be taken seriously." Such a frank admission of the risk involved in doing physics is rare.

A key element that determines a person's ability to make such leaps is the comfort level with being different—even iconoclastic. Minorities are by definition outside the majority culture. Hence, taking risks that would set us further apart from our peers does not feel unnatural. That is, it is easiest to go against the grain when you are not part of the grain!

The outsider status can be used as a great motivating factor to beat the system. Consider, for example, the 1965 physics Nobel laureate and boyhood genius Julian Schwinger. The jacket of Schwinger's 1970 book *Particles, Sources, and Fields* (Addison-Wesley) begins with the quip, "If you can't join 'em, beat 'em." Clearly his outsider status was heartfelt. The 1905 physics Nobel laureate Philipp Lenard, well-known as an anti-Semite, denounced relativity as being derived from an "alien spirit" and dubbed the whole of Albert Einstein's work as part of a "Jewish fraud." Undoubtedly what Lenard recognized, in a through-the-looking-glass way, is that Einstein's minority or outsider status may have been the very thing that enabled him to construct the most brilliant and important theory in physics to date. The "alien spirit" that catalyzed Einstein's derivation of relativity may be the very same outside-the-box mindset that illuminates the thinking of at least some minority theoretical physicists today.

So to answer Roberts's question, central to advancing physics is the ability to be an outsider. For minority physicists, a tendency toward outsider thinking is not fabricated. It is part of who we are, and it is the very thing that is unique to our experience.

It's now 2016, and we have a black president, yet those uninformed comments come from people who are supposed to be the top legal minds in the country. At the very center of what should be a prudent, deliberate consideration of delicate legal matters that affect millions of lives, we find instead insensitive stereotypes that can only detract from the ultimate goal of justice.

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John Bell, relativistic causality, and the arrow of time

Reinhold Bertlmann's reminiscences of John Bell (PHYSICS TODAY, July 2015, page 40) are a pleasure to read and faithfully summarize the generally accepted wisdom on the topic. However, the article ends at a seemingly insurmountable theoretical impasse: the conclusions of Bell's 1980 review describing the apparent incompatibility of quantum correlations with Lorentz invariance. It would perhaps be preferable to conclude on a more optimistic note, by emphasizing the tacit underlying assumption—the causal arrow of time. After all, the quantum correlations are incompatible not with Lorentz invariance per se but with relativistic causality, a time-asymmetric notion. The culprit, apparently, is in the manner that time asymmetry is introduced into the context of a microscopic theory.

Bell himself fully acknowledged the relevance of causality in his 1990 review of the topic,[1] though he remained unwilling to consider the alternative of retrocausation. He clarified that the "locality" of local realism is merely shorthand for "local causality." In his concluding paragraph he wrote, "The more closely one looks at the fundamental laws of physics the less one sees of the laws of thermodynamics. The increase of entropy emerges only for large complicated systems, in an approximation depending on 'largeness' and 'complexity.' Could it be that causal structure emerges only in something like a 'thermodynamic' approximation, where the notions 'measurement' and 'external field' become legitimate approximations?" That is the question Bell left us with.

Is there hope for a more palatable theoretical description?[1] Bell's theorem tells us that it would require either abandoning local causality or abandoning the causal arrow of time altogether, perhaps replacing it with a weaker temporal arrow, an arrow of information or entropy. At the level of a simplistic toy model, an explicit retrocausal (but otherwise local) formulation can reproduce Bell-type correlations.[2] The challenge remains to formulate a general retrocausal and spacetime-local description of quantum phenomena. Such a reformulation of quantum theory, if achieved, is likely to have important ramifications, perhaps comparable to those following from Feynman's development of path integrals.

References

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2. N. Argaman, *Am. J. Phys.* **78**, 1007 (2010).

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▶ **Bertlmann replies:** In analyzing Bell's theorem, Nathan Argaman emphasizes the tacitly assumed time asymmetry, which becomes the "culprit" in the context of a microscopic theory. John Bell certainly was aware of retrocausal formulations, where the causal arrow of time was abandoned, but he did not consider them as alternatives to local hidden-variable theories. The reason was simply that Bell, like Albert Einstein, did not accept the possibility that an effect might happen before the cause.

Sticking to his "no signals faster than light" idea, Bell demonstrated that ordinary quantum mechanics is not locally causal. We have to accept that nonlocal structure of quantum mechanics, which is experienced in nature.

In Argaman's retrocausal model, the propagation of information from the apparatus backward in time to the source is allowed, and thus no instantaneous action at a distance is needed. Therefore, Argaman may conclude that Einstein's spooky action occurs in the past rather than at a distance.

Since the variables, carrying information that has propagated into the past, must not be accessible on a macroscopic level, doesn't Argaman's retrocausal model just shift the problem from "nonlocality" to the arrow of time? Nevertheless, it is an interesting interpretation of an experiment like Einstein-Podolsky-Rosen and Bell.

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