Ralph Baierlein is the Charlotte Ayres professor of physics at Wesleyan University. His book on statistical mechanics, Atoms and Information Theory, *published in 1971, grew out of his reading of Jaynes and of Richard T. Cox. (Professor Cox's book,* The Algebra of Probable Inference, *reviewed in this column by Jaynes in 1963, amplifies a paper published in this journal in 1946.) Star formation and turbulence are Professor Baierlein's current interests.*

E. T. Jaynes: Papers on Probability, Statistics and Statistical Physics. Edited by R. D. Rosenkrantz. 434 pp. D. Reidel Publishing Company, Dordrecht, Holland, 1983. Price: $49.50. (Reviewed by Ralph Baierlein.)

Edwin Jaynes is always perceptive and provocative. Collected here are papers from 30 years of his thought and argument. Two threads run through the selection; each warrants a paragraph of description.

The first thread is Jaynes's espousal of Laplace's view of probability theory: probability theory is common sense reduced to calculation. The probability of A, given B, is the rational degree of belief in proposition A, given the evidence B. This logical relationship is amenable to numerical representation, and the ensuing numerical probabilities satisfy the same algebraic relationships as do probabilities which are conceived strictly as frequencies. If any frequencies are actually appropriate in the problem at hand, they will be calculable from the probabilities as conceived logically. In short, Jaynes advocates the Bayesian view of probability for physics and for scientific application in general.

The second thread is uniquely Jaynes's: the maximum entropy principle for determining probabilities. The algebra of probability theory tells us how to combine probabilities and how to generate new probabilities from old ones. But how do we get the original probabilities? When the data at hand are so meager that they do not by themselves uniquely determine the probabilities, how do we find the proper probability distribution? Jaynes's response is this: From among the probability distributions that satisfy the evidential constraints, we should select that probability distribution—the set $\{p_i\}$—which exhibits the maximum value of the entropy, proportional to the function $-\Sigma p_i \ln p_i$. In this way we avoid prejudice and select the broadest, most noncommittal of the distributions that are consistent with the data. Whereas isolated applications of this principle, in one guise or another, go far back in the history of physics, no one else has championed the principle as has Jaynes.

My own acquaintance with Jaynes's work began in 1965 with an article in this journal, "Gibbs vs Boltzmann Entropies." I loved it and looked around for more. There were earlier papers to be found, and many more have appeared since, but they do not run like a series in *The Saturday Evening Post* or even the *Physical Review*; it is more nearly true that the papers never appear in the same journal twice. The editor, Roger Rosenkrantz, has done the community a service by collecting a baker's dozen in this volume. His introduction is a clear, informative one, and Jaynes himself has written brief introductions to each paper, placing each in context and adding the comments that hindsight or consequences suggest.

Where ought a reader to start in this collection? That depends, of course, but the beginning is unlikely to be the best place. I can recommend the place where, in effect, I began in 1965. The paper is short, not heavily mathematical, crammed with insight, and provocative. Let me quote a paragraph to make the last point:

> From this we see that entropy is an anthropomorphic concept, not only in the well-known statistical sense that it measures the extent of human ignorance as to the microstate. *Even at the purely phenomenological level, entropy is an anthropomorphic concept.* For it is a property, not of the physical system, but of the particular experiments you or I choose to perform on it.

The paper is quintessentially Jaynes.

The next step for the reader might be two years back in time to the Brandeis lectures, where the maximum entropy formalism is laid out succinctly. Or one could go forward a couple of years to the Delaware lecture, "Foundations of Probability Theory and Statistical Mechanics." Another quotation will best convey the spirit of things:

"At this point, confusion entered the subject [Boltzmann's equation], and it has never left it. For Boltzmann then retreated from his original position, and said that he did not intend that $f(x,p,t)$ should represent necessarily the *exact* number of particles in various regions.... It represents only the *probable* number of particles; or perhaps the *average* number of particles; or perhaps it gives the *probability* that a given particle is to be found in various regions....

Unfortunately, neither Boltzmann nor anybody else has ever become more explicit than this about just what Boltzmann's f, and therefore Boltzmann's H-theorem, means....

If you think my characterization of the situation has been too laconic, and unfair to many honest seekers after the truth, I invite you to examine a recent review article on transport theory. On page 271, the author states that "The Boltzmann distribution function...[$f(\mathbf{x},\mathbf{v},t)d^3x\, d^3v$] is the (probable) number of particles in the positional range d^3x and the velocity range d^3v." On page 274 this is altered to: "The quantity f, the Boltzmann distribution function...is, roughly speaking, the average number of particles in a cell in the x–v space (the μ-space). f refers to a single system. A more precise definition of f can be obtained through the use of the master function P." Consulting this master function, we find that neither the definition of P, nor its connection with f, is ever given. This, furthermore, is not a particularly bad example; it is typical of what one finds in discussions of Boltzmann's theory."

Time and again Jaynes counters such muddiness by emphasizing precision of definition and strict logic of deduction. It is an example for us all.

(Actually, Jaynes is not entirely fair to the author of the review article. The author did define the function P, and a strict relationship with f can be traced. But, perhaps in the enthusiasm of polemical flourish, that was overlooked. This sets an example that need not be followed.)

Just as Jaynes is a perceptive critic of the Establishment, so should the reader be a perceptive critic of the collection. For example, there is the objection to the maximum entropy principle—an alleged inconsistency—formulated by Abner Shimony and Kenneth Friedman. Although Jaynes and other proponents have addressed the issue, I have yet to see a compelling rejoinder. (Jaynes's response appears in Chap. 10, "Where Do We Stand on Maximum Entropy?," a comprehensive tableau of the scene in 1978.) Furthermore, Jaynes emphasizes that probability distributions depend on what we know, on the evidence at hand. Right on, but then the canonical distribution is almost always derived by Jaynes, via the maximum entropy principle, in the context of an expectation value constraint on the total energy. Rarely—perhaps never—do we literally know the energy; what we know is the temperature. The realistic situation was addressed by Jaynes already in 1957 (in the paper reprinted as Chap. 2), but the treatment is dismayingly awkward. To be sure, the fault may lie not with the probability theory but rather with the inherent subtlety of the temperature concept, a subtlety we are wont to overlook, ignore, or deny. Still, a method which claims the exponential form of the canonical distribution as a very natural end result ought to be able to derive the canonical distribution in a way that is realistic, efficient, and seen as persuasive by an undergraduate.

How to formulate irreversible thermodynamics and how to select "uninformative" prior probability distributions are two major technical areas that the collection addresses extensively. The "relevance function" (in Chap. 10) neatly codifies the way in which information about the history of one observable affects the prediction of another observable. In Chap. 8 Jaynes uses invariance arguments to generate a unique solution to Bertrand's problem: the distribution of chord lengths when a straw is repeatedly thrown at random onto a circle. These, however, are items of note for the specialist. My greater concern in this review is the influence that the collection can have on our probabilistic framework and on education. A bright undergraduate may find in the collection an entire new world of thought, a new way of looking at old puzzles. The book belongs in every college library—and cataloged such that physics students stand a good chance of running across it.