of the phallic idol in the temple. One of the pieces was laid at the entrance to the Ghazna mosque, to be used as a footscraper by the worshipers (*India*, trans., II, 103; *Nāẓim*, ch. 8).

Abū Rayḥān profited from these events by travel and residence in various parts of India. The names of many of the places he saw are known, but no dates can be given for his visits. They were confined to the Punjab and the borders of Kashmir. Sachau (*India*, text, p. xii) lists some eleven Indian towns whose latitudes Bīrūnī reports as personally determined by him. Bīrūnī himself writes that while living (in detention?) at Nandana Fort, he used a nearby mountain to estimate the earth's diameter (*Taḥdīd*, 222:10). The installation at Nandana, taken by Maḥmūd in 1014, commanded the route by which he, the Moghuls after him, and Alexander the Great long before, penetrated the Indus valley. Bīrūnī's temporary residence overlooked the site where, in the face of King Poros and his elephants, Alexander effected his famous crossing of the Jhelum River, the classical Hydaspes (*Stein*).

It is also clear that Bīrūnī spent a great deal of time at Ghazna. The cluster of recorded observations made by him there commences with a series of meridian solar transits covering the summer solstice of 1019, and includes the lunar eclipse on 16 September of the same year (*Taḥdīd* 291:9). He continued to observe equinoxes and solstices at Ghazna, the last being the winter solstice of 1021. In fact, this is the latest of Bīrūnī's observations that has been preserved. At about this time, according to Barani (*Canon*, III, vii), he completed his treatise on *Shadows*.

In 1024 the ruler of the Volga Turks sent an embassy to Ghazna. These people had trade relations with inhabitants of the polar regions, and Bīrūnī questioned members of the mission to supplement his knowledge of these lands. One of the ambassadors asserted in the sultan's presence that in the far north the sun sometimes did not set for days on end. Maḥmūd at first

angrily put this down as heresy, but Abū Rayḥān convinced him that the report was both credible and reasonable (*Commemoration Volume*, p. 235; *Yāqūt*).

By the late summer of 1027 the treatise on *Chords* was completed (according to the Patna MS). During the same year a Chinese and Uighur Turkish embassy came to Ghazna, and from this mission Bīrūnī obtained geographical information on the Far East which he later incorporated into the *Canon* (*Commemoration Volume*, p. 234).

In 1030 Sultan Maḥmūd died, and the succession was disputed between two of his sons for a short period. Bīrūnī finished the *India* during this interim and, perhaps because of the uncertain political situation, refrained from dedicating it to any particular patron. Within the year Masʿūd, the elder son, won the crown. His accession brought about a drastic improvement in the situation of his most famous scientist, and Bīrūnī named the *Canon* for the new ruler amid “a farrago of high-sounding words” in the preface (*India*, trans., I, xii).

Perhaps it was the change of regime that enabled him to revisit his native land. By whatever means, he made at least one trip back, for in the *Bibliography* he writes that for over forty years he had sought a certain Manichaean work, a copy of which he at length procured while in Khwārazm (*Chronology*, text, p. xxxvi). In the same source Bīrūnī relates that after he was fifty years old he suffered from a series of serious illnesses, and in his distress inquired of several astrologers concerning the length of his life. Their answers diverged wildly, and some were patently absurd. At the end of his sixty-first (lunar?) year he began improving, and had a dream in which he was seeking the new moon. As its crescent disappeared, a voice told him that he would behold 170 more of the same.

Masʿūd was murdered by his officers and succeeded by his son Mawdūd in 1040. During Mawdūd’s eight year reign, Bīrūnī wrote the *Dastur* (RG 167) and the *Gems*. Of his subsequent activities we have no knowledge, save that in the *Pharmacology* (p. 7) he notes having passed his eightieth (lunar?) year; his eyesight and hearing are failing, but he is still hard at work with the assistance of a collaborator. Thus the date of his death given by Ghadanfar as 13 December 1048 is incorrect; Bīrūnī outlasted his third Ghaznavid patron and achieved the life-span foretold in his dream.

When he was sixty-three years old, Bīrūnī prepared a bibliography of the works of the physician Muḥammad ibn Zakariyya al-Razi, to which he appended a list of his own books. This runs to 113 titles (not counting

twenty-five additional treatises written “in his name” by friends), partially arranged by subject matter and occasionally with a brief indication of the contents. Most of the entries also give the length of the particular manuscript in folios. The list is incomplete, for Abū Rayḥān lived at least fourteen years after this, working until he died. Moreover, seven additional works by him are extant and many more are named, some in his own writings and others in a variety of sources. All told, these come to 146. The reckoning is uncertain, for some titles counted separately may be synonyms, and additional items may well turn up in the future.

There is a wide range in size of the treatises. Several amount to only ten folios each, while, at the other extreme, three lost astronomical works run to 360, 550, and 600 folios respectively. Largest of all is the *India*, at 700 folios. The English translation of the latter, incidentally, takes up 654 pages of small type, so that one of Bīrūnī’s folios is roughly equivalent to a modern printed page. The mean length of the seventy-nine books of known size is very nearly ninety folios. Assuming that the same holds for all 146 works, it follows that Bīrūnī’s total output is on the order of 13,000 folios (or pages), consisting for the most part of highly technical material, including numerical tables, the results of involved computations, and analyses of materials from multifarious sources - a formidable accomplishment indeed.

The classification attempted in the table below is only approximate; for instance, a book placed in the geographical category could legitimately be classed as primarily geodetic, and so on. Practically nothing Bīrūnī wrote confines itself strictly to a single subject, and in many cases where the title alone survives, an informed guess is our only recourse. Nevertheless the table gives a reasonable breakdown of the man’s activity. In the second column a “major work” has been taken arbitrarily as anything of 200 folios or more. The third and fourth columns show, respectively, the compositions known to exist in manuscript form and the numbers of these that have thus far been printed. Roughly four-fifths of Bīrūnī’s work has vanished beyond hope of recovery. Of what has survived, about half has been published. Most of the latter (with the notable exception of the *Canon*) has been translated into other languages and has received some attention from modern scholars.

The table also clearly reveals both scope and areas of concentration. Bīrūnī’s interests were very wide and deep, and he labored in almost all the branches of science known in his time. He was not ignorant of philosophy and the speculative disciplines, but his bent was strongly toward the study of observable phenomena, in nature and in man. Within the sciences



themselves he was attracted by those fields then susceptible of mathematical analysis. He did serious work in mineralogy, pharmacology, and philology, subjects where numbers played little part; but about half his total output is in astronomy, astrology, and related subjects, the exact sciences par excellence of those days. Mathematics in its own right came next, but it was invariably applied mathematics.

*CLASSIFICATION OF BĪRŪNĪ'S WORKS*

	Works	Major Works	Extant	Published
Astronomy	35	8	4	3
On astrolabes	4		2	
Astrology	23	1	3	2
Chronology	5	1	1	1
Time measurement	2			
Geography	9	1	1	1
Geodesy and Mapping Theory	10		1	
Mathematics				
Arithmetic	8		1	1
Geometry	5		1	1
Trigonometry	2		1	
Mechanics	2		1	
Medicine and Pharmacology	2	1	1	
Meteorology	1			
Mineralogy and Gems	2		1	1
History	4			
India	2	1	1	1
Religion and Philosophy	3		1	1
Literary	16			
Magic	2		1	
Unclassified	9	1	1	1
Total	146	14	22	13

Below are brief descriptions of most of Bīrūnī's works that are still available. They are our best sources for estimating the extent and significance of his accomplishments.

The *Chronology*. The day, being the most apparent and fundamental chronological unit, is the subject of the first chapter. Bīrūnī discusses the advantages of various calendric epochs - sunset or sunrise (horizon-based), noon or midnight (meridian-based) - and names the systems that use each. Next the several varieties of year are defined - lunar, solar, lunisolar, Julian, and Persian - and the notion of intercalation is introduced. Chapter 3 defines and discusses the eras of the Creation, the Flood, Nabonassar, Philip Arrhidaeus, Alexander, Augustus, Antoninus, Diocletian, the Hegira, Yazdigird, the Caliph Mu<sup>c</sup>taḍid, the pre-Islamic Arabs, and Bīrūnī's native Khwārazm. Chapter 4 discusses the Alexander legend, giving sundry examples of pedigrees, forged and otherwise. Next are lists of the month names, with variants, used by the Persians, Soghdians, Khwārazmians, Egyptians, Westerners (Spaniards?), Greeks, Jews, Syrians, pre-Islamic Arabs, Muslims, Indians, and Turks. In this chapter, the fifth, Bīrūnī commences his very extensive description of the Jewish calendar. (Except for the work of al-Khwārizmī, another Muslim, his is the earliest extant scientific discussion of this calendar.)

Chapter 6 culminates with a table (trans., p. 133) giving the intervals in days between each pair of the eras named above. This is preceded, however, by chronological and regnal tables in years (sometimes with months and days) for the Jewish patriarchs and kings; the Assyrians, Babylonians and Persians; the Pharaohs, Ptolemies, Caesars, and Byzantine emperors; the mythical Iranian kings; and the Achaemenid, Parthian, and Sasanian dynasties. Where tables from different sources conflict, all are given in full, and there are digressions on the length of human life and the enumeration of chessboard moves.

Chapter 7 continues the exhaustive discussion of the Jewish calendar, but includes a derivation of the solar parameters, a table of planetary names, and the *Mujarrad* table giving the initial weekdays of the mean (thirty-year cycle) lunar year.

Chapter 8 is on the religions of various pseudo prophets, the most prominent being the Sabians (or Mandaean, alleged to be followers of Būdhāsaf = Bodhisattva!), Zoroastrians, Manichaeans, and adherents of Mazdak.

The remaining half of the book (save the last chapter) describes the festivals and fasts of the following peoples: Chapter 9, the Persians; 10, the

Soghdians; 11 and 12, the Khwārazmians; 13, the Greeks (including material from Sinān ibn Thābit ibn Qurra on the parapegmatis); 14, the Jews; 15, the Melchite Christians; 16, the Jewish Passover and Christian Lent; 17, the Nestorian Christians; 18, the Magians and Sabians; 19, the pre-Islamic Arabs; 20, the Muslims. The concluding chapter, 21, gives tables and descriptive matter on the lunar mansions, followed by explanations of stereographic projection and other plane mappings of the sphere.

The *Astrolabe*. Amid the plethora of medieval treatises on the astrolabe, this is one of the few of real value. It describes in detail not only the construction of the standard astrolabe but also special tools used in the process. Numerical tables are given for laying out the families of circles engraved on the plates fitting into the instrument. Descriptions are also given of the numerous unusual types of astrolabes that had already been developed in Bīrūnī's time. As for the underlying theory, not only are the techniques and properties of the standard stereographic projection presented, but also those of certain nonstereographic and nonorthogonal mappings of the sphere upon the plane.

The *Sextant*. This two-page treatise describes the giant mural instrument for observing meridian transits built by al-Khujandī at Rayy for Fakhr al-Dawla, and perhaps seen by al-Bīrūnī, although he does not say so.

The *Tahdīd*. The central theme is the determination of geographical coordinates of localities. In particular, Bīrūnī sets out to calculate the longitudinal difference between Baghdad and Ghazna. Several preliminary problems present themselves: latitude determinations, inclination of the ecliptic, the distribution of land masses and their formation, length of a degree along the terrestrial meridian, and differences in terrestrial longitudes from eclipse observations. Techniques and observations used by Bīrūnī and by others are reported. Application is made of a theorem of Ptolemy's that gives the longitudinal difference between two places in terms of the latitude of each and the great circle distance between them. The latter was estimated from caravan routes and lengths of stages. Successive computations then yield the differences in longitude between Baghdad, Rayy, Jurjāniyya, Balkh, and Ghazna, and likewise along a southern traverse including Shiraz and Zaranj. The final result is in error by only eighteen minutes of arc.

The *Densities*. By means of an ingenious form of balance exploiting Archimedes' principle, Bīrūnī worked out a technique for ascertaining the specific gravity of a solid of irregular shape. He reports very precise specific gravity determinations for eight metals, fifteen other solids (mostly precious

or semiprecious stones), and six liquids.

The *Shadows*. As its full title indicates, this is a comprehensive presentation of all topics known to Bīrūnī to be connected with shadows. Of the total of thirty chapters, the first three contain philosophical notions about the nature of light, shade, and reflection. There are many citations from the Arabic poets descriptive of kinds of shadows.

Chapter 4 shows that the plane path traced in a day by the end point of a gnomon shadow is a conic. The next two chapters discuss the properties of shadows cast in light emanating from celestial objects. Chapters 7 and 8 define the shadow functions (tangent and cotangent) and explain the origins of the gnomon divisions used in various cultures: the Hellenistic 60, Indian 12, Muslim 7 or  $6\frac{1}{2}$ . The succeeding three chapters explain rules for converting between functions expressed in different gnomon lengths and for conversions into the other trigonometric functions (sine, secant, and their cofunctions, together with their various parameters), and vice versa. Chapter 12 gives tangent-cotangent tables for the four standard gnomon lengths and discusses interpolation. The next two chapters explain how to engrave the shadow functions on astrolabes. There follows, in Chapter 15, a discussion of gnomon shadows cast on planes other than horizontal, and on curved surfaces. Chapters 16 and 17 consider the effect of solar declination and local latitude on the meridian shadow length. A number of nontrigonometric approximate Indian rules are given. Chapters 18-21 list a variety of meridian-determination methods (including one from the lost *Analemma* of the first-century B.C. Diodorus). Chapter 22 is on daylight length and rising times of the signs as functions of the local latitude and the season. Here and in the next two chapters (on determining the time of day from shadows) rules are reproduced from numerous Indian, Sasanian, and early Islamic documents, many no longer extant. Some early Muslim rules are in Arabic doggerel written in imitation of Sanskrit *slokas*. Chapters 25 and 26 define the time of the Muslim daily prayers, some in terms of shadow lengths. Chapter 27 shows that in many situations on the celestial sphere, Menelaus' theorem gives relations between shadow functions. The concluding three chapters describe Indian and early Islamic techniques for calculating terrestrial and celestial distances by the use of shadows.

The *Chords*. The book begins by stating the following theorem:  $A$ ,  $B$ , and  $C$ , three points on a circle, are so situated that  $AB > BC$ . From  $D$ , the midpoint of arc  $AC$ , drop a perpendicular,  $DE$ , to the chord  $AB$ . Then the foot of the perpendicular bisects the broken line  $ABC$ . There

follow a number of proofs of this theorem, attributed to sundry Greek and Islamic mathematicians, some otherwise unknown to the literature. A second theorem, that in the configuration above,  $AD^2 = AB \times BC + BD^2$ , is also followed by a long series of proofs. The same thing is done for the expression  $\Delta ADC - \Delta ABC = DE \times EB$ . Then comes a set of metric relations between chords, based on the foregoing and leading up to propositions useful for calculating a table of chords (or sines).

The *Patañjali*. Cast in the form of a series of questions put by a hermit student and the answers given by a sage, this book deals with such philosophical and mystical topics as liberation of the soul and its detachment from the external world, the attributes of God, the power of spirit over the body, and the composition of the universe.

The *Tafhīm*. A manual of instruction in astrology, well over half of the book is taken up with preliminaries to the main subject. Persian and Arabic versions are extant, both apparently prepared by Bīrūnī himself. It is arranged in the form of questions and answers. There are five chapters in all, the first (thirty-three pages in the Persian edition) on geometry, ending with Menelaus' theorem on the sphere. The second (twenty-three pages) is on numbers, computation, and algebra. Chapter 3, the longest (229 pages), deals with geography, cosmology, and astronomy. From it a complete technical vocabulary may be obtained, as well as sets of numerical parameters, some of them uncommon. The next chapter (thirty-one pages) describes the astrolabe, its theory and application. Only the last chapter (223 pages) is on astrology as such, but it is complete and detailed.

The *India*. The book commences with a prefatory chapter in which the author states that the subject is difficult because Sanskrit is not easy; there are extreme differences between Indians and non Indians; and Indian fear and distrust has been exacerbated by Muslim conquests. The book will not be polemical and, when appropriate, Indian customs and beliefs will be compared with cognate ones of the Greeks.

Chapters 2-8 are on religion and philosophy: the nature of God, the soul, matter, mysticism, paradise, and hell. Chapters 9, 10, and 11 describe, respectively, the Hindu castes, laws concerning marriage, and the construction of idols. Chapters 12, 13, and 14 are on categories of literature: sacred, grammatical, and astronomical. The latter gives a table of contents of the Brāhmasphuṭasiddhānta. Chapter 15 presents tables of metrological units and gives various approximations to the number  $\pi$ . The next two chapters are on Indian systems of writing, number names, chess rules, and supersti-

tions. Chapter 18 is geographical; in particular, sixteen itineraries are given with the distances in *farsakhs* between successive stages. Chapters 19-30 present astronomical and cosmological nomenclature, legends, and theories. Chapter 31 cites the geodetic parameters used by various astronomers, and the latitudes (observed by Bīrūnī) of a number of Indian cities. Chapters 32-53 are on Indian notions of time, including detailed definitions of the hierarchies of enormous cycles - the yugas, kalpas, and so on - interspersed with accounts of sundry religious legends. Calendric procedures are given in great profusion. Chapters 54-59 are astronomical, dealing with the computation of mean planetary positions, the sizes and distances of the planets, heliacal risings, and eclipses. The remainder of the book is largely astrological, but includes chapters on rites, pilgrimages, diet, lawsuits, fasts, and festivals.

The *Ghurra*. This is an example of an Indian *karana*, a handbook enabling the user to solve all the standard astronomical problems of his time, with the emphasis on actual computation rather than on theory. Hence it resembles an Islamic *zīj* (astronomical handbook). Topics include calendric rules; length of daylight; determination of the astrological lords of the year, month, day, and hour; mean and true positions of the sun, moon, and planets; time of day; local latitude; solar and lunar eclipses; and visibility conditions for the moon and the planets. Bīrūnī has added worked-out examples, in particular, conversions from the Śaka calendar into the Hegira, Yazdigird, and Greek (so-called era of Alexander) calendars. Otherwise, he states, in his translation he has made no changes.

In general, the methods are those common to medieval Indian astronomy, but the parameters are not identical with any extant Sanskrit document. For instance, the radius of the defining circle for the sine function is 200 minutes, and the increment of arc, the *kardaja*, is ten degrees.

The *Canon*. This most comprehensive of Bīrūnī's extant astronomical works contains detailed numerical tables for solving all the standard problems of the medieval astronomer-astrologer. But it also has much more in the way of observation reports and derivations than the typical *zīj*. It is organized in eleven treatises (*maqāla*) that are further subdivided into chapters and sections.

Treatises 1 and 2 set forth and discuss general cosmological principles (that the earth and heavens are spherical, that the earth is stationary, etc.), units of time measurement, calendars, and regnal and chronological tables. This covers much of the ground gone over in the *Chronology*, but the chapter on the Indian calendar is additional.

Treatises 3 and 4 are on plane and spherical trigonometry respectively. There are tables of all the standard trigonometric functions, more extensive and precise than preceding or contemporary tables. Methods of solving many problems of spherical astronomy appear, together with tables of ancillary functions: oblique ascensions, declinations, and so on.

Treatise 5, on geodesy and mathematical geography, reworks much of the subject matter of the *Tahdīd*. A table gives the geographical coordinates of localities.

Treatises 6 and 7 are on the sun and moon, respectively. Here (and with planetary theory farther on) the abstract models are essentially Ptolemaic, but many parameters are independently derived on the basis of all available observations (including Bīrūnī's own).

Treatise 8 treats of eclipse computations and the first visibility of the lunar crescent.

Treatise 9, on the fixed stars, includes a star table with 1,029 entries (cf. Ptolemy's 1,022). Magnitudes according to Ptolemy and to al-Šūfī are given.

The next treatise is on the planets, with tables and text for calculating longitudes, latitudes, stations, visibility, distances, and apparent diameters.

The concluding treatise is on astrological operations, describing various doctrines for calculating the astrological mansions, projection of the rays, the *tasyr*, the sectors (*niṭāqāt*), transits, and the curious cycles apparently developed by Abū Ma<sup>c</sup>shar.

The *Transits*. This book describes the various categories of astrological phenomena to which the term *mamarr* (transit or passage) was attached. One planet was said to transit another if it passed the other planet in celestial longitude, or celestial latitude, or in its relative distance from the earth. The notion seems to have been developed by astrologers using non-Ptolemaic astronomical doctrines described in documents no longer extant. Hence the main interest of the work is the assistance it gives toward the reconstruction of these lost Indian, Sasanian, and early Islamic theories.

The *Gems*. The work is organized in two parts, the first being on precious and semiprecious stones, the second on metals. Bīrūnī brings together material from Hellenistic, Roman, Syriac, Indian, and Islamic sources, supplemented by his own observations. In addition to descriptions of the physical properties of the various substances, there are very extensive etymological discussions of the technical terminology in many languages and dialects, and numerous illustrative quotations from Arabic poetry. The principal mines and sources of supply are cited. Relative weights of the metals with respect

to gold are given, and there are tables showing the prices of pearls and emeralds as functions of size.

The *Pharmacology*. The book commences with an introduction in five chapters. The first presents an etymology for the Arabic word for druggist. The second gives technical terminology for categories of drugs. The next chapter is on the general theory of medicaments. In the fourth and fifth chapters Bīrūnī states his preference for Arabic over Persian as a language of science, and he names polyglot dictionaries available to him.

The main body of the work is an alphabetical listing of drugs comprising about 720 articles. For a typical entry the name of the substance is given in Arabic, Greek, Syriac, Persian, and an Indian language, and sometimes also in one or more less common languages or dialects: Hebrew, Khwārazmian, Tocharian, Zabuli, and so on. There follows a full presentation of the Arabic variants and synonyms, liberally illustrated with quotations from the Arabic poets. The substance is described, its place or places of origin named, and its therapeutic properties given, although Bīrūnī disclaims medical competence on his own part. Sources are fully and critically mentioned.

Abū Rayḥān's dominant trait was a passion for objective knowledge. In pursuit of this he early began studying languages. His mother tongue was Khwārazmian, an Iranian language in which, he wrote, it would be as strange to encounter a scientific concept as to see a camel on a roof gutter (*mīzāb*) or a giraffe among though horses (*irāb*, an example of rhymed prose). Therefore he acquired a deep knowledge of both Arabic and Persian. The former, in spite of the ambiguity of its written characters, he esteemed a proper vehicle for the conveyance of science, whereas the latter he deemed fit only for the recital of bedtime stories (*al-asmār al-layliyya*) and legends of the kings (*al-akhbār al-kisrawiyya*, more rhymed prose; *Pharmacology*, p. 40). Of Greek, Syriac, and Hebrew he attained at least sufficient knowledge to use dictionaries in these languages. His command of Sanskrit, on the other hand, reached the point where, with the aid of pandits he was able to translate several Indian scientific works into Arabic, and vice versa. He took obvious delight in Arabic poetry, composed verses himself, and liberally interlarded his writings with quotations from the classics.

Thus equipped, he made full use of all the documents that came to his hand (many of which have since disappeared), exercising a critical faculty that extended from the minutiae of textual emendations to the analysis of scientific theories. A strong sense of history permeates all his writings, making them prime sources for studying the work of his predecessors, as well as



his own and that of his contemporaries.

Bīrūnī's pursuit of the truth was not confined to the written or spoken word. He had a strong penchant for firsthand investigation of natural phenomena, exercised at times under very trying circumstances. Along with this went an ingenuity in the devising of instruments and a flair for precision in observations. Because of this feeling for accuracy, and because of a well-founded fear of losing precision in the course of calculations, he tended to prefer observational methods that yielded direct results, as against techniques requiring extensive reduction by computation.

Speculation played a small role in his thinking; he was in full command of the best scientific theories of his time, but he was not profoundly original or a constructor of new theories. His attitude toward astrology has been debated. He spent a great deal of time in serious study of the subject, but Krause (p. 10) has collected passages in which Bīrūnī not only heaps ridicule upon ignorant or unscrupulous astrological practitioners, but indicates disbelief in the basic tenets of this pseudo science. Krause also reminds us that there were many centuries when the casting of horoscopes was the only way by which an astronomer could support himself in the exercise of his profession.

As for religion, Bīrūnī was doubtless a sincere Muslim, but there is no firm evidence of his having been an adherent of any particular sect within the faith. In the *Chronology* (trans., pp. 79, 326), written at the court of Qābūs, are passages that have been interpreted as betraying a Shī'ī (hence anti-Arab and pro-Persian) bent. On the other hand, the *Pharmacology*, compiled under Ghaznavid patronage, represents the author as an orthodox Sunnī. Probably these two situations reflect no more than the fact that the two patrons were Shī'ī and Sunnī, respectively. From time to time Bīrūnī inveighs harshly against various groups, but the criticism is of particular acts or attitudes, not of the group as such. Thus his strictures against the Arab conquerors of Khwārazm were called forth, not because they were Arab, or alien, but because they destroyed ancient books. Concerning the Christian doctrine of forgiveness he writes, "Upon my life, this is a noble philosophy, but the people of this world are not all philosophers. . . And indeed, ever since Constantine the Victorious became a Christian, both sword and whip have ever been employed" (*India*, trans., II, 161).

In these, and in most matters, Bīrūnī had a remarkably open mind, but his tolerance was not extended to the dilettante, the fool, or the bigot. Upon such he exercised a broad and often crude sarcasm. Upon his showing an instrument for setting the times of prayer to a certain religious legalist, the

latter objected that it had engraved upon it the names of the Byzantine months, and this constituted an imitation of the infidels. “The Byzantines also eat food,” stated Abū Rayḥān. “Then do not imitate them in this!” and he ejected the fellow forthwith (*Shadows*, 37: 9).

Such were the life, labors, and character of a man known to his contemporaries as the Master (*al-Ustādh*). Unknown in the medieval West, except perhaps by the garbled name Maître Aliboron, his name and fame have been secure in his own lands from his time until the present.

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For points of view somewhat different from that expressed in the text, see Boilot’s article on al-Bīrūnī in the new ed. of the *Encyclopaedia of Islam*, Krause’s paper (cited below), and Sachau’s prefaces to the text and to the translation of the *Chronology and the India*. RG stands for “Répertoire général,” the numbered listing of Bīrūnī’s works in Boilot.

I. Original Works. Following are Bīrūnī’s extant major works, listed alphabetically.

*Astrolabe* (RG 46). The Arabic title is *Kitāb fī isti‘āb al-wujūh fī ṣan‘at al-aṣṭurlāb*. Several MSS exist (see Boilot), but the text has not been published. Sections of it have, however, been translated and studied.

*Bibliography* (RG 168). Bīrūnī calls this *Risala fī fihrist kutub Muḥammad b. Zakariyyā al-Rāzī*. The text was published by Paul Kraus as *Épître de Beruni contenant le répertoire des ouvrages de Muḥammad b. Zakariyyā al-Rāzī* (Paris, 1936). The text of the part giving Bīrūnī’s own bibliography appears in the text edition of the *Chronology*, pp. xxxviii-xxxviii. It is translated into German in Wiedemann’s “Beiträge,” LX.

*Canon* (RG 104). The Arabic text has been published as *al-Qānūn al-Mas‘ūdī* (Canon Masudicus), 3 vols. (Hyderabad-Dn., 1954-1956). References in the article are to page and line of the printed text, pagination of which is continuous, not commencing anew with each volume. A Russian

translation, in preparation by P. G. Bulgakov, M. M. Rozhanskaya, and B. A. Rozenfeld, will be Vol. V of the *Selected Works*.

*Chords* (RG 64). There are three MS versions of this work: (1) Leiden Or. 513(5) = CCO 1012; (2) Bankipore Arabic MS 2468/42 = Patna 2,336, 2519/40; (3) Murat Molla (Istanbul) 1396. The Leiden version has been published in translation and with a commentary, both by H. Suter, as “Das Buch der Auffindung der Sehnen im Kreise . . .,” in *Bibliotheca mathematica*, 11 (1910), 11-78. The text of version (2) has been published as the first of the four *Rasā’il* (Arabic for *treatises*). This contains, however, extraneous material, part of which is probably not by Bīrūnī, and part probably a fragment of RG 11. Many topics in (2) and (3) are missing from (1), and those parts that are in common are in drastically different orders. Two recensions by Bīrūnī himself are indicated. See H. Hermelink, in *Zentralblatt für Mathematik und ihre Grenzgebiete*, 54 (1956), 3; and A. S. Saidan, in *Islamic Culture*, 34 (1960), 173-175. Many of the additional sections in (2) and (3) are described by E. S. Kennedy and Ahmad Muruwwa in *Journal of Near Eastern Studies*, 17 (1958), 112-121. A composite Arabic text based on (2) and (3) was published by A. S. Demerdash as *Istikhrāj al-awtār fi’l-dā’ira* (Cairo, 1965). There is a Russian translation by C. A. Krasnova and L. A. Karpova, with commentary by B. A. Rosenfeld and C. A. Krasnova: *Iz istorii nauki i tekhniki v stranax Vostoka*, III (Moscow, 1963).

*Chronology* (RG 105). In Arabic this is *al-Āthār al-bāqiya min al-qurūn al-khāliya*. It was edited by E. Sachau as *Chronologie orientalischer Völker von Alberuni* (Leipzig, 1878, 1923; repr. Baghdad, 1963). The parts missing from Sachau’s text are given by K. Garbers and J. Fück in J. Fück, ed., *Documenta Islamica inedita* (Berlin, 1925), pp.45-98. It was translated into English by Sachau as *The Chronology of Ancient Nations* (London, 1879). The Russian translation by M. A. Sal’e, *Pamyatniki minuvshikh pokolenii*, is Vol. I of the *Selected Works* (Tashkent, 1957).

*Densities* (RG 63). This work’s Arabic title is *Maqāla fi’l-nisab allatī bayn al-filizzāt wa’l-jawāhir fi’l-ḥajm* (“Treatise on the Ratios Between the Volumes of Metals and Jewels”). The text has never been published, but portions of it have been taken over by other authors and have been studied in modern times.

*Gems* (RG 156). Known as the *Kitāb al-jamāhir fī ma’rifat al-jawāhir*, this text was edited by F. Krenkow (Hyderabad-Dn., 1936). Krenkow also translated the text, but only the chapter on pearls has been published (see Boilot). There is, however, a translation by A. M. Beleskii - *Mineralogiya*

(Moscow, 1963).

*Ghurra*. The *Ghurra al-zījāt* is Bīrūnī's Arabic translation of the Sanskrit astronomical handbook called *Karaṇatilaka* (forehead caste mark of the Karanas), by one Vijayanandin or Vijaya Nanda. The original text is not extant, but a MS of the translation is in the Dargah Library of Pir Muhammad Shah, Ahmadabad. Portions of the Arabic text, with English translation, and a commentary were published in installments by Sayyid Samad Husain Rizvi in *Islamic Culture*, 37 (1963), 112-130, 223-245, and 39 (1965), 1-26, 137-180. Another text, translation, and commentary, by M. F. Qureshi, exist in typescript but have not been published.

*India* (RG 936). Also known as *Kitāb fi taḥqīq ma li'l-Hind . . .*, this was edited by E. Sachau (London, 1888). A later edition has been published by the Osmania Oriental Publications Bureau (Hyderabad-Dn., 1958). Translated by E. Sachau as *Al-Beruni's India*, 2 vol. (London, 1910). Translated into Russian by A. B. Khalidov and Y. N. Zavadovskii as Vol. II of *Selected Works* (Tashkent, 1963).

*Patañjali* (RG 98). Bīrūnī's Arabic translation of this Sanskrit work is extant only in an incomplete MS edited by H. Ritter as "Al-Bīrūnī's Übersetzung des Yoga-Sūtra des Patañjali," in *Oriens*, 9 (1956), 165-200. See Boilot.

*Pharmacology* (RG 158). The Arabic title of this is *Kitāb al-ṣaydala fi'l-ṭibb*. There is no edition of the entire work. M. Meyerhof translated it into German, but of this only the introduction has been published, together with the corresponding part of the Arabic text and an extremely valuable foreword and commentary: "Das Vorwort zur Drogenkunde des Beruni," in *Quellen und Studien zur Geschichte der Naturwissenschaften*, 3 (1932), 157-208. A Russian translation, in preparation by U. I. Kazimov, will be Vol. IV of *Selected Works*.

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of a larger work. Text and French translation appear in L. A. Sédillot, “Les instruments astronomiques des arabes,” in *Mémoires . . . à l’Académie royale des inscriptions . . .*, 1st ser., 1 (1844), 202-206.

*Shadows* (RG 15). The text has been published as the second of the *Rasā’il* with the title *Kitāb fī ifrād al-maqāl fī amr al-zilāl* (“The Exhaustive Treatise on Shadows”). An English translation has been made by E. S. Kennedy, but publication awaits completion of the commentary. References to the *Shadows* made in the article are to page and line of the published text.

*Tafhīm* (RG 73). This is the *Kitāb al-tafhīm li-awā’il šina<sup>c</sup>at al-tanjīm*. R. Ramsay Wright published an edition of the Arabic text with English translation as *The Book of Instruction in Art of Astrology* (London, 1934). Bīrūnī’s Persian version was published by Jalāl Huma’i (Teheran, 1940).

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*Transits* (RG 45). In Arabic this is *Tamhīd al-mustaqarr li-taḥqīq ma<sup>c</sup>na al-mamarr* (“Smoothing the Basis for an Investigation of the Meaning of Transits”). The text has been published as the third of the *Rasā’il*. A translation by Mohammad Saffouri and Adnan Ifran, with commentary by E. S. Kennedy, is *Al-Bīrūnī on Transits* (Beirut, 1959).

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E. S. Kennedy