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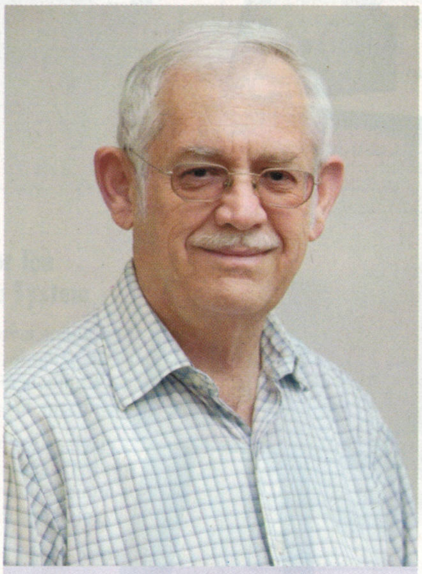
Jacob David Bekenstein

Jacob David Bekenstein died of a heart attack on 16 August 2015 in Helsinki, Finland, where he was visiting to present a seminar. He had made major contributions to many areas of physics, including a proof of the nonexistence of scalar "hair" on a black hole, bounds on entropy and information, and a proposal for a modified theory of gravity that could provide an alternative to the presence of dark matter. As further described below, his most significant and pioneering achievement was his attribution of entropy to black holes, which laid the foundation for the entire subject of black hole thermodynamics. Widely recognized for his accomplishments, Bekenstein received the 1988 Rothschild Prize in Physical Sciences, the 2005 Israel Prize, the 2012 Wolf Prize, and the 2015 Einstein Prize of the American Physical Society.


Jacob David Bekenstein

Bekenstein was born on 1 May 1947 in Mexico City. His family moved to the US in the early 1960s, first to Texas and then to New York. He attended the Polytechnic Institute of Brooklyn, where he received an MS degree in 1969. He then attended Princeton University and received his PhD in 1972, under the supervision of John Wheeler. After a two-year postdoc at the University of Texas at Austin, he accepted a faculty position at the Ben-Gurion University of the Negev in Beersheba, Israel. He moved to the Hebrew University of Jerusalem in 1990.

The period from 1969 to 1972, during which Bekenstein was at Princeton, was an exciting time for the development of the theory of black holes. In particular, the "no hair" theorems, establishing that stationary black holes had no other attributes than their total mass, angular momentum, and electric charge, were in the process of being proven. One implication was that a black hole cannot retain a memory of the baryon number or lepton number of the matter that formed it. Thus the laws of baryon and lepton conservation must be transcended (that is, in practice, violated) when a black hole is formed—a rather radical idea in the pre-grand-unified-theory days when those laws were generally believed to be fundamental. Wheeler fully accepted the transcendence of baryon and lepton conservation. However, he was not comfortable with the idea of a similar transcendence of the second law of thermodynamics: If matter containing entropy is dropped into a black hole, the total entropy in the universe as determined by observers outside the black hole decreases.

Another major development during that time period was the discovery by Roger Penrose that energy could be extracted from a rotating black hole. Demetrios Christodoulou soon showed that the amount of energy extraction was limited by a certain irreversibility in that process. Stephen Hawking then established that the irreversibility was a consequence of the fact that the surface area of a black hole's event horizon could never decrease with time.

It was against that backdrop that Bekenstein began to look into assigning an entropy to black holes. As a fellow student with Bekenstein at Princeton, I regarded the project as foolhardy and highly unlikely to lead to anything fruitful. Although there was a (seemingly superficial) analogy between the second law of thermodynamics and the area-increase theorem, at that time no other relationship between black holes and thermodynamics was known, and it was hard to see what could be done on the subject beyond making a few loose arguments. Nevertheless, Bekenstein fully applied his considerable analytical powers to the issue. He soon settled on horizon area (rather than on some other monotonic function of area) as representing black hole entropy and deduced that the entropy must be inversely proportional to Planck's constant. The fact that black hole entropy is proportional to area rather than volume underlies all modern ideas of "holography" in theoretical physics.

Bekenstein incorporated black hole entropy into a generalized second law—that the sum of the entropy outside black holes plus the newly proposed entropy of black holes must never decrease—and carefully considered processes that might violate it. To avoid violations, he found that he had to assume limitations on how close to the black hole's horizon one could lower matter. Those ideas eventually evolved into a proposal for a bound on the entropy-to-energy ratio of matter confined to a region of given size.

Bekenstein's proposed black hole thermodynamics was not fully consistent because, mathematically, the black hole would need to be assigned a nonzero temperature, but it seemed clear at the time that the physical temperature of a black hole must be absolute zero. Nevertheless, partly inspired by Bekenstein's work, James Bardeen, Brandon Carter, and Hawking showed that black holes actually satisfy mathematical analogues of all the laws of thermodynamics. The final major breakthrough occurred when Hawking showed that as a result of a quantum particle creation process, black holes radiate at a finite temperature. Black hole thermodynamics was now fully consistent, both mathematically and physically. Furthermore, Hawking's formula for the temperature of a black hole allowed one to fix the precise numerical factor in Bekenstein's formula for black hole entropy.

Bekenstein was very modest as a graduate student and was equally modest as a winner of the Wolf Prize. He avoided the limelight as much as was possible for a scientist of his stature. He was as tenacious as any physicist I have met in defending his ideas, but he was never a "salesman." He was an exceptionally original and deep thinker, but he always approached problems in a direct and down-to-earth way. His idea that a black hole should be assigned an entropy proportional to its area is a truly profound legacy to theoretical physics.

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