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Astronomy and Cosmology at Angkor Wat

Measurements of the temple are related to practical astronomy and religious symbolism.

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The temple of Angkor Wat in north-central Cambodia was a favorite tourist attraction in Southeast Asia until war isolated the Angkor region. At present, it is inaccessible to anyone outside Cambodia. Nevertheless, secondary sources such as detailed plans and photographs have provided sufficient data for a numerical and astronomical analysis of the temple. Numerically, Angkor Wat contains calendrical, historical, and mythological data coded into its measurements. Astronomically, it has built-in positions for lunar and solar observation. The sun itself was so important to the builders of the temple that even the content and position of its extensive bas-reliefs are regulated by solar movement. It is not surprising that Angkor Wat integrates astronomy, the calendar, and religion since the priest-architects who constructed the temple conceived of all three as a unity. To the ancient Khmers, astronomy was known as the sacred science.

Physical Aspects of Angkor Wat

Angkor Wat was originally dedicated to the worship of Vishnu. The temple was built during the reign of Sūryavarman II, A.D. 1113 to about 1150, and is his major claim to greatness. Basically, it is a series of five concentric rectangular walls and galleries, which extend for 1500 meters from west to east and 1300 meters from north to south. Figures 1 to 4 illustrate the principal architectural aspects of the temple.

Once the visitor has crossed the western entrance bridge, he passes through the front gateway of the temple, a long vaulted entrance capped by towers. He then descends to a causeway that leads him forward for 350 meters. At the end of the causeway is a large cruciform terrace and the first of three concentric galleries. These galleries mark the main stages in the slow vertical rise toward the massive central tower of Angkor Wat. During the long walk to the sanctuary within the central tower, the visitor would certainly not be aware of the extraordinarily accurate measurements of the temple.

The sets of west-east walls in the central galleries were measured from the center of the chamber marking the end of each gallery (*1*, plan XI) and they were found to be essentially identical in length. The northern and southern walls of the outer gallery both measure 202.14 meters. The northern and southern walls of the middle gallery measure 114.24 and 114.22 meters, respectively. The four walls of the topmost gallery vary between 47.75 and 47.79 meters. This astounding degree of accuracy (the differences are less than 0.1 percent) could mean that the temple was precisely measured because of religious concerns. It could also mean that the physical structure of the temple was carefully aligned with the movements of the sun, moon, planets, or stars. In this instance, both alternatives were merged in an integrated design, combining function and belief.

Solar and Lunar Alignments

In 1969 Nafilyan published more than 100 detailed plans and diagrams of Angkor Wat, the result of 2 years of very thorough surveying (*2*). His work provides all the accuracy and detail necessary for a complete numerical analysis and measurement of the temple. From (*1*) we find that the west-east axis of the temple is diverted 0.75° south of east (and 0.75° north of west) while the north-south alignments show no deviation whatever (*3*). The top of the central tower of Angkor Wat forms an angle of almost 6° with the horizon when observed from the western entrance gate. At the latitude of Angkor Wat (13°27′N) the celestial equator is shifted 1.4° south of due east at 6° of altitude. On the day of the spring equinox, an observer standing at the southern edge of the first projection on the causeway (just in front of the western entrance gate) can see the sun rise directly over the top of the central tower of Angkor Wat (*4*). Three days later, the sun can be seen rising exactly over the top of the central tower from the center of the causeway, just in front of the western entrance gate. Since the Cambodian calendar was based on lunar and solar cycles, this precise observation of the sun at the spring equinox is extremely important. The spring equinox marks the beginning of the sun's annual journey, regardless of the exact date of the lunar-solar new year (*5*). Whether this crucial alignment was intended for practical observation or religious orientation or both is impossible to determine. There is no question, however, that this solar alignment was important to the temple of Angkor Wat.

It is interesting to note that there are also two solstitial alignments from the western entrance gate of Angkor Wat. These two added alignments mean that the entire solar year was divided into its four major sections by alignments from just inside the entrance of Angkor Wat. From this western vantage point, the sun rises over Phnom Bok on the day of the

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summer solstice (6, 7). Phnom Bok is a major hill on the plain of Angkor and is located 17.4 kilometers northeast of Angkor Wat (Fig. 5). The western entrance gate of the temple also has a winter solstice alignment with the temple of Prasat Kuk Bangro, 5.5 kilometers to the southeast (8).

Given these three major alignments from the western entrance gate, it would seem that Angkor Wat had to face west if its primary purpose (in regard to its orientation) was to demarcate the solar calendar. This would be a rational explanation for one of the most unusual aspects of the temple, a characteristic that has been difficult to understand. Of the hundreds of temples located at the site of Angkor, there may be only one or two minor temples that face west, such as the single-celled temple called Edifice C in the Prasat Kok Po group just north of the western edge of the West Baray. Edifice C dates from the 9th century. Virtually all monuments at Angkor face east and are entered from the east. Some of these monuments were the repositories for the ashes or bodies of dead rulers or ministers (9, *10*) just as Angkor Wat could have been the repository for the remains of Sūryavarman II. Therefore, the argument that Angkor Wat faces west because it is a "funerary temple" (*11*, *12*) hardly accounts for its orientation. We submit that the westward orientation of Angkor Wat can be explained by the solar alignments.

There are also various positions for lunar observation within the temple compound. As shown in Table 1 and Fig. 6, a and b, the projections along the causeway could have been used to keep a record of the movements of the moon, which is necessary for the prediction of eclipses. According to the writings of Chou Ta-kuan, a Chinese merchant who visited Angkor in A.D. 1296, just as in

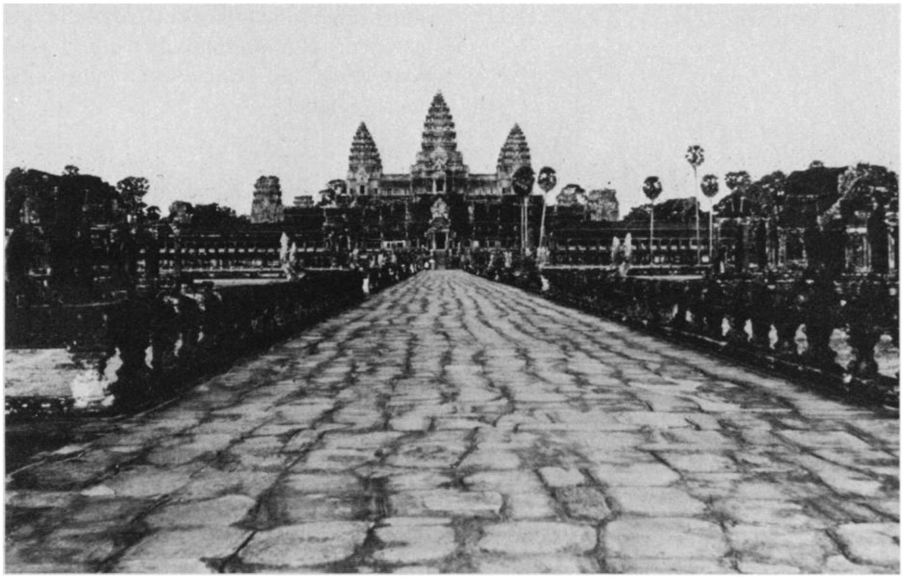
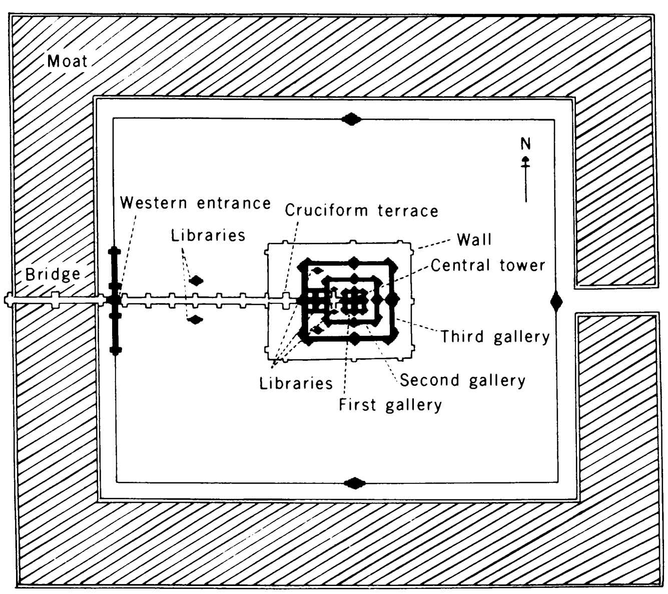


Fig. 1. View of Angkor Wat from the causeway near the western entrance gate. At equinox the sun can be seen rising over the central tower when viewed from just inside the western entrance gate. [Courtesy of H. C. Mills]



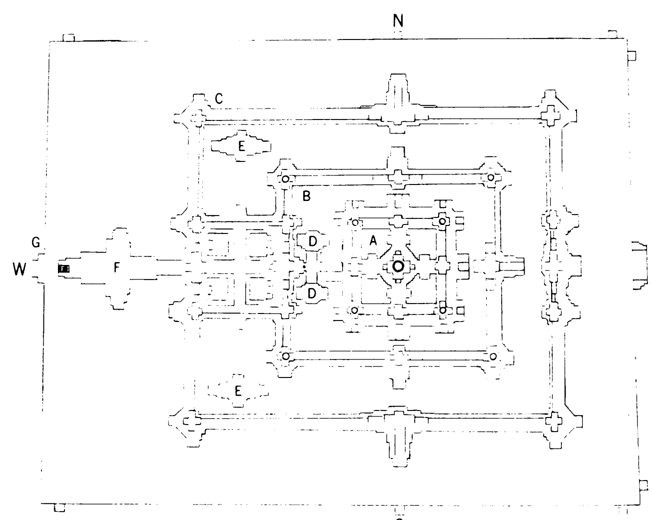


Fig. 2 (left). Plan of Angkor Wat. The site measures 1500 meters from west to east and 1300 meters from north to south, including the moat. The geographic center of the temple is at the end of the porch just inside the second gallery. The inner wall of the third gallery is filled with a long series of bas-reliefs. Fig. 3 (right). An outer surrounding wall (*G*) encloses the cruciform terrace (*F*) and the inner three galleries (*A* to *C*) of Angkor Wat. The second (*B*) and third (*C*) galleries each contain a pair of libraries (*D* and *E*).

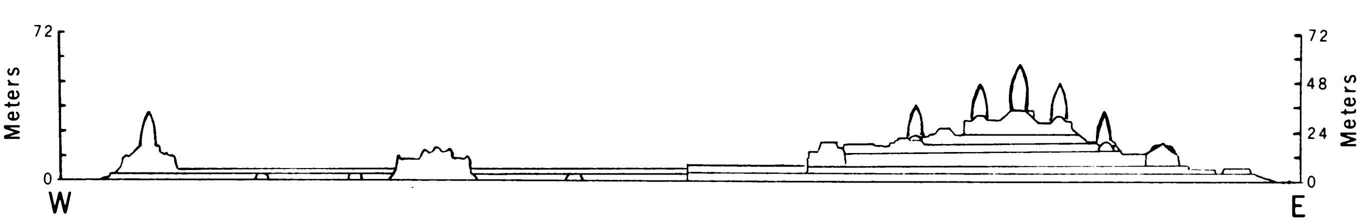


Fig. 4. During the long walk to the main sanctuary, the visitor's perceptual field slowly changes from an open, horizontal, daylight expanse into the enclosed, vertical, restrictive darkness of the central tower.

China ". . .there are people who understand astronomy and can calculate the eclipses of the sun and the moon" (*10*, p. 22).

Determination of Alignments

We have utilized Nafilyan's plans of Angkor Wat to search for significant astronomical alignments in the architecture. Positions of the tops of towers and points along the cruciform terrace and the western causeway, as well as at the libraries and the western entrance gate, were measured with respect to a north-south rectangular coordinate grid centered on the ground level of the central tower. Given two spatial points (that is, their x, y, and z coordinates in meters), we computed the apparent altazimuth orientation of one point as seen from the other, and further related the sighting line to a particular celestial declination. This was done with the classical formula (*13*) for the celestial declination (δ)

$$\sin\delta = \sin\phi\sin h + \cos\phi\cos h\cos A$$

where ϕ is 13°27′N latitude, h is altitude, and A is azimuth. Forty-six sighting points for the observation of the central tower, the four towers of the first gallery, and the two towers on the western side of the second gallery were considered. More than 300 observable declinations were computed. We looked for solar equinoctial and solstitial declinations (0° and ±23.5°, epoch A.D. 1110). Since the apparent lunar motion carries the moon within ±5° of the ecliptic, the declination extrema of ±5°, 19°, and 29° would be significant as well. Measurement errors and eroded tower tops require at least ±0.5° uncertainty, depending on the base length. Several sighting lines matched all these angles, and these are listed in Table 1. In addition, several solstitial and highly precise north-south alignments for the entire site of Angkor are given in Table 1. These alignments were first published by Paris (*6*, pp. 317, 319–321, 323) after a survey of the site (*14*).

We recognize that a few isolated sighting lines do not justify an astronomical interpretation, especially since most of the 322 computed alignments appear to be almost randomly oriented, but from the aggregate we find several interesting tendencies.

1) An angular frequency histogram of all computed lines reveals peaks [at 2 standard deviations (S.D.) from the mean] in the distribution at angles 0°, ±5°, +23°, and +29°.

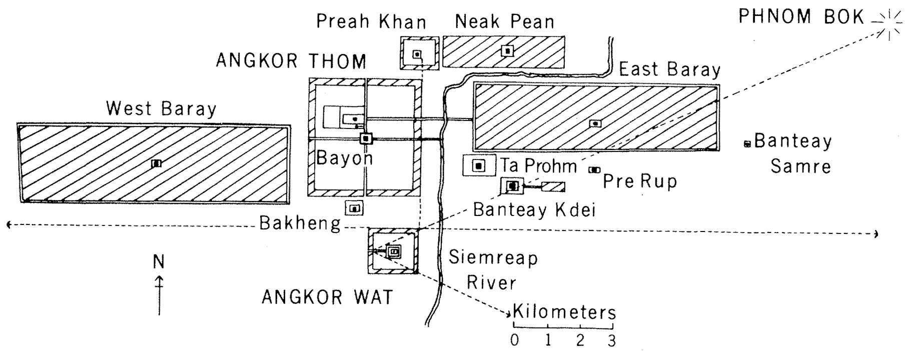


Fig. 5. The site of Angkor flourished for more than 500 years. It contains hundreds of temples, of which only a few are shown here. The two Barays are huge reservoirs which supplied the water for rice irrigation. A few of the longer alignments of Angkor Wat are illustrated by the dotted lines (also see Table 1).

2) The angular frequency histogram of the points along the causeway shows relative peaks (3 S.D.) at ±5°. This, in accord with the six projections along the causeway, suggests that lunar observation may have been its function.

3) All major points on the ground plan have associated alignments which constrain the overall dimensions and arrangement of the structure. As can be seen from the alignments in Table 1, there are important sighting points on the northern and western steps of the cruciform terrace. We suggest that these two points helped to determine the dimensions of the terrace.

Table 1. Computed astronomical alignments at Angkor Wat. Alignments 1 to 18 are those derived in this study. Alignments 19 to 22 were derived in 1941, along with the three cardinal alignments. Alignments 8 to 13 correspond to the points at which five successive projections mark the causeway. The easternmost projection has no computed alignments. Major cardinal alignments are given in (*21*).

Alignment	Observer's location	Tower (top observed)	Declination
1.	North steps, cruciform terrace	Central tower	+0°1′
2.	West steps, cruciform terrace	First gallery, southwest tower	−5°56′
3.	West steps, cruciform terrace	Second gallery, southwest tower	−19°14′
4.	Second gallery, south library	Central tower	+29°7′
5.	Second gallery, north library	Second gallery, northeast tower	+23°11′
6.	Causeway, north library	First gallery, northwest tower	−0°18′
7.	Causeway, 196 m from central tower (western edge of cruciform terrace)	First gallery, southwest tower	+5°1′
8.	Causeway, 313 m from central tower (fifth projection)	First gallery, northwest tower	+5°56′
9.	Causeway, 368 m from central tower (fourth projection)	Second gallery, southeast tower	−5°42′
10.	Causeway, 368 m from central tower (fourth projection)	First gallery, northwest tower	+4°54′
11.	Causeway, 423 m from central tower (third projection)	Second gallery, southeast tower	+5°7′
12.	Causeway, 478 m from central tower (second projection)	Second gallery, northeast tower	+5°17′
13.	Causeway, 530 m from central tower (first projection)	Second gallery, southwest tower	−5°12′
14.	West gate, 542 m from central tower (porch)	Central tower	+0°4′
15.	West gate, 542 m from central tower (porch)	Second gallery, southwest tower	−5°5′
16.	West gate, 30 m north of gate (doorway)	First gallery, northwest tower	−5°32′
17.	West gate, 106 m north of gate (northern porch)	Second gallery, northeast tower	−5°12′
18.	West gate, 107 m south of gate (southern porch)	Second gallery, southeast tower	+5°47′
19.	Northwest corner of Angkor Wat	Northeast corner of east Baray and unnamed temple to northeast	+23°30′
20.	West gate, Angkor Wat	Summit, Phnom Bok (17.4 km northeast)	+23°30′
21.	South entrance, Angkor Wat	Prasat Top	+23°30′
22.	West gate, Angkor Wat	Prasat Kuk Bangro	−23°30′

4) Although alignments of 0° and ±5° are found most frequently with the points observed within the three concentric galleries, we feel that this results somewhat from selection effect due to the limited number of points being considered.

While these numerical investigations are to be regarded as preliminary, we believe that they further our understanding of the designer's intention at Angkor Wat and introduce astronomy as a practical function of the architectural format of the temple.

Numerical Analysis and Time Cycles

So far we have suggested that the precise measurements of Angkor Wat facilitated the practical pursuits of astronomy. However, that is not their sole purpose. When the principal measurements

Table 2. Major solar and lunar measurements at Angkor Wat. The measurements here are derived from the plans of Angkor Wat published by Nafilyan (*1*). They are accurate to 1 millimeter on a plan with a scale of 1 : 50, or 5 centimeters on the ground.

Description	Plan (scale)	Dimension	Measurement			Cosmological interpretation
			On plan (cm)	On ground: Meter	On ground: Hat	
Distance between interior bottom steps of central sanctuary	XXII (1 : 50)	West-east axis	10.35	5.175	11.88	At 12 hat each and 24 hat together, the interior axes of the central sanctuary symbolize the 12 months in a solar (or lunar) year. There are 24 lunar half-months in the lunar calendar, individually named.
		North-south axis	10.55	5.275	12.11	
Interior axial lengths of nine chambers in central tower	XXII (1 : 50)	Total, west-east axis	24.5	12.25	28.13	At 27 and 28 hat, the combined interior axial lengths of the central tower provide the alternate numbers of constellations along the ecliptic in Hindu astronomy, as well as the alternate number of days the moon is visible each month.
		Total, north-south axis	23.7	11.85	27.21	
Exterior axial lengths of central tower (including base)	XXII (1 : 50)	West-east axis	39.65	19.825	45.53	At 90.83 hat, the exterior axes of the central tower approach the average number of days between the solstices and equinoxes (91.31 days average).
		North-south axis	39.45	19.725	45.30	
		Total			90.83	
Interior axial lengths of four axial entrances on upper elevation	XIV (1 : 100)	West	20.05	20.05	46.04	With an approximate total of 180 hat, the interior axes of the four axial entrances on the upper elevation symbolize one-half of a divine year of the gods (360 earth years long), as well as the number of degrees traversed by celestial bodies across the sky.
		East	19.75	19.75	45.36	
		North	19.05	19.05	43.75	
		South	19.90	19.90	45.70	
Interior axial lengths of the four corner pavilions on the topmost elevation	XXV (1 : 50)	West-east axis	13.35	6.675	15.33	The total of all the interior axes of all the chambers on the upper elevation is 358.83 hat,† approaching the length of a divine year of the gods.
		North-south axis	13.35	6.675	15.33	
		Total			122.64*	
Exterior axial lengths of the topmost elevation	XIV (1 : 50)	West-east axis	82.1	82.1	189.00	The two exterior axes of the upper elevation total 365.37 hat, almost the exact length of a solar year (365.25 days).
		North-south axis	76.80	76.80	176.37	
Interior axial lengths of the libraries, second gallery	XC (1 : 50)	West-east axis	13.8	6.9	15.85	The alternate lengths of the north-south axis produce alternate totals of 27 and 28 hat for the interior axes of each library. The moon passes through each of the 27 and 28 Hindu constellations each month.
		North-south axis without doorway indentation	9.7	4.85	11.14	
		North-south axis with doorway indentation	10.6	5.30	12.11	
Exterior axial lengths of the libraries, second gallery	XC (1 : 50)	West-east axis	38.3	19.15	43.98	These numbers have lunar significance when converted into the *phyeam* unit, the only other numerically meaningful measure at Angkor Wat; 4 hat = 1 phyeam. There are 11 lunar gods (*karana*) and 7 days in a lunar week.
		North-south axis	24.6	12.30	28.25	
Distance between floor of north and south libraries of second gallery and sacred deposit of temple	XII‡	North		12.86	29.53	The length of one lunar month is exactly 29.53 days.
		South		12.89	29.60	
Height of libraries of second gallery from level of terrace on which they stand (estimated by surveyors)	XCI (1 : 50)		20.8	10.4	23.88	There are 24 lunar half-months in one lunar year. The days are counted from 1 to 15 for the first half and 1 to 14 or 1 to 15 for the second half, depending on the month.

*30.66 + 4. †122.64 hat + 28.13 and 27.21 hat from the second set of measurements above + 180.85 hat from the fourth set of measurements above. ‡1.65 m added to the numbers on the plan to produce the level of the sacred deposit.

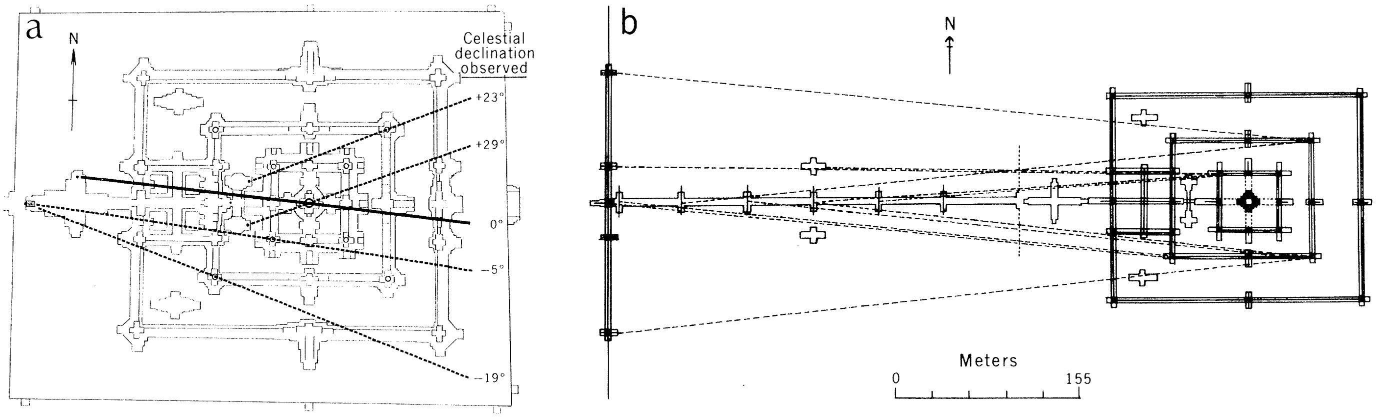


Fig 6. (a and b) A total of 22 alignments within Angkor Wat can be used for the observation of the sun and the moon. Their positions and angles are listed in Table 1.

of Angkor Wat are translated from meters into the unit used in the construction of the temple, very diverse and complete data on the calendar emerge. The original unit of measure (the Cambodian *hat* or cubit) was determined by deriving the common denominator for the broadest range of measurements at the temple. We then found that 0.43545 m produced the greatest number of integral multiples when divided into approximately 200 measurements within the temple (*15, 16*). During this process, we determined that exterior measurements invariably extended from the edges of the projecting bases of all superstructures. Interior measurements excluded all thresholds and steps. Therefore, interior measurements could be adjusted to the larger systems of exterior dimensions by using the number and width of steps within each chamber. In addition, a wide range of measurements, rounded off to whole numbers, were related to numbers in the Hindu calendar and in Hindu mythology (*17*). Table 2 shows ten of the most basic solar and lunar measurements at Angkor Wat, perhaps the most outstanding being the number 365.37 (Fig. 7).

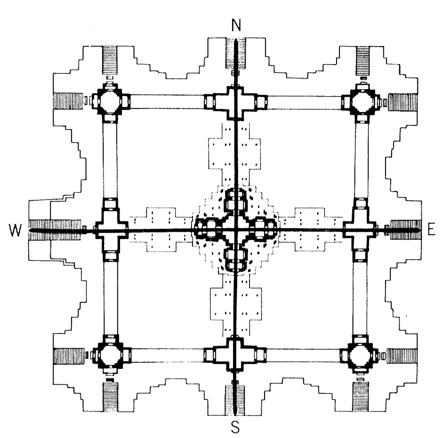
Numbers related to cosmology and mythology are particularly recorded in the bridge, the central tower and its four surrounding towers, and the west-east axis of the temple. We have chosen the latter as an illustration of the ways in which cosmological numbers were incorporated into architectural units (*18*).

In Hindu cosmology, there are four major periods of time, which succeed each other in one great time cycle. These periods begin with the Krita Yuga or "golden age" of man and proceed through the Treta Yuga, Dvapara Yuga, and Kali Yuga, the last being the most decadent age of man. Their respective durations are 1,728,000; 1,296,000; 864,000; and 432,000 years. The elongated west-east axis of Angkor Wat is a perfect vehicle for recording numbers as large as 1,728 hat (Fig. 8). The straight and slender causeway is also an appropriate visual analogy for the long, linear passage of time. The architects who constructed Angkor Wat certainly believed in the auspicious and inauspicious natures of these yugas. Assuming that their beliefs were also inextricably woven into the design of the temple, then it must have been their intent to place the two worst yugas (Kali and Dvapara) farthest from the sacred central sanctuary. The beneficent Krita and Treta yugas are closer to the central sanctuary and they overlap the two inauspicious yugas, perhaps to mitigate their unlucky symbolism. The axial lengths measured at Angkor Wat show a striking correspondence to the durations of the yugas, as shown in Table 3.

The discrepancies between the durations of the yugas and the lengths recorded in the axis of Angkor Wat (Table 2) are within the range of human error (*19*). The largest error is found in the

Table 3. Correspondence between dimensions measured along the west-east axis of Angkor Wat and durations of Hindu yugas.

Measurement	Dimension (hat)	Period	Duration (years)
Width of moat	439.78	Kali Yuga	432,000
Distance from first step of western entrance gateway to balustrade wall at end of causeway	867.03	Dvapara Yuga	864,000
Distance from first step of western entrance gateway to first step of central tower	1,296.07	Treta Yuga	1,296,000
Distance from first step of bridge to geographic center of temple	1,734.41	Krita Yuga	1,728,000



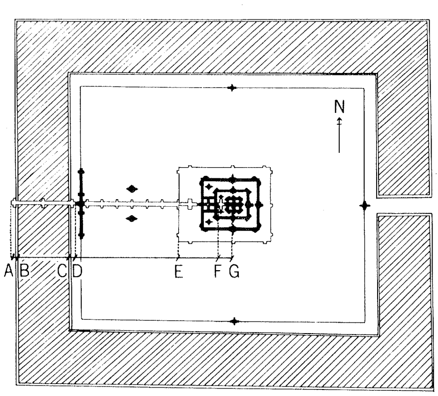


Fig. 7 (left). When the lengths of the exterior axes (*N–S* and *W–E*) of the upper elevation of Angkor Wat are added together, they total 365.37 hat. The upper elevation has many other examples of solar symbolism (see Table 2). Fig. 8 (right). The four Hindu time cycles, called yuga periods, are recorded in the west-east axis of Angkor Wat. They comprise the Kali Yuga (*B–C*), the Dvapara Yuga (*D–E*), the Treta Yuga (*D–G*), and the Krita Yuga (*A–F*). Their lengths in years are 432,000; 864,000; 1,296,000; and 1,728,000, respectively. The axial lengths in hats are 439,78; 867.03; 1,296.07; and 1,734.41.

width of the moat, which measures 191.50 meters between the edges of its masonry borders. Part of this error may be due to centuries of erosion, which have left the borders slanted and slightly sunken. At the same time, we are not certain that we have measured the proper distance. For example, the width of the moat at the level of the water approaches 432 hat much more closely. Further research might clarify this problem.

In summary, we propose that the passage of time is numerically expressed by the lengths corresponding to yugas along the west-east axis. Astronomically, the passage of time is measured along the same axis by a dozen positions for lunar and solar observation. Finally, time is visually and symbolically expressed by the long, linear form of the axis itself. This full integration of astronomy, numerology, and architectural form is characteristic of the temple.

The Role of the Sun

We have indicated that the sun was a determining factor in the westward orientation of Angkor Wat. In reality, the sun has a multifaceted role in the temple. Angkor Wat is dedicated to Vishnu, the member of the Hindu trinity who presides over all the solar-related deities in the Hindu pantheon. The posthumous title of Sūryavarman II was Paramavishnuloka, or the "one who has gone to the supreme world of Vishnu," relating the king directly to the god and indirectly to the sun. The name Sūryavarman itself translates as "protected by the sun."

A further indication of the importance of the sun in the rituals of the temple is the direction of the bas-reliefs on the inner wall of each side of the third gallery. These bas-reliefs constitute the longest series of continuous reliefs in the world—more than 500 m in total length. Even though they are a major part of the temple, it was never fully resolved whether they proceeded from left to right or right to left, or indeed whether they had a direction (*11*, pp. 305–309). However, when they are "read" in relation to the annual and diurnal movements of the sun, it seems certain that their direction is counterclockwise.

In Hindu astronomy, the apparent annual movement of the sun is conceived as counterclockwise. Beginning with the spring equinox (east), the sun progresses to the summer solstice (north), then southward to the autumn equinox (west). From that point, it continues on to the winter solstice (south) and then returns to its eastern starting point.

In fact, the subject matter of the bas-reliefs corresponds exactly to the counterclockwise motion of the sun. On the east wall of the gallery of bas-reliefs, there is a scene of the "churning of the sea of milk," a cooperative venture which produced the elixir of immortality. The scene epitomizes the concept of creativity and new life. On the side of the setting sun and autumn equinox, the most destructive battle ever fought in Hindu mythology is depicted, the battle on the plains of Kurukshetra (from the Indian epic *Mahabharata*). The north wall is the only section of bas-relief which depicts all of the Hindu gods together. The day of these gods (who reside at the north pole, on the cosmic mountain called Mount Meru) lasts for the 6 months between the spring and autumn equinoxes. Although the sun does not shine fully on the north wall during those 6 months because of its 13°27′ southward trajectory as it approaches the zenith, it is the only appropriate direction for the placement of the gods. The night of the gods corresponds to the 6 months between the autumn and spring equinoxes. During those 6 months, the north wall remains in darkness. The same 6 months initiate the dry season, when trees and plants either die or become dormant. During that time, the kingdom of Yama, the god of death, is illumined on the south wall. Thus, the placement of these important bas-reliefs is not haphazard or meaningless. In all cases, their content is directly related to the solar calendar or the rising and setting sun.

Conclusions

The importance of astronomy, the calendar, and the sun in the architecture and bas-reliefs of Angkor Wat is just beginning to be understood. The results of the study of the temple so far are summarized as follows:

1) The rising sun was aligned on the equinox and solstice days with the western entrance of Angkor Wat.

2) The movements of the moon were observed from a variety of positions within the temple, and lunar cycles were recorded in the three pairs of libraries.

3) The bas-reliefs of the third gallery can be understood in relation to the movements of the sun, which establishes their counterclockwise direction.

4) The measurements of the temple record calendric and cosmological time cycles.

In the introduction to the *Silpa Prakása*, a treatise on Orissan temple architecture between the 9th and 12th centuries, Boner has summed up the importance of astronomy for the Hindu temple (*20*).

> . . . the temple must, in its space-directions, be established in relation to the motion of the heavenly bodies. But inasmuch as it incorporates in a single synthesis the unequal courses of the sun, the moon and the planets, it also symbolizes all recurrent time sequences: the day, the month, the year and the wider cycles marked by the recurrence of a complete cycle of eclipses, when the sun and the moon are readjusted in their original positions, a new cycle of creation begins.

Although the role of astronomy in Hindu temple architecture has been widely recognized, our understanding of it has remained quite imprecise and undefined. We hope that future research will reveal whether the astronomical relations that characterize the architecture of Angkor Wat also apply to other major temples in India and Southeast Asia.

References and Notes

1. G. Nafilyan, *Angkor Vat, Description Graphique du Temple* (École Française d'Extrême-Orient, Paris, 1969).
2. There are 113 plans in (*1*). Measurements were taken several times along a wide variety of diagonals and axes. Any disagreement between measurements was resolved by remeasurement; further checks were provided by geometrical analyses and photographs of the areas surveyed. The final drawings were done on a polyester paper, which does not expand or contract with variations in temperature or humidity.
3. North-south alignments are from plan XI in (*1*), drawn to a scale of 1 : 250. There is not 1 millimeter of deviation in the north-south axes on this plan. Nafilyan used the north-south axis of the western side of the first (upper) gallery for the north-south alignments on his plans. Aside from actual measurement in situ, there is no other source for determining the angle of the west-east axis of Angkor Wat.
4. This was estimated from plan II in (*1*), scale 1 : 5000. The distance from the central tower to the center of the projection just in front of the western entrance gate was calculated as 530 m. The height of the central tower is 57 m from the causeway level or 55.5 m (approximately) from eye level. The tower, seen from just in front of the western entrance gate, thus subtends an altitude angle of 5.9°. Based on an axial shift of 0.75° south of due east, the observed celestial declination over the tower top is +0.7°. The southern and northern edges of the projection are 6.9 m from the center line of the causeway. From these two edges, the observed celestial declinations are −0.1° from the northern position and +1.4° from the southern position. The *American Ephemeris and Nautical Almanac* (Government Printing Office, Washington, D.C., 1971) lists the change in solar declination at the equinox to be about 0.4° per day. The Khmers could then, in principle, have monitored the solar declination quite exactly from 0° to 1.5° north over a 3- to 4-day period. This monitoring would permit accurate determination of the spring and autumn equinoxes.
5. F. G. Faraut, *Astronomie Cambodgienne* (Schneider, Saigon, 1910), pp. 113–117.
6. P. Paris, *Bull. Ec. Fr. Extr. Orient* **41**, 323 (1941).
7. This alignment includes the eastern entrance of Banteay Kdei, constructed at the end of the 12th century. Phnom Bok rises 160 m from ground level. An observer would have to be high up on the tower in order to observe the sun rise over Phnom Bok on the summer solstice day. The alignment is very important, whether actual observations took place or not.
8. See the plan of the site annexed to the article in (*6*) and p. 323 (*t*′). The date of Prasat Kuk Bangro has not been published.
9. According to Chou Ta-kuan (*10*, p. 24), "the sovereigns themselves are buried in the towers, but I do not know if one buries their bodies or their bones."
10. Chou T.-K., *Mémoires sur les Coutumes du Cambodge du Tcheou Ta-kouan*, P. Pelliot, Transl.

(Librairie d'Amerique et d'Orient, Paris, 1951).
11. G. Coedès, *Bull. Ec. Fr. Extr. Orient* **33**, 305 (1933).
12. It has been postulated that temples entered on the west were primarily funerary in intent whereas temples entered on the east were simply used in the worship of the Hindu gods. In reality, the question is more complex since many temples in India have no other explanation for their orientation except geographical convenience.
13. W. Campbell, *Practical Astronomy* (Macmillan, New York, 1913), p. 8, Eq. 4.
14. Twelve east-west alignments, 16 north-south alignments, and 26 solstitial alignments have been traced at the site of Angkor.
15. E. Morón, thesis, University of Michigan (1974).
16. The basic unit of measure was first derived in 1973. There are approximately 45 measurements of independent architectural parts of the temple, 35 of which are related to astronomy or cosmology in a direct manner.
17. E. Morón paper presented to the College Art Association, Detroit, January 1974.
18. J. Cohen and B. Kalman, *Angkor: Monuments of the God-kings* (Abrams, New York, 1975), pp. 98–99. The text contains a brief discussion of the yugas as proposed by E.M.
19. It is possible that the original plan of the yugas was much more accurate (*15*).
20. R. Kaulaćara, *Śilpa Prakása*, A. Boner and S. Rath Śarma, Transls. (Brill, Leiden, 1966), p. xxxiii.
21. The major cardinal alignments at Angkor Wat are as follows. The northern side of the moat of Angkor Wat is along a 27.6-km line between Wat Khnat and Wat Trach (about 10 km north of Roluos). The eastern edge of the moat of Angkor Wat is aligned with the east wall of Preah Khan and the outer wall of Angkor Thom. The north-south meridian of the topmost elevation of Angkor Wat terminates at Prasat Einkosei 4 km to the south; 5.5 km to the north it joins the earthen ridge west of the western side of the moat of Preah Khan.

Elementary Modes of Excitation in the Nucleus

Ben R. Mottelson

In the field of nuclear dynamics a central theme has been the struggle to find the proper place for the complementary concepts referring to the independent motion of the individual nucleons and the collective behavior of the nucleus as a whole. This development has been a continuing process involving the interplay of ideas and discoveries relating to all different aspects of nuclear phenomena. The multidimensionality of this development makes it tempting to go directly to a description of our present understanding and to the problems and perspectives as they appear today. However, an attempt to follow the evolution of some of the principal ideas may be instructive in illustrating the struggle for understanding of many-body systems, which have continued to inspire the development of fundamental new concepts, even in cases where the basic equations of motion are well established. Concepts appropriate for describing the wealth of nuclear phenomena have been derived from a combination of many different approaches including the exploration of general relations following from considerations of symmetry, the study of model systems, sometimes of a grossly oversimplified nature, and, of course, the clues provided by the experimental discoveries which have again and again given the development entirely new directions (*1*).

The situation in 1950, when I first came to Copenhagen, was characterized by the inescapable fact that the nucleus sometimes exhibited phenomena characteristic of independent-particle motion, while other phenomena, such as the fission process and the large quadrupole moments, clearly involved a collective behavior of the whole nucleus.

It was also clear from the work of Rainwater that there was an important coupling between the motion of the individual particles and the collective deformation; and one was thus faced with the problem of exploring the properties of a dynamical system involving such coupled degrees of freedom (*2–5*)

$$H = H_{\mathrm{vib}} + H_{\mathrm{part}} + H_{\mathrm{coupl}}$$

$$H_{\mathrm{vib}} = \tfrac{1}{2} C_\lambda \sum_\mu |\alpha_{\lambda\mu}|^2 + \tfrac{1}{2} D_\lambda \sum_\mu |\dot{\alpha}_{\lambda\mu}|^2$$

$$H_{\mathrm{coupl}} = \sum_{\mathrm{p}} k(r_{\mathrm{p}}) \sum_\mu \alpha_{\lambda\mu} Y_{\lambda\mu}(\theta_{\mathrm{p}}\phi_{\mathrm{p}}) \qquad (1)$$

where $\alpha_{\lambda\mu}$ are the amplitudes of the nuclear deformation expanded in spherical harmonics and (r_{p}, θ_{p}, ϕ_{p}) are the coordinates of the particles considered. The coupling term represents the effect of the deformation on the one-particle potential.

I remember vividly the many lively discussions in these years reflecting the feeling of unease, not to say total disbelief, of many of our colleagues concerning the simultaneous use of both collective and single-particle coordinates to describe a system that we all agreed was ultimately built out of the neutrons and protons themselves. Niels Bohr participated very actively in these discussions. Something of the flavor of his contribution can perhaps be gathered from the exchange recorded in the Proceedings of the CERN International Physics Conference in Copenhagen from June 1952; I had given a report on our work, and in the discussion Rosenfeld "asked how far this model is based on first principles." Niels Bohr "answered that it appeared difficult to define what one should understand by first principles in a field of knowledge where our starting point is empirical evidence of different kinds, which is not directly combinable."

I would like to take this opportunity to acknowledge the tremendous inspiration it has been for me to have had the privilege to work for the entire period covered by this report within the unique scientific environment created by Niels Bohr.

Interpretation of Low-Energy Nuclear Excitation Spectra

In the beginning of the 1950's, there existed very little evidence on nuclear spectra which could be used to test these ideas. In the following years, however, a dramatic development of nuclear spectroscopy took place. The new data made possible the identification of the characteristic patterns of rotational spectra (*6*) and, shortly afterward, the recognition by Scharff-Goldhaber and Weneser (*7*) that a significant class of spectra exhibit patterns corresponding to quadrupole vibrations about a spherical equilibrium (*8–14*). The existence of the static defor-

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