than the acoustic energy necessary for sonic agglomeration, and is even less than the sound from a small portable radio.

Scientists studying air ions generally acknowledge that ion effects are poorly understood and that some published experiments lack adequate controls. This situation can only be corrected by more careful research which avoids past mistakes. It is also important that public information be as factual and unbiased as possible.

MICHAEL YOST
Air Ion Research Laboratory, Department of Biomedical and Environmental Health Sciences, School of Public Health, University of California, Berkeley 94720

A. D. MOORE
Department of Electrical and Computer Engineering, College of Engineering, University of Michigan, Ann Arbor 48109

References

1. A. L. Tchijevsky, *Transactions of Central Laboratory Scientific Research on Ionification* (The Commune, Vorenej, 1933); *Air Ionization, Its Role in the National Economy* (State Planning Commission, U.S.S.R., Moscow, 1960) (Office of Naval Intelligence translation No. 948, Washington, D.C., 1963), pp. 139–145.
2. A. P. Krueger, R. F. Smith, I. G. Go, *J. Gen. Physiol.* **41**, 359 (1957); A. P. Krueger, W. W. Hicks, J. C. Beckett, *J. Franklin Inst.* **266**, 9 (1958).
3. A. D. Boyco and A. N. Sverchkov, *Gig. Tr. Prof. Zabol. No. 10* (1963), p. 60; R. Fuerst, *Annu. Rep. M. D. Anderson Hospital* (1955), p. 60; K. H. Kingdon, *Phys. Med. Biol.* **5**, 1 (1960); G. B. Phillips, G. J. Harris, M. W. Jones, *Int. J. Biometeorol.* **8**, 27 (1964); R. Pratt and R. W. Barnard, *Am. Pharmacol. Assoc. Sci. Ed.* **49**, 643 (1960).
4. E. W. Kellogg, M. G. Yost, N. Barthakur, A. P. Krueger, *Nature (London)* **281**, 400 (1979).
5. K. T. Whitby, B. Y. H. Liu, C. M. Peterson, *J. Colloid Sci.* **20**, 585 (1965); R. Whitlaw-Gray and H. S. Patterson, *Smoke* (Arnold, London, 1932); N. Fuchs and I. Petrjanov, *Acta Phys. Chem.* **3**, 827 (1935); W. Cawood and H. S. Patterson, *Nature (London)* **128**, 150 (1931).
6. K. T. Whitby and A. R. McFarland, in *Proceedings of the 1st International Conference on Ionization of the Air* (Franklin Institute, Philadelphia, 1961), vol. 1, sect. 7, p. k-30.
7. G. W. Penny and R. D. Lynch, *AIIE Trans.* **76**, 294 (1957).
8. E. S. Kanter, *Radio Electron.* **51**, 62 (1980).
9. H. S. Patterson and W. Cawood, *Nature (London)* **126**, 667 (1931); O. Brandt and H. Freund, *Z. Phys.* **92**, 385 (1934); E. B. Pearson, *Proc. Phys. Soc.* **47**, 136 (1935); H. W. St. Clair, M. J. Spendlove, E. V. Potter, *U.S. Bur. Mines Rep. Invest. 4218* (1948).

R & D and Productivity

Rather sharply, between 1964 and 1965, the federal investment in research and development (R & D) went through a uniquely significant change in trend. For perhaps a century before 1964 the federal gross expenditure in R & D had been increasing exponentially relative to the federal budget at a rate of about 11 percent per year. It was about 1 percent of the budget in 1940, 2 percent in 1947, 4 percent in 1953, and 8 percent in 1960. It peaked in 1965 at about 12½ percent, which is a remarkably high proportion when one considers that about half the budget consists of unallocable items fixed by law. Since 1965 the budget share has decreased, also rather steadily and exponentially at a rate of about 6½ percent per year. In 1980 it was about 5½ percent, and it will probably decrease shortly to less than 5 percent. It is worth noting that the peaking out occurred even before the Mansfield Amendment cut off Defense-supported research. The same phenomenon of saturation occurred in the United Kingdom just before the adoption of their Rothschild Convention, which had a similar effect of motivating a sudden decompression that seems to have been happening anyway.

John Walsh writes (News and Comment, 13 Feb., p. 685) that Edward F. Denison suspects this R & D change may have something to do with the productivity problem. It has, however, long been known from the work of Freeman (*1*) and others that the empirical data for several industries in the United States and in the United Kingdom show that the R & D investment in industry goes up as about the cube of the growth rate. The marginal costs of innovation pressure are rather high. The name of the game in high technology is that growth is largely produced by product and process innovation. If we suppose that what the economists call productivity in our high technology industry is produced by the R & D in this way, we must infer that the 1964–1965 transition should have produced a change (taking the cube root of the R & D change) from a positive growth rate of about 3.7 percent to a negative one of about 2.2 percent, thereby producing a decline in the high technology sector of almost 6 percent each year below that produced traditionally before. Of course, not all our industry is high technology, but it seems clear that the expected decline resulting from saturation of federal R & D spending capacity can be held responsible for the major component in declining productivity and profitability of the industries involved. Since these are also a large part of the import/export balance of trade, as Boretsky has shown (*2*), it follows that this may be a similarly large factor in the turnaround of that balance and the consequent weakening of the dollar and inflation of the currency (at approximately the same rate of 6 percent per year).

Because of this plausible mechanism one needs to look closely at the reasons for the silent transition of 16 years ago. Denison sees that this was also the period when the steady 0.5 percent per year migration of agricultural labor into industry and services could hardly go further; what in fact happened is that the process then switched (circa 1965) to a rather slower migration from industry to the service sector, in what Daniel Bell calls the onset of a post-industrial society. Another part of the transition occurred because the federal R & D budget simply could not become greater than about a quarter of the allocable resources, and the Office of Management and Budget foot was firmly transferred from the accelerator to the brake. The universities also suffered a sudden transition at this time, although it was masked by the Vietnam War. Again for maybe a century the student population had grown exponentially at a rate of about 6 percent per year, mostly because the increasing enrollment rate was taking us from an elite to a democratized higher education. When half the young were going to college, no further growth was possible; very suddenly we stopped producing professors at a rate of 8 percent per year and needed only the 2 percent replacement rate for those leaving by retirement and death. This meant a lot for the R of R & D because a large part of the nation's R is performed in the universities; a cut of the needed training rate by a factor of 4 inevitably reduced graduate student research and our investment in this sort of future.

The university, budget, and employment crunches all happened almost simultaneously (circa 1964–1965), but there is a pipeline of 5 to 10 years between putting the R & D in and getting the economic impact out. It is entirely reasonable to my mind that the decline in the economy did not begin to be perceived until about 1973.

The moral of this story seems clear. If we wish to live in the affluent life-style of a post-industrial society, we must see to it that the service economy produces via high technology the profits and exports to pay for it. To do that we, alas, cannot possibly invest in R & D in the old style. The projection of the exponential curve up to 1964 would give us by now an investment of about 72 percent of the federal budget, which is ludicrously impossible. We might, however, do better than the current 5 percent, most especially on the R side of the ledger, where scientific technological innovation begins.

DEREK DE S. PRICE
History of Science, Yale University, New Haven, Connecticut 06520

References

1. C. Freeman, *Natl. Inst. Econ. Rev.* **20**, 21 (1962).
2. M. Boretsky, *Am. Sci.* **63**, 70 (1975).