pensive reductions of carbon dioxide while the basic science is still being analyzed. They advocated a BTU tax in 1993, and I was one of the leaders who stopped them. Their proposed tax on fossil fuels did not pass, even in a Congress then controlled by Democrats. As everyone in the physical sciences knows, the science must come first, before we can start making policy.

The Department of Energy, the Department of Commerce and NASA have been doing good science for many years, and I will continue to support their research funding. The funding situation for each program needs to be reviewed on an individual basis despite any changes to the overall agencies. I am committed to reorganizing DOE and Commerce, such that the research money goes to support researchers, rather than for agency overhead. In the Dole administration, there will be better coordination of Federal R&D efforts through the Office of Science and Technology Policy. An across-the-board review of programs should be an ongoing effort throughout the year. There should be an open dialog between Federal agencies, Congress and the scientific community.

We need to work with the physics community to foster a better understanding of science and technology among the general public. Recently, the Federal government has made things worse. For instance, in the Clinton Administration's Goals 2000 program, national history standards were developed that had no mention of Thomas Edison or the Wright brothers. How can we get kids excited about becoming scientists, engineers, or technological entrepreneurs if they are taught a form of history in which role models are removed?

Under the Dole administration, I look forward to working with you in an era where good science will be consistently supported.

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Future of Quantum Computing Proves to Be Debatable

In presenting their opinions in the article "Quantum Computing: Dream or Nightmare?" (August, page 51), Serge Haroche and Jean-Michel Raimond conclude that large-scale quantum computation will remain merely a dream of computer theorists. Their principal argument is that, for a quantum computer to be useful, the ratio R of quantum gate speed to decoherence rate would have to be much higher than what can be obtained in the laboratory. Based on what has been achieved so far, this may be a safe bet. However, the subject is still in its infancy and at this time, its fundamental limits are not understood. Lacking such an understanding, Haroche and Raimond's pessimism about quantum computing is, in our opinion, premature.

To put developments into perspective, it should be recognized that although the field of quantum computation is about 15 years old, algorithms that could provide dramatic speedup over conventional computers (by employing quantum entanglement) were discovered only a couple of years ago,[1,2] and the experiments on quantum logic they stimulated are less than a year old.

Although the application of quantum computers to factoring large numbers[1] seems extremely difficult to implement, it is highly unlikely that no other applications of quantum logic will ever be discovered.[3] In addition, theorists have begun to investigate "quantum error correction" codes only within the last several months, and indications are that the maximum number of gate operations may not necessarily be limited by the value of R. As Peter Shor has informed us, quantum error correction may be able to stabilize the decoherence of entangled states providing that R reaches some threshold value—say between 10^4 and 10^8—regardless of the number of operations. It therefore seems premature to claim that a quantum computer would be useful only if R is of order 10^{11}, or that any application requiring more than 3×10^6 optical operations would be fundamentally disallowed.

Experimentally, our laboratory has demonstrated a "controlled-NOT" quantum logic gate with a single trapped ion,[4] following the ideas of Ignacio Cirac and Peter Zoller.[5] (See PHYSICS TODAY, March, page 21.) In the experiment, R was about 10^1 and the gate time was about 50 s. However, as is often the case in experimental physics, this apparatus was assembled with the least effort necessary to exhibit the desired behavior and should not be taken to represent the technological limit. Although the task of scaling this system to large numbers of ions and gates involving massively entangled quantum states is daunting, the pitfalls are technical, not fundamental.

It is too early to make absolute assertions regarding the viability of quantum computation when such a large degree of uncertainty in both theory and experiment remains. Theorists are focusing on uncovering new algorithms that may benefit from quantum logic and investigating the limits of quantum error correction. For their part, experimentalists exploring entangled quantum states and mesoscopic "Schrödinger's cat"–like states are investigating "how big" and "how entangled" they can prepare their systems using quantum logic. Although we heartily agree with Haroche and Raimond that this research may shed light upon fundamental issues of quantum measurement and decoherence, these experiments may also lead to useful applications such as quantum computation, whose feasibility is unresolved and whose limits have not yet been determined.

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HAROCHE AND RAIMOND REPLY: Christopher Monroe and David Wineland find too pessimistic a view of quantum computing that, needless to say, is not only ours.[1] Of course, we may be proved wrong if some unforeseen technology emerges one day to break through the quantum/classical boundary and make it possible to build large systems in coherent superpositions of quantum states. That would be great news indeed, a true revolution going far beyond computing. But such an event is unpredictable, and our discussion must be restricted to reasonable extrapolations from present knowledge.

Monroe and Wineland think that quantum computing could be achieved by improving on today's technology. They qualify the difficulties they will encounter in scaling up their beautiful ion trap experiment to large number of gates and operations as merely "technical, not fundamental," and herein lies our basic conceptual disagreement with them. We remain convinced that, in the context of presently known physics, the fundamental phenomenon of quantum decoherence, whose probability increases exponentially with the system size, will make it impossible to "push back" far enough the quantum/classical boundary. Note that the magnitude of the decoherence problem for quantum computing had already been stressed theoretically before our paper appeared.[2] Recently, working with atoms in cavities, our group has observed decoherence effects on "Schrödinger's cat"–like systems and demonstrated the fragility of mesoscopic quantum coherences in a well-controlled environment.[3]

Error correcting codes, on which Monroe and Wineland place big hopes, are very important for the light they shed on fundamental aspects of decoherence. However, we do not believe that they could make large-scale quantum computing feasible, in that they are prone to adding their own detection errors[1] and impose a tremendous overload on already very challenging experiments.

Ultimately, time will be the referee of this friendly dispute, although it may take a decade. Meanwhile, to end on a bright note, we are convinced that, whoever is vindicated, science will be the winner because outstanding physics—even if not a quantum computer—is bound to emerge from the beautiful theoretical and experimental studies being pursued in this field.

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Physics Ties to Cuba Should Be Personal, Not Institutional

Jean Kumagai's "Physics Community" story (April, page 53) on US scientists' ties with Cuban colleagues needs some amplification. As a strong believer in the importance of person-to-person communication and as a former physics professor at the University of Havana (1950–60), I support strengthening personal relations between US and Cuban physicists. There are many good physicists in Cuba, most of them trained in the former Soviet Union, and they would benefit from exchanges with US physicists. In recent years, for example, I have maintained a correspondence with a few Cuban physicists.

However, I oppose relations with Cuba at the institutional level, because such links imply support for a dictatorial government that exerts tight controls on all of the country's institutions, as well as individual scientists. In Cuba, there are no private institutions or organizations, including the Cuban Physics Society. For a Cuban scientist to hold an academic position, he or she has to be politically correct—that is, express support for the Communist Party of Cuba or even be a party member. Otherwise his or her professional opportunities are severely limited. Those who dare to express their opposition to the regime are demoted or put in prison, and there are many examples of this having happened. Furthermore, Cuban scientists are not free to travel abroad, and may do so only by obtaining special permission from the Cuban government; even then, they are not allowed to take their families with them.

" HONESTLY, ERWIN. CAN'T YOU JUST FLIP A COIN?"