Omicron variant in mid-November 2021, roughly 250 million COVID-19 cases had been reported to the World Health Organization. Random stochastic counting says that out of those 250 million cases, some 10 000 should have been physicists. But physicists are rational and generally careful people, so the actual number of infected physicists may have been much lower than that.

I write from the perspective of a highly active theoretical condensed-matter physicist who also happens to be the director of the University of Maryland's Condensed Matter Theory Center (CMTC), which consists of more than 30 young researchers. All CMTC members and all my colleagues in the University of Maryland physics department are fully vaccinated, and quite a few had received their booster shots by early November.

The physicists I know understand the science well and have taken responsible precautions throughout the pandemic. But infection and illness are just two aspects of the COVID-19 pandemic. The all-encompassing ramifications of COVID-19 extend way beyond the disease itself.

From my perspective, the most profound effects of COVID-19 on the physics community have been the absence of direct face-to-face discussions among physicists at the blackboard and of in-person conferences and workshops. I used to travel 150 000 to 500 000 kilometers per year before COVID-19, attending conferences all over the world, giving talks, and interacting with collaborators face to face. CMTC members and visitors used to go out to lunch or dinner together, often in groups of 10–15. The center used to host around 30–50 seminars per year, with the seminar speakers spending several days on campus.

All of that has vanished and may not come back for a long time. My last extended physics-related trip was to Aspen, Colorado, for a month in the summer of 2019, and the CMTC has hosted only one visitor during the past 20 months. The very thought of wearing a mask while traveling and then throughout a conference is sobering, and for me, foreboding. Traveling to do physics is supposed to be fun, not a chore. In-person interaction with other physicists at other institutions often led spontaneously to new ideas and new physics. I worry that it will be a long time before the culture of direct face-to-face interaction among physicists gets reestablished.

Of course, physics talks and conferences continue in virtual modes. Some of those meetings are excellent, and often the question sessions can go on for a long time, which is useful. My remotely delivered 2021 APS March Meeting talk on Majorana quasiparticles was followed by an almost hour-long discussion online. But such discussions can never replace the in-person interactions that dominated physics conferences and workshops. Among all COVID-19-related problems adversely affecting the physics community, I miss in-person interactions the most.

*To view my writings on COVID-19 and its dynamics, see my blog at https://condensedmattertheorycenterblog.wordpress.com/blog/.*

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LETTERS

# Solar energy considerations

I would like to add several details to David Kramer's item "The cost of solar energy production has plunged, but it needs to fall further" in the June 2021 issue of PHYSICS TODAY (page 27).

First, while the monetary costs are important for investment decisions, they are less relevant in decisions regarding sustainability and decarbonization because they depend not only on where and with what energy source panels are made but also on financing, depreciation, taxes, and government subsidies. Costs should be accrued in energy units and compared with energy outputs in the same units. This ratio is typically referred to as energy return on energy invested (EROEI), which is a useful figure of merit for an energy source. Carbon saved over carbon invested would be another useful figure of merit.

I presume that the costs of solar photovoltaics (PV), particularly for the energy-intensive production of silicon crystals and aluminum frames, have not fallen in energy units as much as they have in dollars. I also presume that the EROEI for solar PV is still rather poor, and storage further reduces EROEI. In addition, one must consider the low duty factor (around 20% in my area) for solar energy.

Second, while solar PV is locally "clean," one must look at the whole production cycle—including mining of materials, fabrication (particularly of crystalline silicon and the aluminum frames), and transportation—and the energy involved and carbon produced in those processes. All these energy and carbon costs are up-front, and they are only recovered over some fraction of the life expectancy of the facility, which is about 25 years. The disposal process must be considered as well.

Third, I have found the transparency about the costs of solar PV to be abysmal, and I have found it nearly impossible to get detailed information about projects in my region. When public support, in the form of subsidies, tax advantages, or soft costs such as government reviews, goes to such projects, the public has a right to know about them. If the economics and the sustainability of the projects were as good as we are led to believe, I expect that this information would not be hidden behind corporate and government curtains.

David Kramer is right that the costs of solar PV need to fall further, but I would modify that to read as follows: The costs of solar PV measured in energy units need to fall a lot.

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David Kramer's report "The cost of solar energy production has plunged, but it needs to fall further" (PHYSICS TODAY, June 2021, page 27) gives an excellent overview of the present state of solar technology. One point, however, needs clarification. In evaluating cadmium telluride, the author correctly recognizes the toxic properties of cadmium, which is a carcinogen. He cites the claim that CdTe is virtually insoluble in water, but that dismisses the groundwater contamination risks posed if CdTe panels end up in a landfill.

In 2010–11, I worked at the now-defunct Amelio Solar in Ewing, New Jersey. Suspecting that the fluid that oozes through most landfills might be sufficiently acidic (or sometimes basic) to dissolve CdTe, my colleagues and I conducted experiments in collaboration with a team at the Catholic University of America in Washington, DC.[1]

Both groups cut 50 mm squares from a commercial CdTe module. My team cracked each square with one hammer blow to simulate the breakage that would likely occur when discarded panels were dumped. We then placed each piece in a closed jar containing 150 mL of citric-acid-based buffer solution with a pH value of either 3, 4, 5, or 6. The last square went into deionized water. The Catholic University team members scribed their samples with a diamond saw to avoid the randomness of the hammered breakage. They used rainwater as the reference and solutions with pH values of 4 for acid and 10 for base.

Over the course of six months, my team analyzed the solutions for cadmium using inductively coupled plasma optical spectrometry. The sample in pure water with a pH of 7 showed no additional damage, and even at the end, the cadmium concentration in the solution was only 7 ppm. The results were markedly different for the acidic solutions. The farther the pH diverged from 7, the faster the cadmium leached into the solution. After three months, the most acidic samples had completely delaminated, and the cadmium concentrations in the solutions in which they were immersed had reached over 100 ppm. We also observed that the higher concentrations had leveled off well before the end of the experiment, suggesting that virtually all the cadmium had leached out of those specimens.

The Catholic University team ran their tests for 70 days. They obtained essentially similar results, with about 3 ppm cadmium for rainwater, 54 ppm for pH = 4, and 140 ppm for pH = 10.

In 2017 a team at the University of Arizona published a study with experiments similar to ours in both method and results.[2]

Even if CdTe-module makers promise to reclaim the products at the end of their useful life and recycle the cadmium, can we be confident that they will actually do so 30 years in the future?

At least two additional tests have shown that CdTe modules present a serious groundwater pollution hazard if they end up broken in a landfill permeated by something other than neutral water with a pH of 7.[3,4] If we are to use such technology, we must guarantee a safe disposal and recycling program, and include its full cost and risks in any evaluation of CdTe photovoltaics.

## References


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# Medieval astrometeorology's legacy

Anne Lawrence-Mathers's article "Medieval weather prediction" (PHYSICS TODAY, April 2021, page 38) is a welcome work of history of science that introduced me to some people and works I had never before encountered. As far as I can judge, it is quite accurate, although Johannes Kepler was surely never a *pupil* of Tycho Brahe.

It is nonetheless a serious failing of the article to not call attention to the most striking feature of medieval astrometeorology: It did not work. That Eyno of Würzburg claimed to have predicted heavy snow three times is no more an indication of success than an occasional win yielded by a gambler's system.

In a follow-up online piece ("The triumphs and failures of astrometeorology," PHYSICS TODAY online, 30 April 2021), Lawrence-Mathers acknowledges that the theoretical basis of astrometeorology was incorrect but states that, on balance, its contributions to scientific developments were positive. She seems to think the complexity of astrometeorology was a beneficial aspect of it. But astrology, which shared features with astrometeorology, was just as complex. So, was astrology a plus for the development of astronomy? Well, in a way it was, but it was also an obstruction to it.

Kepler knew astrology was nonsense but hoped to improve it. His enhancements were equally nonsensical at first, but they drove him toward creating a really good astronomy. I rate astrology a net negative, but nonetheless, we can acknowledge and learn from the ways it was positive. Similarly, while we can learn from medieval astrometeorology, the predictions it produced "worked" only accidentally. I call that a net negative. There is no arithmetic for weighing the pluses and minuses of history. Any such weighing is therefore a personal judgment.


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▶ **Lawrence-Mathers replies:** Astrometeorology was fully compatible with models of the universe going back to the classical period; it was radical in that it made detailed calculations about localized weather. Its power is seen in its practitioners' quest to improve the model by keeping weather records and attempting to correlate them with predictive factors in it. In espousing that tradition, Kepler, and many others, paved the way for the expanded observations of the 18th century. It was that practice, rather than the theoretical model, that was astrometeorology's lasting contribution.


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