ling!) are quite beside the point.

Counterexamples. I have been sent many spurious counterexamples, with the *ar* either unaccented or followed by a vowel or a second *r*. Only slightly more to the point, I have been told of the villages of Warkentin, Warkton and even simple Wark, all, unfortunately, in lands where they do not speak standard American. A dozen people have brought Newark, Delaware, to my attention. Fortunately my colleague Barbara Cooper was born and raised there. "Where were you born and raised?" I asked her. "NEWark," she replied. "Where?" I pressed. "NEWark," she maintained, clearly rhyming the clearly *unaccented* second syllable with *ark*. Only one counterexample has caused me concern: *Edwardian*. I admit to always having pronounced it to rhyme with *card*. All my English friends claim it rhymes with *ward*, but by my own rules their opinions don't count. Most Americans never utter the term at all. Until somebody convinces me otherwise, I'm adding it to the list of words I've somehow managed to mispronounce all my life. Should this position become untenable I plan to fall back on the fact that proper names are notorious for defying general rules.

Quarks as boojums. For more on the subject than he could have dreamt of, I refer Carsten M. Haaland to chapter 1 of my book *Boojums All the Way Through* (Cambridge University Press, 1990). While the phenomenon of confinement might suggest that quarks do indeed qualify as boojums, closer inspection reveals that quarks are confined to remain near each other, while boojums are confined to remain near the surface of the helium-3 drop or, in more recent reports, the nematic bubble. This is a pity, since the hunting of the Snark can easily be read as a prophetic vision of things to come. The man who announces the arrival at "just the place for a Snark" is called Bell-Man, and three is taken early on as the number to reason about. My own *Hunting of the Quark* (unpublished) ends with the shattering revelation that the Quark is a Boson, an altogether more alarming denouement.

Expert opinion. I thank Margaret M. Bishop for endorsing my analysis. I have also had an encouraging correspondence with Geoffrey K. Pullum, a linguist in the distinguished department at the University of California, Santa Cruz, who commended the way I marshaled the evidence. "It was when you discovered rule interaction . . . that I realized I was dealing with someone who could have been a phonological theorist," he added. "Too bad physics snapped you up."

On the other hand I recently ran into V. F. Weisskopf at a reception in Ithaca. "I thought your last column in PHYSICS TODAY was silly," he said, drawing out the last word into a verbal stiletto.

"Well," I stammered, "an eminent linguist wrote me to say that my methodology was remarkable for an amateur."

"Linguistics," said Viki, "is also silly."

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7/94

Photovoltaics' Promise Still Less Than Sunny?

We read Jack L. Stone's well-written article "Photovoltaics: Unlimited Electrical Energy from the Sun" (September 1993, page 22) with much interest. Having been both advocates and critics of solar energy over the past 20 years, we believe Stone overlooked an important point. He implies that solar energy only needs to compete 1:1 against the consumer price of energy from fossil or nuclear power plants. Unfortunately, this does not recognize an important economic fact of life: A standby power generator is required for any intermittent power producer controlled by externalities.

Solar energy, operating only during bright daylight hours, requires a standby fossil, nuclear or hydropower plant in the power grid. The alternative of scaling back demand ("gray-out") on cloudy days or at night is hardly acceptable in a modern competitive society. A very large-capacity energy storage subsystem could in theory span conceivable periods of bad weather, but at considerable added cost. Storage to back up the solar component would need to hold several days of reserve power at a minimum. If solar power were eventually to replace fossil fuels (because of depleted resources or "greenhouse" pollution) or nuclear power (because of waste products or safety concerns), the combined output of wind, wave and solar energies would leave an industrial society at great risk unless energy storage were sufficient to bridge a potentially immense demand gap. Hydro-storage dams would be inadequate and are socially unacceptable. Batteries are expensive and have too short a deep-discharge lifetime. Exotic energy storage concepts such as chemical storage in a reversible storable cycle (granular aluminum), fly-

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wheels or superconducting magnets are only dreams at this point.

An alternative would be to have a huge solar generating system spread across the entire United States, so large that when one part of the country was cloudy another could pick up the deficiency. Again, the economic impacts would be serious.

This investment in backup energy storage or generating facilities somewhere in the national grid becomes part of the cost burden faced by solar and wind power. Their true value therefore is only the fuel conserved in the national power system during periods when they are making their contribution. However, the situation is even more adverse, because part of the backup system must be on "spinning reserve" owing to the time needed to bring a system up to required output level.

Merely equaling the consumer price of conventionally produced electrical energy is therefore not sufficient by a large margin to make solar energy competitive. The value of fossil fuel saved is but a small fraction of the consumer price; the value of nuclear fuel saved is even smaller. Solar electrical power indeed has a large hurdle to cross before it can become a major factor in the national energy picture.

ADEN B. MEINEL
MARJORIE P. MEINEL
10/93 *Santa Barbara, California*

Although Jack L. Stone's article "Photovoltaics: Unlimited Electrical Energy from the Sun" presents some useful information regarding the status of photovoltaic technology, it is all too reminiscent of similar articles that were abundant in the 1970s. It does not critically define the subject. I shall restrict myself to just three of its deficiencies.

Start with the title. "Unlimited energy" is not what is needed. Peter Kapitza pointed out, roughly 20 years ago in *New Scientist*, that what consumers need to run compact devices is power flux (energy per area per time). The fundamental difficulty with solar technology is that the peak solar-power flux is 4–5 orders of magnitude smaller than demands require and other technologies can supply. Therefore *inexpensive* impedance-matching devices are needed to efficiently bring approximately 1 kW/m^2 up to the 1 GW/m^2 that an ordinary household circuit delivers. The article passes these over. They are not easily designed to efficiently cover the range from zero to a peak voltage.

Next, Stone states that "the bottom line—the cost per watt—is more important than the efficiency." This is not true in at least two cases: one, when the efficiency approaches zero; the other when the cost of capital (the real interest rate) is high. Any utility that I would care to invest in would also carefully consider how the return on investment varies with the parameters, a highly nontrivial problem.

Finally, something is wrong with figure 6. If I cross-plot the blue line and I am satisfied with about 8% efficiency, my modules will cost me nothing. The other cost lines present similar absurdities.

In view of these difficulties, together with others, Stone's conclusions are questionable, and one must wonder when, if ever, large-scale photovoltaic solar power will stop being "politically correct" and become economically viable.

JOHN J. GILMAN
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10/93 *Los Angeles*

Jack L. Stone concludes his article by comparing the cost of photovoltaic systems with that of conventional energy sources. I wonder if the disparity in cost would be as great if environmental damage, health problems and "protecting national interests" (military expenses for Operation Desert Storm have been estimated at a billion dollars per day) were factored into the "cost" of oil, coal, gas and nuclear-generated electricity.

Manufacturers do not pay for these disadvantages, but the cost to society as a whole is very real. I am not an economist, but I'm sure measures such as a pollution tax could be employed to rapidly reduce the cost differential and encourage the manufacture of large-scale photovoltaic systems. Solar collectors do not require strip mining or drilling, their operation does not produce a continuous supply of carcinogenic by-products, and a war over gallium arsenide or black paint is highly unlikely.

Predictions that wise applications of currently available technology such as photovoltaics and electric cars will be adopted 20 years hence aim at an infinitely receding future. We will remain "20 years away" from clean energy until either the oil consortiums have used up the world's supply of fossil fuels or business as usual becomes "uneconomical."

PETER REPPERT
10/93 *Baltimore, Maryland*

STONE REPLIES: I agree with Aden and Marjorie Meinel's central point, that solar energy has significant hurdles to cross before it can become a major factor in the national energy

picture. The intent of my article was primarily to give a technical description of photovoltaics and to consider a number of important applications; I did not say that if the technology had to supplant present sources it could do it. At this point the issue is not whether technical feasibility has been demonstrated but rather whether photovoltaics can be economically viable. Although there are a large variety of storage approaches, relatively little attention has been given to exploring ways to reduce their cost. Several examples of backup systems for when the sun does not shine exist: There has been a recent rebirth of interest in the concept of the solar-powered satellite, which would beam microwave power generated by solar cells in space back to Earth. The satellite would always be in sunlight, except during predictable eclipses. The production of hydrogen using solar power also is being seriously considered. The improvements in performance in high-temperature superconductors make superconducting magnetic energy storage and superconducting flywheels practical possibilities. Rather than debate the merits of each of the above, I prefer to stay with the natural evolution of the technology. As costs decline with the introduction of new, larger, cost-effective production facilities, new applications will emerge. At the appropriate time, electric utilities will introduce photovoltaics in larger quantity, first in high-value applications and eventually in central-station ones.

With respect to John Gilman's criticisms, I pointed out in my article that the availability of the solar resource is not the problem: "A photovoltaic generating station 140×140 km in area at an average US location could generate all the electricity needed in the US," assuming certain reasonable efficiencies and other factors. An area of that size is not prohibitive, though of course one would need to factor the requirements for storage into the economics to determine whether the approach would be viable. Gilman's second point is correct. However, I know of no one advocating zero-efficiency modules. Obviously if the cost of money is high, high efficiency becomes a premium. Gilman's third point is a misinterpretation of figure 6. That figure is one way to plot the module efficiency and cost needed to produce the cost of electricity shown on the abscissa. What figure 6 actually shows is that with a module efficiency of 8% the modules would have to be free in order to produce electricity costing 6¢ per kilowatt-hour, due to other balance-of-systems costs. My response to Gilman's last comment is that there are now many economically viable applications. Recent calculations have shown that if electricity is needed at a location more than about a third of a mile off the utility grid, at today's price photovoltaics with battery storage is more economical than the cost of line extension to serve the application. There are numerous other examples of distributed electrical requirements. I urge Gilman to keep his eyes open as he travels around: He may be surprised by how much photovoltaics has been deployed.

Peter Reppert makes a very important point about the necessity of placing a monetary value on the environmentally benign aspects of renewable energy systems. Although care must be exercised not to harm the environment during the production of photovoltaic modules, the operation of the installed systems is essentially pollution free. The several attempts to determine the value of this characteristic have yielded results of a few cents per kilowatt-hour. I purposely did not spend much time on this matter in my article, feeling that if photovoltaics can compete without this "subsidy," its benefits will be recognized and appropriately valued. I disagree with Reppert's assertion that the technology is aimed at "an infinitely receding future." The number of economically viable applications is large and is growing rapidly as the costs decline. Certainly if Reppert's points could be addressed, deployment of the systems would be accelerated.

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8/94

A Tale of Two Mesons

In his review of the late Robert Marshak's *Conceptual Foundations of Modern Particle Physics* (April, page 63), Sidney Bludman writes: "Independently of Shoichi Sakata and Takeshi Inoue (1946), Marshak and Hans Bethe (1947) were responsible for the two-meson hypothesis, correctly distinguishing the weakly interacting μ lepton from the strongly interacting π meson. Marshak (1951) went on to propose the detailed balance experiment by which Bethe and Marshak's prediction of zero spin for the π^+ was confirmed." Like many brief historical remarks, this needs some qualification: The Sakata–