

moral aspect of quantum mechanics."³ In particular, Nauenberg's comment that "experiments have revealed that the nature of reality in the quantum world is different from our experience in the classical world" is, in my opinion, the lesson we have to learn from Bell inequalities.

I do not appreciate so much Nauenberg's example of the helium atom since it distracts from the issue of nonlocality. In fact, it is at macroscopic distances where the "puzzle" arises and not at atomic distances of separation.

I have a confession: I am not the realist one might expect after reading Bell's article "Bertlmann's socks and the nature of reality"; the world in its very foundations is much more abstract than we think with our "anschauliche" (intuitive) concepts, to borrow Werner Heisenberg's term. My personal feeling is that Bell's theorem, which reveals an apparent nonlocality in nature, points to a more radical conception whose onset we do not yet have.

References

1. J. S. Bell, *Speakable and Unsayable in Quantum Mechanics*, 2nd ed., Cambridge U. Press (2004), p. 67.
2. R. A. Bertlmann, *J. Phys. A* **47**, 424007 (2014).
3. J. S. Bell, M. Nauenberg, in *Preludes in Theoretical Physics in Honor of V. F. Weisskopf*,

A. De-Shalit, H. Feshbach, L. Van Hove, eds., North-Holland (1966), p. 279.

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"Salty" conversation

The "Salty solutions" Quick Study by Greg Thiel (PHYSICS TODAY, June 2015, page 66) was encouraging for the progress it described in desalinating seawater by reverse osmosis (RO). There is, however, some confusion with the thermodynamics. Thiel does recognize that not all kilowatt-hours are created equal, and the electrical energy (work) to drive the RO pump is the highest-grade energy, as compared with the low-grade heat that drives an evaporative process. He lists energies for RO in kWh_e (kilowatt-hours of electrical work) per cubic meter of fresh water and compares that with the kWh_e of heat required for thermal evaporation processes, but there is no specified conversion or equivalence factor. Is it based on the Carnot equation (for an assumed temperature difference) or on some practical thermodynamic cycle such as Rankine? A conversion factor is fundamental if the reader is to make any useful comparison.

Permit me also to raise a practical point. We generally use an engine, a water or wind turbine, or a photovoltaic array to generate electricity, whereas heat is readily available from solar thermal collectors or geothermal sources. Some may even be virtually free, such as waste heat from another process or industry. The economic choice, therefore, between RO and thermal evaporation may not always favor RO despite its numerically lower kWh_e input number. The decision would properly depend on the forms of energy available to a particular desalination plant.

In no case other than a survival emergency would it make sense for either process to run on fossil-fuel combustion, since the resulting carbon dioxide emissions would only exacerbate the climate change that is often at the root of the drought that the desalination plant is supposed to alleviate.

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■ **Gregory Thiel presents** an informative look at the technology and economics of seawater desalination through reverse osmosis. California, evidently, is

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moving strongly toward such desalination to deal with its water shortages.¹

Two issues spring to mind, however—one environmental, the other societal. What is to be done with the concentrated toxic salty brine produced by seaside desalination plants? I'm reminded of the still-existing problem of nuclear waste disposal. Also, through desalination, millions worldwide will no doubt benefit from access to clean, fresh water. Would that not then exacerbate the problem of population growth, which, as Thiel says, "threaten[s] to throttle our most essential, life-sustaining resource" in the first place? There are significant repercussions, I think, and no quick technological fixes to deal with them.

Reference

1. California Water Boards, <http://www.waterboards.ca.gov>.

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■ **Thiel replies:** When thinking about potential toxicity, which Neal Reid mentions, it's key to remember that almost all the material in the brine originated in the ocean. Nevertheless, ensuring environmentally friendly disposal continues to be an active area of research, and mod-

ern outfalls are very effective at dispersing the brine flow so as to minimize local increases in the concentration of salts and other dissolved compounds. A study for the Carlsbad desalination project in California concluded that properly designed outfalls have "impacts that extend only a few tens of meters from the discharge."¹ The Carlsbad plant also mixes the reverse-osmosis brine with seawater used for cooling a colocated power plant prior to discharge, which reduces its salinity before it hits the ocean. And as for the comparison to nuclear waste, let's not forget that the diffusion time for the salt in the disposed brine is orders of magnitude less than the half-life of radioactive waste!

To answer Jonathan Allen's concern, the kWh_e values given for the evaporative systems are exergetic values of the heat input. That approach uses the Carnot efficiency between the desalination system's top temperature, which often reaches 70 °C, and an ambient temperature of 25 °C to convert between heat and work. The cost of the thermal energy input itself may be less than for electricity, but the costs associated with constructing, for example, a solar-thermal collector or a heat exchanger required to use waste heat can be signifi-

cant. Lower energy consumption may not imply lower cost, but reverse osmosis is far and away the dominant choice of recent installed desalination capacity.

Desalination powered by renewable energy is a topic of great interest to many in the desalination community—myself included!

Reference

1. S. Jenkins et al., *Management of Brine Discharges to Coastal Waters: Recommendations of a Science Advisory Panel*, tech. rep. 694, Southern California Coastal Water Research Project (March 2012), p. ii.

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A last word on quantum Darwinism

In the opening paragraphs of "Quantum Darwinism, classical reality, and the randomness of quantum jumps" (PHYSICS TODAY, October 2014, page 44), Wojciech Zurek invokes an analogue to Schrödinger's cat and describes how the environment-driven process of decoherence removes the interferences that would otherwise exist between the live and dead states. He thus explains how

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