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Negative Poisson's Ratio Materials

Reentrant polymer foam materials with negative Poisson's ratios, as described by Lakes (*1*), are a new class of materials with unique properties. The thermodynamic restriction on the compressibility, K, of an elastic material is that it must be positive for stability. The compressibility is related to the shear modulus, G, and Poisson's ratio, ν, by $K = 3/2[(1 - 2\nu)/G(1+\nu)]$, so ν is restricted to $-1 < \nu < 1/2$ for positive K, as is well known. However, polymer foams are not elastic continua and develop couple-moment stresses that bend the internal connecting ligaments. The negative values of ν in the reentrant foams are a direct result of the size scale, intrinsic in couple-moment elastic theory. Thus there are hidden variables in the material. Anisotropic materials with matrix elastic constants have some negative Poisson's ratios. These materials also have additional hidden variables—the complete set of tensorial, stress-strain, state variables.

Although a proof does not exist that restricts the ratio of transverse-to-lateral strains to a value that is larger than zero, for a system of two independent variables, that is, two stresses and two strains, Lakes' observations should not be construed as evidence that such a proof is impossible. His material has additional hidden state variables. All known continuum solids that are described by two independent-state variables have thermodynamic couplings that are greater than zero. The proof that this must be true has simply eluded us.

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Response: Burns raises some interesting points regarding materials with negative Poisson's ratios. I agree that foam materials are not continuous media and that the cell ribs transmit bending moments as well as tensile and compressive forces. I also agree with the idea that these bending moments can be incorporated as a "hidden" variable (that is, couple stress) in a more general continuum description, Cosserat elasticity (*1*). I disagree, however, with the suggestion that the negative Poisson's ratios result from the size scale. In the Cosserat model for structured solids, many phenomena are predicted and observed (*1*) that depend on the material size scale in relation to the length scale associated with the deformation. A simple tension deformation, however, is uniform and has no associated length scale. Consequently both the Cosserat model and classical elasticity predict the Poisson effect to be independent of scale (*2*).

The role of structural assumptions in the prediction of Poisson's ratio can be traced to the foundations of the theory of elasticity (*3*). Navier proposed in 1821 a theory of interatomic interaction in which the forces are central and act along the lines joining pairs of atoms, and Poisson himself soon after concluded from this theory that Poisson's ratio must be 0.25 for all materials. This view was accepted for many years until experiments disclosed different Poisson's ratios for various materials. In common materials for which Poisson's ratio differs from 0.25, the interatomic forces must be noncentral, implying the existence of couple stresses to satisfy the condition for equilibrium. Hence Burns' reference to additional hidden state variables appears to be relevant to most materials with Poisson's ratios that differ from 0.25, not only to the new foams with negative Poisson's ratios. As for continuum solids, they exist as conceptual representations for physical solids, all of which exhibit structure on some scale.

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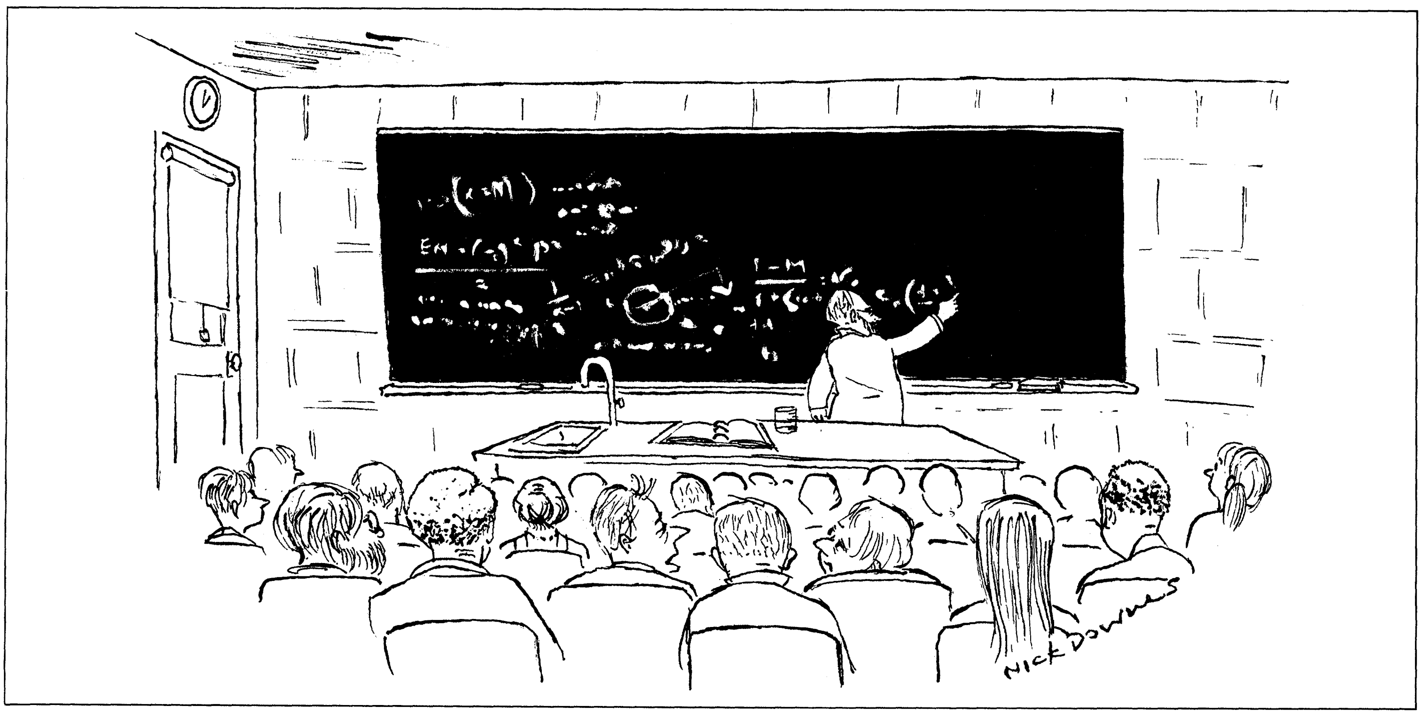

"I think I'm beginning to grasp the concept of infinity."