BOOK REVIEWS

Revelations from Farm Hall

Heisenberg's War. The Secret History of the German Bomb. THOMAS POWERS. Knopf, New York, 1993. xii, 610 pp. + plates.

This thick book is really two books. The first is a spy story. In it Powers gives a detailed and often vivid description of how the Allies kept tabs on the German nuclear program in the Second World War. Powers deserves credit for unearthing much unfamiliar material on these intelligence activities. Some of it strikes me as incredible. The idea of ex–baseball player, scholar, and spy (ours) Moe Berg sitting in a lecture of Werner Heisenberg's in Zurich in December 1944 with a loaded gun prepared to shoot Heisenberg dead if he so much as mentioned nuclear physics is beyond my belief. As far as I can make out, we have only Berg's word for this assassination plot, plus the undeniable fact that he was at the lecture and did often carry a gun. Stranger things have happened in the world of espionage. In the event, Heisenberg gave a lecture on the S-matrix. Happily for him, if we believe this tale, he did not illustrate it with examples involving nuclear scattering. To have shot him in late 1944 on the grounds that he constituted a danger because of his knowledge of nuclear weaponry would have been a tragic absurdity. As I will try to demonstrate below, Heisenberg had no real knowledge of nuclear weaponry in December 1944 and gave no indication of having thought seriously about the matter until after he learned of Hiroshima the following August. This brings us to Powers's second book, which deals with Heisenberg's wartime activities.

In the summer of 1939 Heisenberg made a lecture tour of American universities. Many of the people he encountered were Jewish refugees who had left Germany after the racial laws of 1933 took effect. *Kristallnacht*—the night of the broken glass—had occurred the previous September, and Jews were already being put in concentration camps. Heisenberg's colleagues pleaded with him to stay in the United States. But he chose not to. He returned to Germany, prepared to do his part in the war he knew to be inevitable. Fission had been discovered the previous year by Otto Hahn and Fritz Strassmann, and in September 1939 a project was organized by the German War Office in Berlin to utilize nuclear energy. On 26 September Heisenberg joined Hahn and others engaged in the project and began working on reactor development. As far as I can tell, this, and only this, is what he did with regard to nuclear energy during the war. That is not to say that Heisenberg was unaware of the potential destructiveness of nuclear weapons or that, after his protégé C. F. von Weizsäcker observed that transuranics such as neptunium and plutonium were likely to be fissionable, he did not grasp how a reactor could be used to create these potentially explosive elements or even serve as a power source for submarines. All such possibilities depended on achieving a self-sustaining fission reaction, which is what Heisenberg spent the war trying to do. But, I will argue, he did not make any serious effort specifically to design a nuclear weapon and had little understanding of how one worked.

Powers has a diametrically opposite point of view, which he attempts to bolster using what are known as the Farm Hall transcripts. These are transcripts of wire recordings that were made in secret of the conversations among ten key German nuclear scientists, including Hahn and Heisenberg, who were interned in a manor house in Britain called Farm Hall for six months beginning in July 1945. Powers writes (p. 452): "The Farm Hall transcripts offer strong evidence that Heisenberg never explained fast fission to [Walther] Gerlach [who had become director of the fission project with which Heisenberg was associated and was also interned at Farm Hall], that he cooked up a plausible method of estimating critical mass which gave an answer in tons, and that he well knew how to make a bomb with far less, but kept the knowledge to himself. Small wonder that with such an adviser the German authorities concluded that a bomb was beyond them." In other words, Powers contends, the Farm Hall transcripts show that Heisenberg understood during the war how an atomic bomb worked but kept his knowledge to himself in order to stall the German project.

Powers is a recent arrival at an old controversy, one that dates back to the publication of Samuel Goudsmit's book *Alsos* in 1947. Goudsmit, who had seen the then-classified transcripts, maintained that Heisenberg and the other Germans did not understand the physics of nuclear weaponry. Now that the transcripts have been declassified we can all see what they actually say. I am going to focus on them, avoiding a large number of what I think are peripheral issues that Powers raises in support of his view. It was in the transcripts that the Germans revealed what they did and did not understand about the physics of nuclear weaponry in 1945. It is impossible for me to believe that they had a better understanding earlier but forgot it when they got to Farm Hall.

The Farm Hall transcripts, in the version I have, consist of 212 large folio pages. Taken as a whole they read like a play. (Indeed, when I put together an annotated version of a small portion of them for the *New York Review of Books* of 13 August 1992 I wanted to call it "Nuclear Shakespeare"—it is a human drama at the highest level.) Here I will concentrate on only two parts of the transcripts: the conversation between Hahn and Heisenberg that took place on the evening of 6 August, just after the Germans had been informed of Hiroshima, and the colloquium that Heisenberg gave for his fellow internees on 14 August on how he thought a nuclear weapon worked. Powers claims (p. 451) that "the general discussion prompted by Heisenberg's lecture on August 14 made it clear that only some of the scientists really understood bomb physics—Heisenberg, Harteck, Weizsäcker and Wirtz—while the

Farm Hall.

others were evidently hearing much that was new to them." In fact, what this discussion makes clear is that none of them understood much of anything about bomb physics. In not grasping this Powers, who is not a physicist, shows the limits of his own understanding.

First, 6 August. After a general and rather tumultuous exchange among the Germans following their first news about the bomb, Heisenberg and Hahn find themselves alone. Heisenberg makes a conjecture that the Allies had been able to separate about 30 kilograms of uranium-235 a year from natural uranium. Hahn then asks, "Do you think they would need as much as that?" Heisenberg replies, "I think so certainly, but quite honestly I have never worked it out as I never believed one could get pure '235.' " As a statement of what Heisenberg knew what could be clearer? But then Hahn goes on to ask, "How does a bomb explode?" Heisenberg's answer reveals that at that moment he understood next to nothing about bomb physics. He did know from news reports that the Hiroshima explosion was equivalent to that of about 20 kilotons of TNT. He knew that each kilogram of uranium, if it was entirely fissioned, yielded about that energy. He also knew that there were some 2.58×10^{24} nuclei in each kilogram of uranium. He also knew that each fission would produce about two neutrons. Since 2^{80} is about 10^{24} he reasoned that it would take about 80 fission-producing collisions to do the job. He guessed on the basis of his experience with reactors that the average distance between collisions would be 6 centimeters. If the neutron diffusion is considered a random walk this sphere would have a radius of six times the square root of 80 centimeters—about 54 centimeters. Heisenberg then computes the mass of the sphere as 1 ton. In fact, if you take Heisenberg's 54 centimeters and put in the correct density of uranium, which is 19.04 grams per cubic centimeter, the calculation gives about 13 tons—about 3 tons more than the total payload of a World War II bomber! At Heisenberg's conjectured rate of accumulation of about 30 kilograms a year it would take four centuries to accumulate that much uranium-235. One thing that surprised me in reading the transcripts was Heisenberg's ineptness with arithmetic.

But this calculation is in any event irrelevant to how a bomb works. Heisenberg's picture was of the neutrons diffusing from the center and colliding with the nuclei before leaving the sphere. In fact what is relevant is a comparison of the number of fission neutrons being produced per second in the sphere (whatever its volume) with the number escaping from its surface. When these two numbers are equal the reaction will become self-sustaining. The mass at which this happens is the so-called critical mass. Furthermore, in his calculation Heisenberg did not take into account the fact that the uranium sphere—because of the fission energy—rapidly heats up and expands. Indeed after about 5×10^{-8} second the density is reduced enough that the fission process stops. Most of the material will not have fissioned by then. In the Hiroshima bomb, only about 2 percent of the uranium-235 fissioned. So much for Heisenberg's understanding on 6 August. Now to the lecture of 14 August.

By 14 August Heisenberg has come to understand what a critical mass is. He presents his colleagues with a crude diffusion-theory calculation of it. To understand the difference in sophistication between this calculation and what the Allied scientists knew in April 1943 the reader is

advised to consult Robert Serber's *Los Alamos Primer*—the notes of the lectures Serber gave at Los Alamos, now available from the University of California Press. Serber's exposition comes from a different world. In his lecture at Farm Hall Heisenberg, making certain special assumptions and guessing at the mean free path, arrived at a critical radius for the uranium sphere somewhere between 6.2 and 13.7 centimeters, giving a critical mass of somewhere between 19 (the transcripts say 16) and 205 kilograms. In his book Serber quotes the actual critical mass of uranium-235 as 56 kilograms. Heisenberg's discussion then turns to the possibility of putting a material around the sphere that would reflect neutrons and thus reduce the critical mass, something he had brought up with Hahn on 6 August.

This is something that was known as a "tamper" at Los Alamos. Powers makes much of the fact that Heisenberg was aware of this possibility. However, it is evident from the transcripts that Heisenberg did not understand the difficulty with using a tamper. This is clearly discussed in Serber's book. The neutrons tend to get delayed in the tamper because they scatter in it. Hence they are not reflected back rapidly enough to do very much good in the explosive process. Tampers reduce the critical mass by a significant factor—nearly a quarter in the case of uranium-235—but do not increase the efficiency of the explosion by anything like the same amount. That neither Heisenberg nor any of the other Germans understood this is reflected in their discussion about using carbon as a tamper. Indeed, contrary to a footnote of Powers's, this is one of the suggestions Heisenberg makes to Hahn on 6 August. No choice of a tamper material could be worse. Carbon scatters neutrons strongly, which is why it is used as a moderator in reactors to slow down the neutrons—the last thing one wants in a bomb. For a uranium-235 bomb natural uranium is the tamper of choice. Because it is very dense it has the additional useful property of retarding the expansion of the fissioning uranium. With a uranium tamper the critical mass of uranium-235 is reduced to 15 kilograms. (In doing his calculation Heisenberg implicitly used a uranium tamper, which is why at the lower limit he got a number that is close to this.) The Hiroshima bomb employed about three tampered critical masses of uranium-235. In proposing carbon as a possible tamper Heisenberg and his colleagues were thinking like reactor physicists, not bomb designers.

But the tangle of misconceptions on the part of the German physicists gets worse. Heisenberg goes on to say, "They [the Allies] claim that the whole mass only weighed 4 kilograms." Now he has a real quandary—how to reduce his critical mass by a factor of 4. Wolfgang Pauli had a wonderful phrase, "desperation physics," and it perfectly characterizes the ensuing discussion. Von Weizsäcker, one of Powers's *clairvoyants*, volunteers the silly idea of putting carbon—graphite—into the explosive sphere itself. The rest of the participants sound no more astute. The dénouement comes when one realizes that the 4 kilograms that Heisenberg was citing do not represent uranium at all but plutonium. Heisenberg mixed up the Hiroshima and the Nagasaki bombs. To none of the Germans, including von Weizsäcker, who independently invented the idea of using plutonium as an explosive, does it occur that the 4 kilograms might not be uranium at all. So much for their understanding of bomb physics.

What is one to make of Powers's book in light of all this? Obviously the book, like a critical mass of uranium, should be handled with extreme caution. I do not know what would have happened if Heisenberg had actually been able to build his reactor and then had been confronted with the question of actually building a bomb. There is nothing in his wartime behavior that suggests to me any high moral purpose, so my guess is that, like any good soldier, he would have done what he was told to do. That it never came to that point we can all be grateful.

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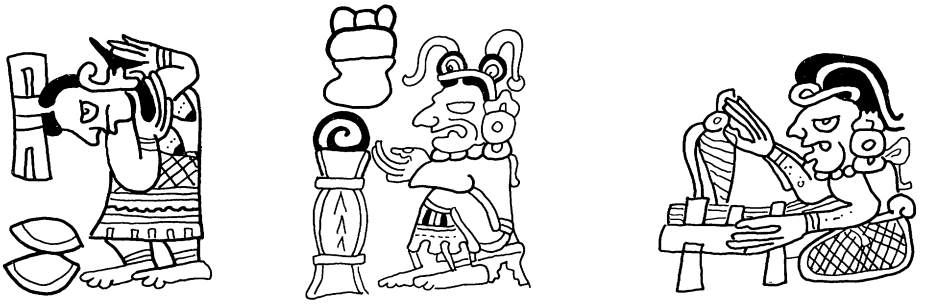
The Maya Pantheon

The Major Gods of Ancient Yucatan. KARL ANDREAS TAUBE. Dumbarton Oaks Research Library and Collection, Washington, DC, 1992. viii, 160 pp., illus. Paper, $18. Studies in Pre-Columbian Art and Archaeology, no. 32.

The ancient Maya of southeastern Mesoamerica conceived of the world of ordinary human beings, animals, plants, and other objects as coexisting with and interpenetrated by a vital supernatural realm pervaded by sacred power and populated by a host of deities and spirits. The often baffling complexity of Maya gods, usually depicted as marvelous mixtures of human, feline, reptilian, and avian features, has contributed to the popular image of the "mysterious Maya." *The Major Gods of Ancient Yucatan* is an excellent new analysis and synthetic interpretation of most of the principal gods of the ancient Maya, clarifying and demystifying their forms and functions in a rigorous, scholarly manner, while simultaneously conveying some sense of the numinous powers they represented for their devotees.

Taube notes in his introduction that there is no "elegant model" by which the manifold deities of the Maya of Yucatan can be organized and interpreted. His method thus is to reexamine methodically the widely used alphabetical classification of Maya gods first established by the German scholar Paul Schellhas (in articles of 1886 through 1904) and subsequently modified by scholars such as Günter Zimmermann, J. E. S. Thompson, Ferdinand Anders, and David Kelley. In his introductory remarks Taube first addresses a recurrent debate regarding whether Classic Maya religion was based on a well-defined pantheon of gods or consisted of a series of shifting, metaphorical depictions of natural forces. Citing the many continuities between Post-Classic and Classic gods outlined in his study, Taube makes a strong case that the Classic Maya worshipped individualized deities, although he notes that the same term that refers to a god (*ku* or *ch'u*) can also refer to the concept of sacredness (as is the case for the Nahuatl term *teotl*).

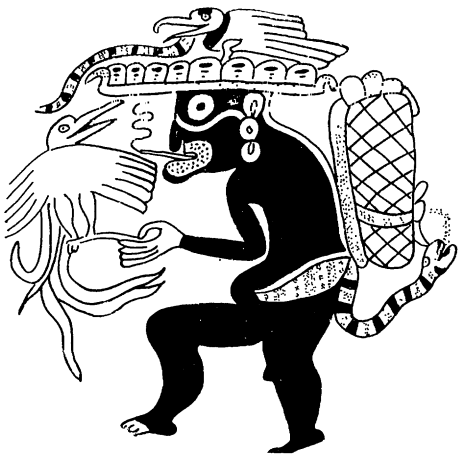


Maya Goddess I, "an aged and frequently clawed water goddess who wears a serpent as a headdress." In these Post-Classic portrayals the goddess is shown (left to right) letting blood from her ear; with offerings; and weaving. "The suggested glyph [for Goddess I], a youthful female head prefixed with the *zac* white sign, is almost identical with the glyph assigned for Goddess O," suggesting that the two may be "young and old aspects of the same being." [From *The Major Gods of Ancient Yucatan*]

The principal value of Taube's new contribution is its successful effort to relate the alphabetical god list, which originally was derived primarily from contextual studies of deity representations in screen-fold manuscripts or "codices," to other, newer sources of evidence. These include recent discoveries in the epigraphy and iconography of Classic Maya sculpture (as outlined in *Science* **256**, 1062 [1992]), as well as a tremendous increase in knowledge of the subject matter depicted on Classic Maya ceramics. Michael Coe and others have demonstrated that such pottery scenes sometimes depict Classic-period forerunners of the mythical heroic twins described in the Quiche Maya epic, the *Popol Vuh*. Taube demonstrates that these and many other deities portrayed in Classic-period art have clear counterparts in the Post-Classic codical representations. Examples include the rain god Chac (God B), who has an axe-wielding prototype in the Classic-period deity Chac-xib-chac (GI of the Palenque Triad); the young maize god (God E), shown emerging from a turtle carapace on Classic ceramics; the young moon goddess (Goddess I); the storm god and lineage patron (God K or *kawil*); and the old mountain god and world sustainer (God N or *pauahtun*). Because he emphasizes the deities of the Post-Classic manuscripts, however, Taube devotes less attention to other important Classic-period gods or personifications of sacred locales (such as the cosmic monster, the *cauac* or *witz* monster, or the jaguar god of the underworld).

The book also provides an overview of foreign deities, such as Xipe Totec, Quetzalcoatl-Kukulcan, and Tlahuizcalpantecuhtli, most of which represent late introductions into the northern Maya region from Central Mexico or the Gulf Coast region during the Post-Classic period (about A.D. 900–1521). The identification of these deities is generally persuasive, although two central Mexican deities, Tlachitonatiuh (earth sun or sun at horizon) and Tezcatlipoca (smoking mirror), originally identified at Chichen Itza by J. E. S. Thompson, are not discussed.

Taube marshals a wide range of epigraphic, iconographic, ethnohistorical, and ethnographic evidence to identify the character and significance of the major deities of Yucatan in a clear and persuasive manner. An ample number of excellent illustrations depict the variations in the gods' hieroglyphic names and pictorial representa-



Maya God L, smoking, with a merchant bundle and long-tailed bird. Traits of God L include agedness, black body coloration, and the bird worn on the head. The bird has been identified as the Moan screech owl, which is closely identified with the underworld and with rain. "God L is not a major deity of the Late Post-Classic period; instead the vast majority of known God L representations appear in early Classic scenes." [From *The Major Gods of Ancient Yucatan*]