STONEHENGE PHYSICS

by Gerald S. Hawkins

STONEHENGE CONSISTS OF about 2500 tons of stone blocks, which ancient Britons managed to move, some a distance of more than 200 miles, and set in circles and archways on the chalk downs. The stone structures were placed within a circular chalk bank and ditch about 350 ft in diameter. Just within the bank was a ring of 56 equispaced holes, which archaeologists discovered in this century and named in honor of the antiquarian John Aubrey. According to radiocarbon dating of cremated bones the holes were dug about 1850 B.C. Similar dating of a deer-antler pick indicates that the stonework was put up about 150 years later. Needless to say, no written messages were carved on the stones by the builders, and they left no other clues to their purpose. In my first published discussion of Stonehenge[1], I showed that the stones and archways point to the sun and moon as these bodies rise and set during the year and that the symmetry of the structure permits it to be used as a computing device for predicting the year in which eclipses of the sun and moon will take place at a particular season, such as midsummer. The 56 chalk-filled Aubrey holes can be used to predict the year of an eclipse, and the 30 Sarsen archways permit one to count off the actual day of an eclipse. The hour of an eclipse can be determined by watching sunset and moonrise in the appropriate archways; thus, Stonehenge can be used as a sort of vernier. The astronomical alignments are beyond doubt, but the computer aspects are speculative. I have described both more fully in my book.

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STONEHENGE DECODED. By Gerald S. Hawkins with John B. White. 202 pp. Doubleday, Garden City, N. Y. 1965. $5.95.

My fellow astronomers have checked over the calculations and have remained relatively unexcited about the findings. A scientist who is primarily concerned with the solar system and beyond (with preference to beyond) accepts without question that living beings will show some natural empathy with the sun and the moon whether they are ancient Britons, migrating birds, or soft-shelled crabs. Similarly, the values found from Stonehenge for the obliquity of the earth's axis and the inclination of the lunar orbit at about 2000 B.C. are not very exciting to an astronomer because they agree with modern extrapolations. These Stonehenge values are perhaps the best rebuttal of Velikovsky's thesis of cataclysmic shifts in the axis of the earth in the first millenium B.C., but then Velikovsky's thesis has not been warmly accepted for other reasons.

On the other hand, the work has aroused a great deal of interest in cultures other than the scientific. Prehistorians have become interested in a set of stones that could convey and preserve information without need for a written record, and classical scholars have begun to find confirmation for part of the heritage of myths and legends. Anthropologists have used the information to debate the intellectual achievement of people in the stone age compared to the standards of present-day primitive peoples. One extreme school of thought believes that when we deal with people who could not write and who had not discovered metals, we are dealing with an inferior *Homo sapiens*. The other extreme position regards *Homo sapiens*, whatever the date in the past may be, to be our equal.

Physics in the stone age

Astroarchaeology has several interesting aspects for physicists. An experimentalist might take satisfaction in the alignment of Stonehenge. These stones, some weighing close to 50 tons, were set so that the sun would stand momentarily on their peaks at the critical dates during the year. With clockwork precision the sun

Stonehenge, on Salisbury Plain in southern England, has been a mystery for centuries. Some have thought it was a pagan temple, others that it was a monument to slaughtered British chieftains. Legends invoked the power of Merlin to explain how the stones were brought to their present location. Recent studies indicate that Stonehenge may have been an astronomical observatory and eclipse computer.

would shift from the midsummer extreme to the midwinter extreme. The space between the trilithon archways was so narrow that it was impossible for a man to walk through—yet in its extreme position the orb of the sun would rise or set in the narrow slot formed by two such archways. Figure 1 shows midwinter sunrise in December 1964. In 1700 B.C., when the archway was erected, the tilt of the earth's axis was half a degree greater and the sun appeared almost exactly one diameter lower. Thus the erection of the archways had commendable precision, if one remembers that the total mass of the two archways is close to 200 tons.

Positional astronomy in 1700 B. C.

For the theoretical physicist there is the attraction of symmetry and the fun associated with the whole numbers of commensurability. The Stonehengers were marking the direction of the sun and the moon as shown in figure 2. At midsummer the sun rises and sets at its extreme northerly position, and at midwinter it reaches its extreme southerly position. At the time of Stonehenge the declination of these positions was +24 deg and −24 deg, respectively. On the first day of spring and fall the declination is 0, and these positions are also marked.

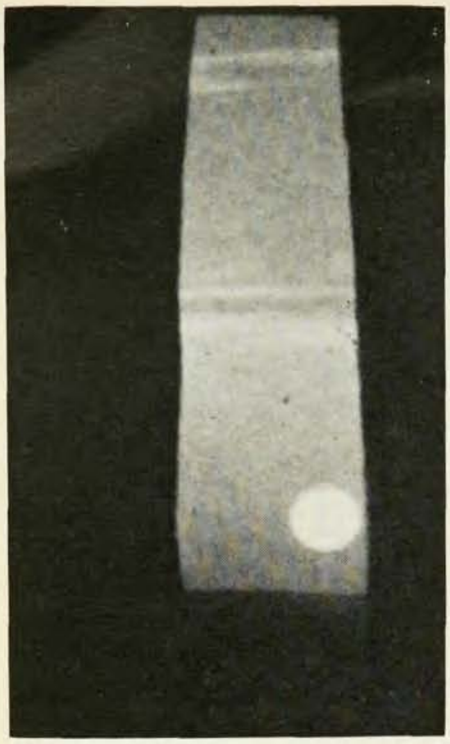
The moon follows this general pattern of movement, accomplishing the swing on the horizon in a period of a synodic month, 29.53 days, instead of the 365.2422 days required by the sun. In addition, the moon has an 18.61-year cycle caused by the precession of its tilted orbit. It therefore has one extreme high position and one extreme low position for every position of the sun. To put it succinctly, the 18 positions in this pattern are defined by the set of declinations $(24p + 5q)$, where p and q are independently $0, \pm 1$. This pattern is symmetrical about the east-west line $(p = q = 0)$ and also about the north-south line. If the high priests had chosen either of these axes for Stonehenge the meaning would have been obvious a long time ago.

From the earliest beginnings at Stonehenge, however, the line to midsummer sunrise in the northeast quadrant was chosen as the axis, and symmetry was forced upon this line. Prior to the major stone work at the site, Stonehengers built what can be conveniently called Stonehenge I (figure 3). The basic rectangle of the station stones is clearly marked, and the corners are placed so as to touch the circle of 56 Aubrey holes. It is not so obvious at a first glance, but in this structure use was made of the right angle formed by the lines to midsummer sunrise and midsummer moonrise. Thus the short sides of the rectangle point to the extremes of the sun at midwinter and midsummer, and the long sides of the rectangle point to the greatest extremes of the moon at midwinter and midsummer. The other extremes of the moon are marked by the diagonal between stones 91 and 93. This ingenious arrangement, marking ten positions of the sun and the moon with only four stones, can be checked out by tracing figure 2 and superimposing it on figure 3. Strangely enough, the right angle exists only at the latitude of Stonehenge, 51.17 deg. north or south of this critical latitude the rectangle would degenerate into a parallelogram. Did they pick the location with this geometry in mind?

The position of the sun at the equinox can be readily found by bisecting the angle between the lines to the solstice positions. Note that it cannot be found by observing the sunrise on a date midway between midsummer

Menhir Mechanics

The mass of the megaliths conjures up problems of mechanical interest. Imagine the variant on the time-worn freshman physics question: "A 50-ton menhir (vertical stone, set up by ancient people) of uniform density begins to topple under the action of gravity. Calculate the angular momentum and kinetic energy when the tilt angle becomes 45 deg. Define an inverse operator that will restore this situation." This was far from an academic question to stone-age man, and we have no clear idea how the builders carried out such operations with no wheels, pulleys nor mechanical sources of energy. It was a very real question indeed for the man who was toppling a stone at Avebury near Stonehenge around 1360 A. D. His flattened skeleton and the dated coins in his pocket were recently found under the stone. He clearly failed to find the inverse operator.



WINTER SOLSTICE SUNRISE (1964). The camera was placed near the fallen stone 59, and the picture was taken through the narrow gap in the sunrise trilithon 51-52 and the Sarsen archway 6-7. In 2000 B. C. the sun would have been one diameter closer to the horizon. From "The Mystery of Stonehenge," a program broadcast over the CBS television network. —FIG. 1

and midwinter because the first day of spring is not exactly the midway point in time. (The ellipse of the earth's orbit and Kepler's law of areal velocity introduce an asymmetry of three or four days between the time from winter solstice to spring equinox and the time from spring equinox to summer solstice. The dates are 22 Dec. 1965, and 21 March and 21 June 1966.) Also, I doubt whether the exact day of the solstice could be determined observationally to an accuracy of better than a few days. The equinox alignments are marked by stones, B, C, D, and E viewed from 94, and F viewed from 93. For example, an observer standing at 93 would see the *extreme moonrise* over 92, the "neap" midsummer moonrise over 91, the midsummer sunrise over 94, the equinox sunrise over F, and the midwinter sunrise over H.

The later structure, which has been termed Stonehenge III (figure 4), was again a symmetrical solution to an *asymmetrical problem* along the midsummer axis. In this later structure the equinox positions have not been incorporated, although of course they would still be usable in the earlier structure of Stonehenge I, because only the diagonal sight line was obscured.

In looking at the plans of Stonehenge one is immediately struck by the numerology. The Sarsen ring contains 30 archways, the nearest whole *number to the* average length of the synodic month. By moving a stone one archway each day the Stonehengers could keep track of the phases of the moon even during periods of bad visibility. The 30 Y and 29 Z holes represent the next approximation. By counting one hole from each ring per day they would mark off an interval of 29.5 days. As confirmation, we note that the bluestone circle, inside the Sarsen circle, is thought to have held 59 stones. (30 + 29 or twice 29.5).

But this type of interpretation is controversial, as one might imagine. Some archaeologists argue that the Stonehengers intended to dig 30 Z holes, but gave up. If this indeed was the reason, then they never reached the second approximation to the synodic month, and they certainly dug a great number of holes for nothing—or should we say more logically, for no apparent reason? I have attempted to expound on some of this controversy in *Stonehenge Decoded*.

Eclipse calculation by carrying stones

What about the strange number of Aubrey holes, 56? Until recently no explanation had been offered. By recomputing events that occurred at Stonehenge between 2000 and 1000 B.C., I slowly realized that 56 years was the basic periodicity of an eclipse cycle that had hitherto been unrecognized by astronomers. When the full moon nearest to the winter solstice rises over the heelstone, a lunar eclipse will take place. Only half of the lunar eclipses will be visible from Stonehenge, of course, but the condition signals the "danger" of a winter eclipse. On the average this condition occurs every ninth or tenth year with 30% of the intervals being the longer span of ten years. Equinoctial eclipses are predicted when the moon rises over D or F as seen from the center, and the intervals here are either 19 or 18 years with 30% of the intervals being 18 years in length. The number that governs this pattern is 56, since it is the sum of 19, 19, and 18, and also twice the sum of 9, 9 and 10. I believe that the Stonehengers discovered this pattern the hard way.

Nowadays one recognizes the cycle as a result of the commensurability of the eclipse year with the tropical year. Eclipses take *place at two seasons of the* year centered on the two dates when the sun is in the plane of the moon's orbit. This plane rotates 360 deg in 18.61 tropical years, that is, years of the true calendar. Thus 18.61 tropical years (18.61 T) are equal to 19.61 eclipse year (19.61 E) and $E = 18.61T/19.61 = 346.620$ days. If an integral number of eclipse years has elapsed, then the danger of eclipses is again present; if an integral number of tropical years has also elapsed, then the eclipses will repeat in the same calendar month. (Note that the classical astronomical eclipse cycle, the so-called "Saros," is based on an integral number of lunar months, which is quite a different matter.) One simply has to find integers n and m that come close to satisfying the equation $346.620\ m = 365.2422\ n$. When n is 56 and m is 59 the two periods agree within four days. Thus, the winter moon is in danger of eclipse every 56 years, and this cycle will be sustained accurately for a period of about 350 years.

I have suggested[2] that the 56 holes were used as a crude computing device by moving 6 stones around 1 place each year. There are other possible ways of using this basic raster. In some of the other modes one can reduce the number of stones to three or even one. Every 350 years or so the computer has to be reset by advancing all stones by one position; then the computer is ready for the next 350 years. Of course the computer can predict all the danger periods for eclipses on a seasonal basis, particularly eclipses during the lunar month at summer solstice, winter solstice, spring, and fall.

As partial confirmation that the Stonehenge people had recognized this remarkable commensurability, one notices that the central horseshoe of

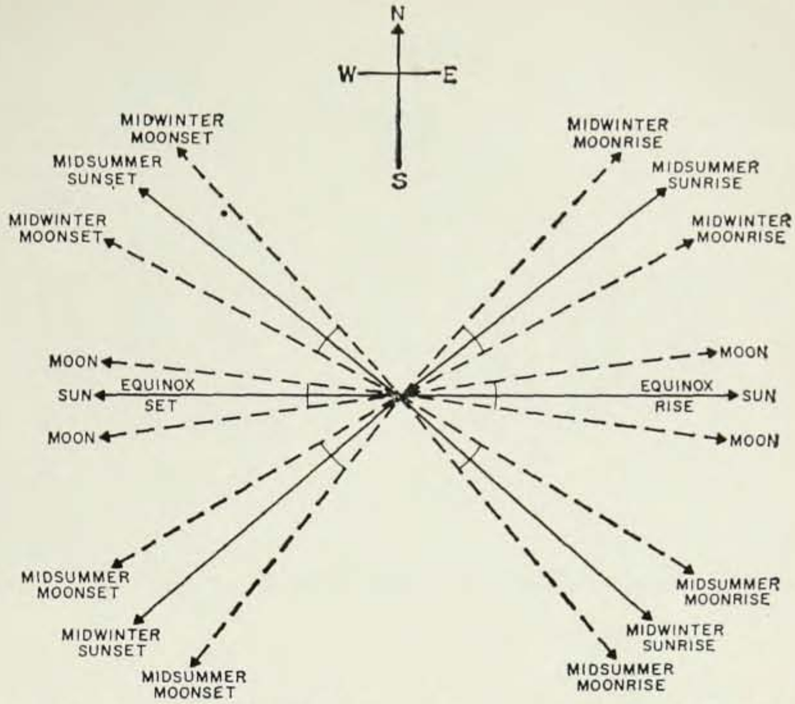
Stonehenge III contains 19 stones. This is the basic and most important prime number in the subcycles within the 56-year period. C. A. Newham has continued this investigation for the period prior to the "stone" parts of the structure. On the basis of holes, which archaeologists are sure originally contained wooden posts, Newham claims to have followed year by year the observational process involved in several of these 56-year cycles.

Again, my computer suggestion has proved controversial. As one authority pointed out, Stonehenge can indeed be used as a computer, but was it ever put to use? Since there is no written historical record one would require a time machine to answer this question with the rigor demanded by a physicist. But G. de Santillana of MIT has recently[3] pointed out the science of eclipses that underlies the classical mythology. Plutarch refers boldly to Typhon, "the shadow of the earth into which they believe the moon to fall when eclipsed," and quotes the ancient sage Eudoxus as relating that Typhon exhibits the figure of 56 angles. The node of the moon's orbit does indeed take up 56 positions around the ecliptic during the 56-year cycle.

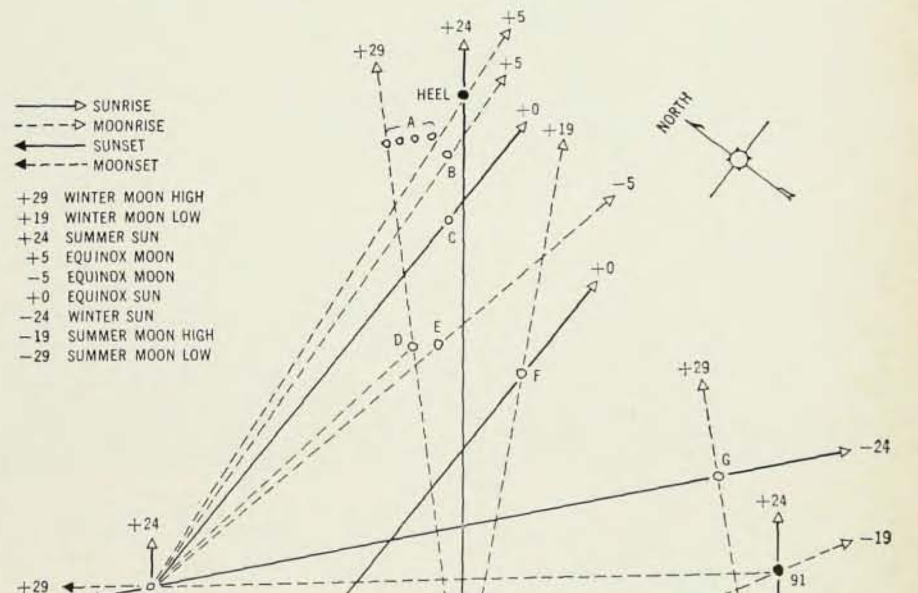
Arithmetic without writing?

It is difficult enough to concede that Eudoxus of antiquity had this knowledge, but it is more difficult to link this fact to prehistoric Britain. Stonehenge was in use a thousand years before Eudoxus. This gap in time is a scientific lacuna; no related astronomical knowledge can be found in the cuneiform tablets of the Middle East or in the hieroglyphic records of ancient Egypt.

Archaeologists and prehistorians have established that the Stonehengers had no written language. It is contended that a person can have no numerology without a written record, nor could the hundred years or so of sun-moon observations be recorded mentally and transmitted from generation to generation. Yet there is a concept of numbers. The Aubrey circle is divided with precision into 56 equal parts, the Sarsen circle contains 30, etc. The architectural planning, the engineering and transportation could hardly have been executed without

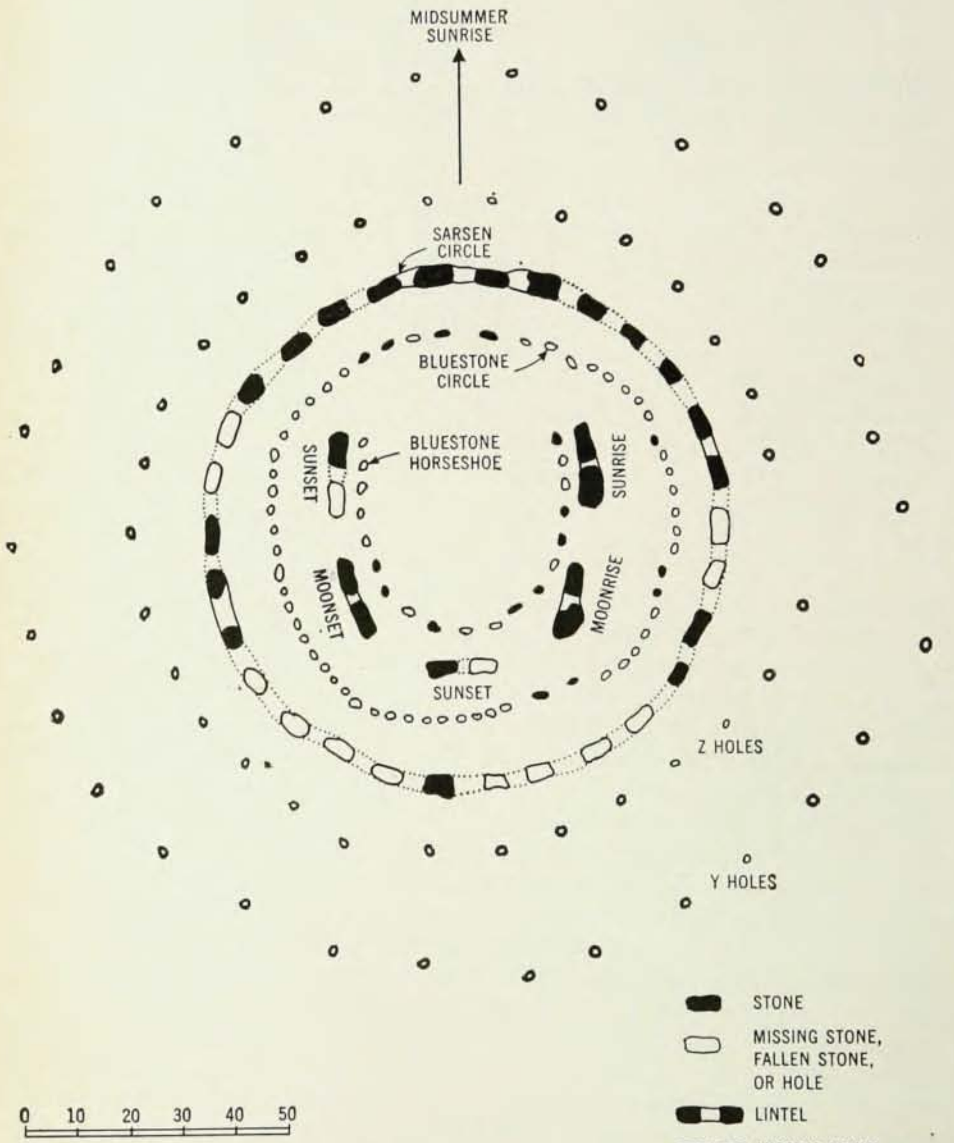


AZIMUTHAL DIRECTIONS of the rising and setting of the sun and moon at equinox and solstice for the latitude of Stonehenge. —FIG. 2



ALL ALIGNMENTS for sun and moon at Stonehenge I. From *Stonehenge Decoded* © 1965 by G. S. Hawkins and J. B. White. —FIG. 3

PHOTO BY DON SANDERS



PLAN OF STONEHENGE III according to present archeological knowledge. **From *Stonehenge Decoded* © 1965 by G. S. Hawkins and J. B. White.—FIG. 4**

some form of mental arithmetic and applied mechanics.

If we concede a numerical system, did they have the concept of zero; did they count on the base 2, 10, or 60? Here again we have no incontrovertible evidence. Certainly the problem of zero is avoided by the circular nature of the computer. Hole 56 was the end of one cycle and the start of the next. It served as both zero and 56.

To speculate about the numerical relationship at Stonehenge without the help of a written record is like opening Pandora's box. Certain writers have concerned themselves with the significance of the height of the stones, the diameter of the circles, the total number of stones in the structure, etc. I have limited myself strictly to the obvious features, the number of holes in the concentric circles. Nor would I have published my computer conjecture if it had not agreed so remarkably with the pattern of alignments to the sun and the moon.

Perhaps my reticence is a product of training in the physical sciences. In particular one comment from what Lord Charles P. Snow calls the second of the two cultures set me to thinking. An anthropologist[4] agreed that Stonehenge was an observatory and an eclipse predictor, but disagreed with my statement that this was an early example of the scientific method. I had tried to imagine the various processes of trial and error, fitting, moving of stones, observation of eclipses, recognition of a cyclic pattern, and layout of angles on the ground to establish the solution. All this seemed to me to be similar to the scientific method. But the anthropologist suggested that it was better described as "magical understanding." Perhaps this comment closes the circuit between 2000 B.C. and 2000 A.D. By 2000 A.D. there seems to be an even chance that the reader of PHYSICS TODAY may have just this comment about our understanding of the fundamental processes of physics. □

References

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4. Y. Schwartz, Science **148,** 444 (1965).