contributions to both physics and society. In physics it covered his work in astro-, nuclear, and condensed matter physics and in quantum electrodynamics. Perhaps not as well known were his extraordinary contributions to atomic physics. Our recent article discusses this aspect of his voluminous output.[1] It covers his seminal work on the stability of the negative hydrogen ion; details of his atomic-physics calculations regarding the Lamb shift; aspects of his important work in collision theory, especially his work in stopping power; several important aspects of atomic physics related to crystalline solids; and his books and review articles in the field.

Reference

1. M. Inokuti, B. Bederson, *Phys. Scr.* **73**, C98 (2006).

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I am a student from India now working on my PhD in chemistry at Emory University in Atlanta, Georgia. I am also deeply interested in the history of modern physics, and Hans Bethe was one of my favorite scientists. Saddened by his passing, I wrote a 12-page, spur-of-the-moment biography, mostly from my memory of the things I had read and heard about him. To me, Bethe will always be an exceptional example of the ideal scientist-citizen. He set the standards for the rest of us both in his scientific work and in his efforts towards arms control.

The influence of science and scientists really transcends time, nationalities, and generations. Every person on the street may not be familiar with Bethe and his work, but I am certain that he and others of his stature have, in many subtle ways, inspired young people like me to pursue careers in science and to be more conscientious citizens of the world. I believe that this often unseen, subtle, and deep influence of science and scientists fuels the engines of conscience and progress. Those who want reassurance about the enduring benefits of science as an instrument of rationality and social enlightenment need not look very far.

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Gottfried comments: I erred in not including an article on Hans Bethe's work in solid-state physics in the special issue. PHYSICS TODAY published "A Conversation About Solid-State Physics" by Bethe and N. David Mermin in its June 2004 issue (page 53). And fortunately, an excellent article by Mermin and Neil W. Ashcroft was published recently: "Hans Bethe's Contributions to Solid-State Physics," in *Hans Bethe and His Physics* (World Scientific, 2006, p. 189).

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NASA's mission of space exploration: Some fine points

Roger Blandford's Reference Frame titled "Exploring the Universe" (PHYSICS TODAY, April 2005, page 10) summarizes many of his concerns regarding NASA's plans for astronomy and space science in the context of President Bush's vision for space exploration. As Blandford notes, given the long list of ambitious space telescopes in NASA's plans, clearly priorities need to be set, and some astronomers worry that "programs with a connection to life will be favored over fundamental investigations in the inanimate, physical sciences." The president's vision explicitly calls for NASA to "conduct advanced telescope searches for Earth-like planets and habitable environments around other stars"[1] and categorizes future NASA missions such as the *Space Interferometry Mission* and the *Terrestrial Planet Finder* as high-priority and life-oriented. Blandford states, "The discovery of extrasolar planets, 150 and counting, demonstrates that our solar system is unrepresentative with immediate consequences for the quest for extraterrestrial life." This statement would seem to weaken the case for placing high priority on *SIM* and the *TPF*. However, Blandford draws the incorrect conclusion that the more than 160 current extrasolar planet candidates[2] imply that our solar system is unrepresentative and hence that the search for habitable planets may be extraordinarily difficult.

Finding an exact analogue of our planetary system is highly unlikely, given the chaotic processes involved in planet formation, yet scientists have no reason to believe that planetary systems similar to our own are not commonplace. The 160 known extrasolar planetary systems were nearly all discovered by Doppler spectroscopy and photometric transits, methods that strongly favor the detection of gas-giant planets with short-period orbits. Such planets are indeed likely to prevent the formation and stability of habitable, Earth-like planets, but they orbit only about 10% of nearby Sun-like stars. For the remaining 90% or so of such stars, the planetary census takers have not been collecting high-precision data long enough to detect Jupiter-like planets on the 12-year-period orbits that would herald the presence of exact solar-system analogues. In fact, the recent discovery of more than half a dozen super-Earths, planets in the range of 5 to 15 Earth masses, implies that Earth-mass planets are commonplace.

NASA's *Kepler* mission, slated for launch around 2008, will determine the frequency of Earth-like planets through an exhaustive transit survey of 100 000 stars.[3]

References

1. See http://www.nasa.gov/pdf/55583main_vision_space_exploration2.pdf.
2. See the International Astronomical Union's Working Group on Extrasolar Planets website, http://www.dtm.ciw.edu/boss/iauindex.html.
3. See http://www.kepler.arc.nasa.gov.

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Blandford replies: First, in remarking about the ubiquity and diversity of extrasolar planets, my (unstated) point was that the field of astrobiology had been greatly enriched by these discoveries and that the options for life developing elsewhere in the universe had been increased, not decreased. More important than what I think, though, is that many young people and universities had invested in this field. I apologize if I conveyed the opposite view.

Second, when I wrote this piece, NASA was a very different organization from the one it is today. For example, I think its mission statement—"to improve life here, to extend life to there, to find life beyond"—distorted the science program. Now, NASA's stated mission is "to pioneer the future in space exploration, scientific discovery, and aeronautics research," which, to me, is a better description of what NASA should be doing.

Third, I stand by my assertion that choices will have to be made between proceeding with exciting missions like the *Space Interferometry Mission* and the *Terrestrial Planet Finder*, and with equally compelling investigations drawn from cosmology and high-energy astrophysics. I believe the scientific community should be heavily involved in these choices rather than sidelined as NASA has chosen to make it this past year.

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Scientist as artist: The role of imagination

In the Opinion piece "Being True to Our Own Imaginations" (PHYSICS TODAY, November 2005, page 48), Gregory Benford makes the case that "among reviewers, 'speculation' is a word mostly deployed as a pejorative." Perhaps reviewers should first be required to read some of the works of Robert Scott Root-Bernstein. Readers may find the quotation below interesting.

> Most eminent scientists agree that nonverbal forms of thought are much more important in their work than verbal ones. This observation leads me to propound the following hypothesis. The most influential scientists have always nonverbally imagined a simple, new reality before they have proven its existence through complex logic or produced evidence through complicated experiments.
>
> There is a simple reason for this phenomenon. Experiment can confirm or disconfirm the tentative reality that imagination invents, and experiment can suggest the need for the invention of a new reality to account for anomalies to the existing one. But experiment cannot, in and of itself, produce conceptual breakthroughs or be used to explain data.
>
> Logic is similarly limited. Indeed, philosophizers of science are almost universally agreed that logic can be used to test the coherence of theories and to provide proofs of existing ideas, but logic does not produce the ideas to be tested. One must be able to imagine that which is to be tested and how to test it before one can even begin to employ logical, experimental, and verbal forms of thought.
>
> Furthermore, I suggest that this ability to imagine new realities is correlated with what are traditionally thought to be nonscientific skills—skills such as playing, modeling, abstracting, idealizing, harmonizing, analogizing, pattern forming, approximating, extrapolating, and imagining the as yet unseen—in short, skills usually associated with the arts, music, and literature.[1]

Picasso might have made a great analytical physicist.

Reference

1. R. Root-Bernstein, *Trans. Am. Phil. Soc.* **75**(6), 50 (1985). For further reading, see R. Root-Bernstein, M. Root-Bernstein, *Sparks of Genius: The Thirteen Thinking Tools of the World's Most Creative People*, Houghton Mifflin, Boston (1999).

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Benford replies: Kent Eschenberg's quotation from Robert Root-Bernstein makes a valuable point. Scientists are more like artists than bank clerks (though T. S. Eliot was both). Allowing for a broad range of personality types could enhance our sciences and avoid the narrow constraints that trap many into stylized thinking.

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Recent graduate aims to buck conformity trend

I'd like to say thank you for two items PHYSICS TODAY has published recently: Don Howard's "Albert Einstein as a Philosopher of Science" (December 2005, page 34) and Lee Smolin's "Why No 'New Einstein'?" (June 2005, page 56). Both of these pieces have resonated with me.

As the recent recipient of a bachelor's degree in physics, I read in these articles an encapsulation of my frustration with my undergraduate experience. I came into physics expecting that creativity and independent thinking would be celebrated virtues, but to my disappointment I learned that this was not the case. I came to assume that the problem was my young idealistic naiveté. However, on reading Smolin's and Howard's articles, I learned I was not alone in my early expectations. I now hope that during my career I can contribute to and encourage a greater respect for creative and independent thought in physics.

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