S. Chandrasekhar at age six, 1916. [From *Chandra: A Biography of S. Chandrasekhar*]

on astrophysics in America. His scientific energy was prodigious. With Gerard Kuiper he set up 18 courses for the graduate students and proceeded to teach most of them himself. He took up one field of mathematical astrophysics after another, solving outstanding problems in a series of papers and in due course summarizing the field in one of seven authoritative monographs. An elegant lecturer himself, he presided over 1000 colloquia. He served as editor of the *Astrophysical Journal* from 1952 until 1971, maintaining conspicuously high standards. In the meantime he found time to supervise the Ph.D. research of over 50 students, many of whom have gone on to illustrious careers. Few if any of his peers have equaled his contribution to science.

The book closes with a section entitled Conversations with Chandra. After reading the facts of his life, it is most interesting to read Chandra's own views of it. Most surprising are those toward the end, where he says, "I have a feeling of disappointment because the hope for contentment and a peaceful outlook on life as a result of pursuing a goal has remained unfulfilled." He goes on to speak of the distortion and one-sidedness of his life, his loneliness, and his inability to escape from it all. He wonders whether he was justified in imposing that type of life on his wife. Generalizing from his own experience, he says, "It does not seem to me that the pursuit of science results in the feeling of contentment or peace after years of pursuit."

As a person who counts Chandra one of his heroes, I am disquieted that he has not found peace of mind, and I find myself wondering why. Could it have been the humiliation by Eddington early on his career? the reproaches of his father? or, more generally, his decision not to return to India? We may never know, but I admire Chandra for raising the question whether complete dedication to science leads to happiness.

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Cosmologists Queried

Origins. The Lives and Worlds of Modern Cosmologists. ALAN LIGHTMAN and ROBERTA BRAWER. Harvard University Press, Cambridge, MA, 1990. xii, 564 pp., illus. $29.95.

Origins is a collection of 27 lightly edited transcripts of 90-minute interviews with scientists who have made notable contributions to the study of galaxies and cosmology, together with a 49-page introduction to modern cosmology. The scientists were asked to talk about their childhood experiences and education and about the influences that helped shape their research interests and "attitudes about cosmology." Each scientist was also asked a fixed set of questions intended to elicit his or her "reactions to recent developments in cosmology." Finally, each scientist was asked two "philosophical" questions: "If you could have designed the universe any way that you wanted to, how would you have done it?" "Have you ever thought about whether the universe has a point or not?"

The project was intended to throw light on a number of metascientific questions, among them: "How do scientists choose the problems they work on and the questions they ask?" "What decides whether a question is scientific or not, worth worrying about or not?" "Why do some questions gain legitimacy only after their solution?" "How do scientists respond to new empirical results that challenge their previous thinking?" "Do questions about the initial conditions of the universe lie within the domain of science?"

Surprisingly, Lightman and Brawer never return to these questions. They don't analyze or discuss their findings, preferring to "let the interviews speak for themselves." *Origins*, therefore, is more an archive than a study. Still, readers who are curious about how temperamental and sociological factors affect the making of science and of scientists will find much to interest them in the nontechnical parts of the interviews.

I doubt, though, whether nonspecialists will be able to make much of the technical parts. The introduction was intended to be helpful in this respect. It gives a clear but oversimplified description of two or three strands teased from the tangled web of contemporary cosmological research. The scientists, however, break out of the mold that has been prepared for them. They speak freely about the portions of the web that interest them most, often in ways that take issue with the scientific presuppositions of the questions they have been asked and usually in ways that assume a lot of specialized knowledge on the part of the listener. The text cries out for explanatory notes. More vigorous editing of the transcripts could easily have made room for them with no loss of substantive content.

The scientific questions relating to theoretical cosmology focus on the "horizon problem" and the "flatness problem," which are introduced in the following way:

> In the last 15 years, a revolution has occurred in cosmology—associated in part with the application of subatomic physics to theories of the beginning of the universe. . . . One product of the union of subatomic physics and cosmology has been a major modification of the big bang model called the inflationary universe model, proposed in 1980. . . . The attraction of the inflationary universe model comes in large part from its resolution of two outstanding difficulties with the standard big bang model: the so-called horizon and flatness problems. The horizon problem asks why the universe appears to be homogeneous over a much larger region than could reasonably be expected—unless it began that way. The flatness problem raises the question of why the universe began with its gravitational energy and its kinetic energy of expansion so closely balanced [pp. vii–ix].

In fact, particle physicists began to take a professional interest in cosmology immediately after the discovery of the cosmic radio background by Arno Penzias and Robert Wilson in 1965. Andrei Sakharov in 1967 sketched a scenario in which baryon-nonconserving processes might account for the emergence of baryon-antibaryon asymmetry, and hence predict the present temperature of the cosmic radio background, in a universe with initially equal numbers of particles and antiparticles. Baryon-nonconserving processes are allowed by grand unified theories, which also permit neutrinos to have finite rest mass. Since it was becoming clear that primordial nucleogenesis in a hot universe would overproduce helium unless most of the gravitating mass was nonbaryonic, cosmologists and particle physicists looked forward with great excitement to the emergence of a grand unified theory that would in one stroke explain the background radiation and account for the bulk of the gravitating mass in the universe.

During the 1970s these high hopes gradually faded. The simplest grand unified theories were found to underpredict the lifetime of the proton. Massive neutrinos began to seem less than ideal candidates for the invisible gravitating mass. But the heaviest blow came from the simultaneous discovery in 1974, by G. t'Hooft and A. M. Polyakov, that nearly all grand unified theories predict a hugely excessive production of superheavy magnetic monopoles in the early hot universe. It was these and related historical developments (none of which is mentioned by Lightman and Brawer) that set the stage for the series of theoretical studies that culminated in Alan Guth's 1981 paper on inflation. As Steven Weinberg mentions in his interview, particle physicists welcomed inflation primarily because it offered a cure for the fatal disease of over-copious magnetic-monopole production in the early universe.

It is true that Guth also stressed the flatness and horizon problems. But, as several of the theorists remark, the solutions to the flatness and horizon problems offered by the inflationary model are not only less important but also more problematic than the solution of the magnetic-monopole problem. Dennis Sciama (p. 149) gives a characteristically lucid account of an argument he attributes to Roger Penrose: Inflation doesn't guarantee large-scale homogeneity, for "if the small scales are very rough and they're pulled out to larger scales, the larger scales are rough" (p. 148). As for the "the question of why the universe began with its gravitational energy and its kinetic energy of expansion so closely balanced," the need for fine tuning disappears, as Steven Weinberg points out (p. 459), when one talks about spatial curvature rather than the kinetic and gravitational energies of the universe (neither of which, incidentally, has a well-defined meaning in the cosmological context). The question then becomes, Why is the radius of curvature deduced from current estimates of the cosmic mass density comparable in magnitude to the radius of the theoretically observable universe? Inflationary cosmology evades rather than answers this question: it predicts a value of the cosmic mass density five to ten times higher than current estimates.

Lightman and Brawer not only ignore the chief argument in favor of inflationary cosmology. They also ignore what many theorists consider to be the most serious difficulty with any theory that invokes spontaneous symmetry-breaking phase transitions: the so-called cosmological-constant (or vacuum-energy) problem. Every symmetry-breaking phase transition causes the vacuum energy density to decrease by an amount that is immensely greater than the present cosmic energy density. Inflationary cosmologies based on standard particle physics require the cosmic mass density (related to the cosmic energy density by Einstein's mass-energy relation) to decrease, in three independent steps, from an initial value of order 10^{80} g cm^{-3} to its present value, which is certainly less than 10^{-29} g cm^{-3}. Here is fine tuning of an initial condition with a vengeance!

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West Orange Works

Edison and the Business of Innovation. Andre Millard. Johns Hopkins University Press, Baltimore, 1990. xvi, 387 pp., illus. $38.50. Johns Hopkins Series in the History of Technology.

By 1887, 40-year-old Thomas Edison had already accomplished the work of many lifetimes. He had created the electric light, power, and electrical manufacturing industries, made major contributions to telegraphy and telephony, and, with his most original invention, the phonograph, heralded future entertainment and consumer product revolutions. What would he do for an encore?

He would, Andre Millard explains, devote his remaining 44 years to the "business of invention." He would build an "invention factory" at West Orange, New Jersey, ten times as large as any other laboratory in the United States. There he would start by carrying out contract research for other companies, until he had made enough inventions to spawn a new industrial empire.

This central place for invention flew in the face of business wisdom. "Pioneering don't pay," Andrew Carnegie had concluded. Modern experts, including Millard, agree. Invention must be meshed with the needs of sound design, productive manufacturing, and customer-responsive marketing if a company plans to make money.

Edison did not scorn money-making, but he put it in its place. Business or lives should not, he said, be measured solely by "the metronome of money." For him, invention, as both achievement and culture, set the tempo. Money-making only proved the success of past inventions and financed future ones.

The strength of Millard's book is his evocation of this "machine shop culture." Edison sought, against the current of the times, to keep it as central to the process of invention in the 20th century as it had been in the 19th. It was built around experiment-

Manufacture of talking dolls in Edison's Phonograph Works, about 1890. "With [his] dictating machine in trouble, Edison looked to the doll to keep the business afloat. . . . There was nothing wrong in the marketing strategy; the talking doll proved to be so popular that orders soon out-stripped supply. The problem was in the small phonograph movement inside the dolls. The diaphragm/stylus assembly simply would not stay in the fine groove of the wax record. Consequently most of the dolls failed to work properly, steadfastly refusing to talk for their owners. One dealer reported that 188 dolls were returned out of 200 sold." [From *Edison and the Business of Innovation*]