Obviously this does not succeed in breaking the lower bound for the classical communication complexity (which is in any case a mathematically provable result). Timing is a very commonly used form of communication—as for example in comedy and irony. In the precise definitions of information science, however, we quantify it along with all other forms of communication, by counting the number of different eventualities that might arise. In Knauer's scheme there are four eventualities in Bob's message to Alice: flag up in 1st time period; flag down in 1st time period; flag up in 2nd time period; flag down in 2nd time period. Hence, if the timing is adhered to, a single message carries two classical bits.

As far as the "Guess My Number" game show is concerned, of course the information scientists employed by the television company pointed out the danger of this form of sneakiness, so the hostess is under strict instructions not to have any particular pattern of timing when she conveys messages to Alice. Indeed, they often have a review of the score just before the hostess announces one of Bob and Charles's messages to Alice, ostensibly to keep up the element of suspense, but really to close this type of classical communication avenue.

Finally, Knauer is mistaken in thinking that quantum entanglement observations require coincidence measurements—no particular timing of measurements is needed when using entangled states of things like atoms, which can be held in one place. See, for example, C. A. Sackett *et al.*, Nature **404**, 256 (2000).

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Digital TV: Artificial Obsolescence?

This letter is in response to the article by Louis A. Bloomfield, entitled "Television Goes Digital" (Physics Today, November 1999, page 42). Hidden in the article is the assumption that digital television is a done deal. This is far from evident; advertisers (the driving force behind TV) are not going to use the medium unless citizens have the equipment to receive signals. Consumers are demonstrating widespread opposition to being forced to buy all new (and very expensive) TVs, VCRs, and other hardware.

The article's comparison of the two types of television is fully consistent with standard advertising ethics; the older rival analog is smaller, dimmer, "out of it." However, the fact is that the difference in picture quality is not great for the general run of pictures.

But the aspect of difference that is a lead-pipe certainty is that consumers would be forced to spend thousands of dollars in yet another artificial obsolescence scam. The waste of resources involved in junking 50 million television sets and replacing them with the "newer technology" hardware will certainly give pause to all of us concerned with the environment.

There are several engines driving this latest attack on consumers. But a prominent one is evident—market saturation (overproduction) of electronic equipment. We have seen the response over and over again: in music, AM, FM, vinyl, 78s and 33s, eight-track, cassettes, CDs, and now digital. Mainstream television has, of course, also seen several rounds of forced obsolescence.

Enough already.

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Bloomfield replies: I agree with much of what William Meecham writes. I am not a lover of television and don't look forward to watching marketers of new digital technology manipulate owners of existing analog equipment. I already feel sad seeing people of limited means rolling new big-screen analog televisions and VCRs through store parking lots, knowing that in a few years they'll probably regret those purchases.

However, unlike Meecham, I fully expect digital TV to replace analog TV. I don't necessarily expect it to go according to schedule, but it's going to happen. Digital really is better and the fact that the transition will make enormous amounts of equipment obsolete won't stop it. Previous revolutions in television brought everyone along: Black and white televisions still work, and UHF and cable adapters allow even antique sets to receive modern analog transmissions. But the transition to digital is going to be far more disruptive. Adapters that convert digital signals to analog and perhaps vice versa will be everywhere but they won't solve all the problems. Among the casualties will be VCRs, video games, camcorders, videotapes (including home movies), and televisions with picture-in-a-picture. It will be a good time to read more books.

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Calculating buckyballs and nanotubes

It is a sad feature of our times that in spite of the powerful tools that are available to search the literature, few comprehensive searches are made. The result is misinformation such as that given by Jerzy Bernholc in his letter in Physics Today, (February, page 76), that carbon nanotubes are exceptionally strong. The article cites a breaking strain of "at least 5%." But, more than 60 years ago, breaking strains of 25% were reported for silica fibers,[1] and strains as large as 13% were observed in sizable silica rods.[2] Also in silicon micromechanical structures breaking strains of at least 8% are observed. Even humble oriented-polyethylene breaks at 17% strain.[3] Thus, the statement of Bernholc that nanotubes are "the 'strongest' material known!" is quite hollow.

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In his Reference Frame article (Physics Today, September 1999, page 11), Philip W. Anderson makes the statement that "computational physics" should be considered an oxymoron. Yet his comment is challenged a few pages later by the article of Jerzy Bernholc (page 30), which describes the role of computational materials science by giving three examples: superconductivity in the fullerene compounds, polycrystalline silicon, and magnetism in low-symmetry systems. The last two examples seem reasonable to me, but I am not an expert in those fields. The fullerene case, however, is misleading and sets an example for Anderson's point of view. Bernholc's article gives the impression that *ab* *initio* calculations have clarified that the microscopic origin of superconductivity in the C_{60} compounds is due to the strong electron–phonon interaction that arises from the curvature of the molecule. In addition, there is a prediction that C_{36} compounds should become superconducting at much higher temperature due to their even larger curvature. That there is no trace of this effect in real C_{36} materials is then explained as being due to difficulties in the preparation.

Unfortunately, there is a tendency to overlook completely the following essential facts, which cannot be addressed by the methods that Bernholc discusses:

▷ Only A_3C_{60} is metallic. A_4C_{60} and other compositions are insulators. (Here, A is an alkali atom.)

▷ Fullerene compounds have a very small carrier density (as do the high-T_c superconductors), which is very difficult to incorporate successfully into the Bardeen-Cooper-Schrieffer (BCS) model because the small carrier density leads to a small density of states and to weak screening of the Coulomb interaction.[1] Bernholc argues that the narrow bands may lead to a relative increase in the density of states but, due to the small carrier density, the density of states still remains lower than the best traditional BCS materials.

▷ Finally, the BCS theory and the more exact Migdal–Eliashberg theory are intrinsically inconsistent for these systems. In all fullerene compounds the principle of adiabaticity (Migdal's theorem), on which BCS theory is based, is violated. According to that principle, the effective interaction between electrons and ions is computed assuming that the phonon potential is quasi-static, having slow dynamics and small energy with respect to the rapid, high-energy electronic dynamics. This picture neglects important interference effects that are present if electrons and ions move with similar speed, that is, if their energy scales are similar and their dynamics are correlated in a specific way. In fullerenes and in the other high-T_c materials, the energy scales for the two dynamics are indeed similar. A generalization of the superconductivity theory to the nonadiabatic regime is therefore required.[2]

In summary, I agree with Bernholc that C_{60} and C_{36} compounds are extremely interesting materials. Their superconductive properties, however, are much more complex and interesting than he describes and, up to now, first principle calculations have contributed little to their understanding.

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BERNHOLC REPLIES: The strength of a material is usually defined as the maximum stress (force per unit area) that the material can support, rather than the maximum strain. In engineering, the maximum elastic (yield) strength is the most important quantity, since at the yield point the strain is still reversible. From Hooke's law, the yield strength is equal to the product of Young's modulus and the maximum elastic strain. Nanotubes have an exceptionally large Young's modulus of 1.25 TPa,[1] while the moduli of silica, silicon, and polyethylene are only 74,[2] 163,[2] and 220[3] GPa, respectively. Reversible elastic strains of 5.8% have already been measured for single-walled nanotubes.[4] Furthermore, the computed barriers for the formation of stress-induced defects are very large,[5] indicating that "perfect" nanotubes should be kinetically stable at much greater strains. Reference 2 has an in-depth review of the factors affecting strength as well as extensive tables of the strengths of various materials.

With regard to Luciano Pietronero's concerns: Opinions on "computational physics" range from considering this area as a third pillar of physics along with theory and experiment to questioning whether it is needed at all. The extraordinary growth of the field at this time argues positively for its usefulness, but I will not debate the point; I suggest that this debate will be settled in the future.

Although many inventive ideas for superconducting mechanisms were suggested when the C_{60}-based superconductors were found, the general consensus now is that the electron–phonon (intramolecular) interaction is the dominant pairing mechanism. The isotope effect for C_{60} and the lack thereof for Rb, transport properties, and the consistency with theoretical estimates are strong support for this interpretation. The applicability of the Migdal approximation to low Fermi energy materials referred to by Pietronero has been discussed since the 1960s with a variety of opinions on the scaling parameter and parallel paths for truncation based on the energy dependence of the interactions. That is outside the scope of my article.

The extension of the curvature argument for creating allowed electron–phonon matrix elements extrapolated from the graphite to C_{60} systems is a useful instructional guide but a loose one. However, these couplings were computed for C_{60} and C_{36} systems and as Pietronero has written, "even if there may be appreciable indetermination in the absolute values of the parameters (say electron–phonon coupling), the relative difference is much more meaningful."[6] This exact approach was used as an argument for suggesting experimental investigation of C_{36} for superconductivity.

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Corrections

May, page 12—Reference 1 of Richard Wilson's letter should be: R. Wilson, AAPT Resource Letter, Am. J. Phys. **67** (5), 372 (1999).

May, page 18—The page number in reference 3 should be 2075.

May, page 47—The Indian Institute of Science in Bangalore was actually founded through the vision and drive of Jamshedji Nusserwanji Tata, a prominent industrialist who donated the land. Tata died in 1904, and his sons completed initial construction of the Institute, which opened its doors in 1911. C. V. Raman worked at the Institute from 1933 to 1938, as head of its physics department. ■