Doubting Bose-Einstein Condensation in Helium

ADRIAN CHO'S ARTICLE "NEW STATE OF matter not so new?" (News Focus, 1 March, p. 1630) describes a debate on whether Bose-Einstein condensation (BEC) has been observed in a system of helium-4 films adsorbed in porous glass (*1*, *2*). Although Cho mentions that there are scientists who doubt that BEC was observed in this system, the reasons for this doubt are not presented. I wish to clarify the origin of the doubt.

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Our laboratory has been conducting studies of phase transitions in helium films adsorbed in alumina powders for many years (*3*, *4*). Although we find results entirely similar to those in porous glass, by carefully calibrating the data we have found that our results can be explained in terms of the two-dimensional Kosterlitz-Thouless (KT) transition, which is well known to occur in helium films (*5*). The KT transition involves thermally excited vortex-antivortex pairs that drive the superfluid density to zero. We have studied the details of the phase transition over a wide range of pore sizes and superfluid film thicknesses and find good agreement with an interpretation based on a finite-size broadening of the KT transition in the finite pores (*3*, *4*, *6*), followed by a crossover (*7*) to full three-dimensional criticality as the separation between the vortex pairs becomes greater than the pore size. It is significant to note that the helium atoms in these adsorbed films are not "dilute." The total thickness of the film is more than two atomic layers, and every helium atom is 0.36 nm from another helium atom. This is a very different system from the dilute trapped-atom BEC systems, where the interparticle distances are on the order of 1000 nm.

GARY WILLIAMS

Department of Physics and Astronomy, University of California, Los Angeles, Los Angeles, CA 90095, USA. E-mail: gaw@ucla.edu

References and Notes

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6. A comparison of our data and analysis with that of the most recent porous-glass data (*2*) can be viewed at www.bol.ucla.edu/~gaw/porousweb.htm.
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Response

THE CENTRAL POINT OF CONTROVERSY IS whether the results from the helium-in-Vycor (a spongelike glass) experiments done by J. Reppy and colleagues are sufficient to prove the presence of a dilute Bose-Einstein condensate. Reppy and colleagues varied the thickness of the helium coating the Vycor pores, and for each coverage, they tracked the onset of resistance-free flow, or "superfluidity," as the sample cooled below a critical temperature that depended on the coverage (*1*). They found that for thicker coatings, the superfluid fraction increased as the temperature decreased in proportion to $|T - T_c|^{-2/3}$, where T is the temperature and T_c is the critical temperature. For thinner coatings, however, the researchers found that the superfluid fraction varied as $|T - T_c|$ (*1*). It has been argued (*2*, *3*) that this change in critical exponent was evidence of crossover from a strongly interacting regime resembling bulk liquid helium to a dilute Bose gas regime. In the latter, the onset of superfluidity would signal the formation of a dilute Bose-Einstein condensate.

However, Reppy and colleagues could not directly probe the many-particle quantum wave function of the superfluid helium. In particular, they could not demonstrate that the wave function possessed a type of structure known as "off diagonal long range order," which theorists Oliver Penrose and Lars Onsager had established as the criterion for Bose-Einstein condensation in a system of interacting particles (*4*).

Of course, if Reppy's results are not sufficient proof of Bose-Einstein condensation, then other explanations of the behavior of helium in Vycor are possible. Williams argues that for thinner coatings, the helium acts as a two-dimensional film and undergoes a Kosterlitz-Thouless transition, although this strictly two-dimensional phenomenon is slightly modified by the geometry of the underlying three-dimensional substrate.

ADRIAN CHO

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Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 6 months or issues of general interest. They can be submitted by e-mail (science_letters@aaas.org), the Web (www.letter2science.org), or regular mail (1200 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space.

Uncertainty in Climate Models

THOMAS M. SMITH *ET AL.* ("HOW ACCURATE are climate simulations?", Perspectives, 19 April, p. 483) suggest that today's climate models simulate the climate history of Earth over the past 150 years "within the observed uncertainty of the observations." In comparing model results with trends in sea surface temperature in several ocean basins, they estimate the uncertainty in model output arising from the inherent chaotic variability of the climate system from the spread of three separate simulations of a single climate model "forced with the same greenhouse gases and sulfate aerosols" but initiated with different conditions. They conclude that the variability in modeled temperature trends arising from the nonlinear dynamics of the climate system is small relative to the uncertainty in observations. However, as the model studies used only a single set of forcings, the conclusions neglect the major source of uncertainty in model simulations of temperature trends, that arising from uncertainty in the forcing.

As emphasized in the recent reports of the Intergovernmental Panel on Climate Change (IPCC) (*1*) and the National Research Council (*2*), this uncertainty is substantial, a factor of severalfold, arising mainly as a consequence of uncertainty in the totality of aerosol forcings, not just that of sulfate. What is therefore required to estimate uncertainty in modeled temperature trends is a set of calculations for forcings that span the estimated uncertainty range. If this range of forcings were input into climate model calculations, the range of model results would greatly exceed that due to climate system chaos reported by Smith *et al.* The spread of modeled temperature trends would be even greater if a suite of modern climate models were used, because of the spread in climate sensitivity of these models. Such uncertainties preclude inference from the observed temperature trend either of the historical trend in forcing or of the sensitivity of the climate system. Thus, although the need for improving the observational climate record noted by Smith *et al.* should not be minimized, the need for improved knowledge of climate forcing must be viewed as far greater.

STEPHEN E. SCHWARTZ
Atmospheric Sciences Division, Brookhaven National Laboratory, Upton, NY 11973, USA. E-mail: ses@bnl.gov

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Response

THE IMPORTANCE OF ACCURATELY MEASURING climate forcings that cause climate variability and change is, indeed, critical to our ability to understand and predict climate. The IPCC (*1*) report indicates that the range of global temperature increase estimated by climate model projections is large (1.4° to 5.8°C), because of differences in climate model responses to changes in climate forcing as well as the future changes in the forcing, such as the growth of anthropogenic greenhouse gases and aerosols. Clearly, we cannot ignore the importance of precisely monitoring the changing composition of the atmosphere, as well as other potential climate forcings, such as solar variability.

However, in our Perspective, we show that one set of GFDL model simulations forced with greenhouse gases and sulfate aerosol concentrations that are similar to those of several other simulations (*1*) is not deficient in simulating long-term trends in sea surface temperatures (SSTs). This is because of the significant uncertainties related to observed SSTs and the inherent chaos in the climate system. By far, the primary forcing of the late 19th century and the 20th century has been changes in the concentration of carbon dioxide, methane, and the halocarbons, which are known quite accurately (*1*). The time history of changes in other forcings, such as anthropogenic aerosols and greenhouse gases like ozone, is less certain. For natural forcings such as solar variability, there is substantial uncertainty, but this uncertainty is almost certainly much smaller than that for greenhouse gas forcing (*2*). If these additional uncertainties related to all these forcings were included in climate model simulations, they would surely have added to the model uncertainty somewhat. This further emphasizes one of our points: that existing models reproduce large-scale changes in observed SST as well as can be expected, but reductions in SST biases are also essential. Whether uncertainties related to credible scenarios of past forcing greatly exceed the uncertainties due to climate chaos, as Schwartz states, is speculative and remains to be shown, but it is clear that we must improve observations related to both climate state and climate forcings to better evaluate our models.

THOMAS M. SMITH, THOMAS R. KARL, RICHARD W. REYNOLDS
National Climatic Data Center, 151 Patton Avenue, Asheville, NC 28801, USA.

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