LETTERS

Ultrafast Streak Camera

The Research News update on "Laser spectroscopy: Probing biomolecular functions" (6 June, p. 1002) was timely and interesting. Jean L. Marx quite appropriately conveys the explosive flurry of research activity that has increased the understanding of large biological macromolecules since the advent of a number of laser spectroscopic techniques—in particular, the picosecond light probe. We would like to point out a very important development—the application of the ultrafast streak camera.

Streak cameras have been in existence for some time, but recent tube developments by Bradley and co-workers (*1*) have resulted in transit time spreads sufficiently small to demonstrate resolution of events as short as 500 femtoseconds. Briefly, the camera works as follows. Light from a picosecond event enters the slit of the camera and is focused onto a photocathode where electrons are released via the photoelectric effect, the number of electrons released at any particular instant being proportional to the light intensity on the photocathode during that period of time. The electrons are accelerated through an anode and then deflected by a voltage ramp which streaks them across a phosphorescent screen so that electrons released at different times strike the screen at different positions. A densitometer trace of a photograph of the resulting phosphorescent "streak" then gives an accurate measure of the lifetime of the event. By including additional image intensifier stages, the sensitivity of the camera can be improved to the point where individual photoelectrons can be observed. Compared to the alternative techniques, the streak camera has powerful advantages, such as high resolution, high sensitivity, commercial availability, and a simpler and more reliable experimental arrangement.

Streak cameras have recently been used to measure picosecond fluorescent lifetimes for a number of dyes (*2*). Our group at Los Alamos has been using these devices to investigate the fluorescent properties of pigment molecules in photosynthetic systems. For example, we have measured fluorescent lifetimes of various pigments in vitro (α and β carotenes, chlorophylls a and b, and phycocyanin) (*3*), algae [*Chlorella pyrenoidosa*, *Anacystis nidulans*, *Agmenellum quadruplicatum* (PR-6), *Chlamydomonas reinhardi*] (*3*), and higher plants (chloroplasts and leaves of spinach, jack bean, lettuce, and tobacco). Perhaps not surprisingly, we have found that all chloroplast-bearing plants and algae have nearly the same fluorescent lifetimes in vivo (40 picoseconds), which suggests a universal chloroplast behavior for the higher plants.

A statement in the Marx article that recent results are consistent with the picture that the excitation energy spreads through photosystem pigments by means of a resonant dipole-dipole energy transfer is a well-known hypothesis, first postulated by Förster in 1948. Since then, plausible analyses have been performed by Bay, Pearlstein, Dexter, Robinson, Knox, and Montroll, to name but a few. Experimentally, there has been some indirect, although not entirely convincing, evidence to support this view. Recently, we demonstrated directly in the time domain that such a dipole-dipole interaction is appropriate (*4*), at least in the case of chlorophyll in vitro at concentrations comparable to that found in chloroplasts. The lifetimes as a function of pigment concentration and the nonexponential form of the fluorescent decay were consistent with existing theory. However, based on the decay rates we measured, we estimate that each chlorophyll a homotransfer in vivo takes only 0.2 to 0.3 picosecond. This is so rapid that, perhaps, as has long been suspected by theoreticians, a delocalized or coherent exciton description may be necessary. These and other recently developed experimental techniques may soon lead to answers to many of these fundamental questions.

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Economic Growth

Glenn Hueckel, in his article "A historical approach to future economic growth" (14 Mar., p. 925), asserts that "the history of technological advance suggests an optimistic outlook for future economic growth." This statement and the text of the article which purports to support this point of view reflect the adoption of an overly narrow time perspective on the part of the author. In effect, he has taken a minute segment of human history and projected interactions which occurred within this brief time span into the future.

Until the beginning of the 19th century, energy consumption and population growth remained relatively stable, with very slow growth in both indices. Between 1800 and 1974, however, the growth of these variables has been exponential. Hueckel suggests that, in the past, technology has served to remedy resource shortages and that, in the future, the market system will serve to allocate resource utilization away from those inputs which are scarcest. However, this analysis is based upon the *brief* experience of industrial societies.

Human societies have been on a consumption and production binge for the past 200 years. This period represents a unique and temporary transition from preindustrial social structures. Hueckel overlooks the commonality of the dynamic factor which made this type of growth possible, in both energy consumption and in population—man's extension of his tool-using capabilities through the use of fossil (terrestrial) fuel reserves which have accumulated over millions of years (*1*). Thus, the basis of the accelerated energy consumption and population growth over the past 200 years has been energy reserves which we now recognize are rapidly dwindling.

The extreme dependence of industrial societies on fossil fuel for terrestrial energy resources has facilitated the development of social and economic structures which are inconsistent with long-run basic ecological and thermodynamic principles (*2*). The primary structural changes requisite for the establishment of a tractable economic and social structure compatible with basic physical and ecological restrictions are unlikely to be promoted by the indirect allocation signals generated by the market mechanism. This is not to say that market signals do not perform a useful function. Given the long-run trajectory of the economic and social system, fluctuations which occur within this trajectory can, in part, be modulated through economic signals. It is unrealistic, however, to expect market signals to interpret and alter the trajectory itself.

Indeed, the best we can do in the context of thermodynamic constraints—in an evolutionary time perspective—is to "buy time." And perhaps the best way to do so is to focus our attention on the structural parameters of the system and to devise policies which—viewed in toto—can alter the trajectory. This does not require the identification or agreement of what is best or optimum. Rather, it necessitates the continual evaluation of where the system is headed and which directions are undesirable.

To paraphrase an editorial comment appearing in a *New York Times* feature story (*3*) on a recent American Economic Association meeting, economists appear to be busily rearranging and optimizing the arrangement of deck chairs on the Titanic. It is not simply a question of *how* we are getting there; we must determine *where* we are going.

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Hueckel's article warrants the same kind of optimism as that expressed by the man who has fallen halfway down from the top of the Empire State Building without yet encountering any substantial limits to his acceleration. Backward-looking empiricism has its limits and must be supplemented by rational deduction from first principles. I presented (*1*) a commonsense argument against continuous growth, based on the first principles of diminishing marginal utility and increasing marginal cost. Hueckel claims that I misused the concept of diminishing marginal utility (by applying it to income rather than to a single commodity) and thereby somehow smuggled my own value judgments into the argument. If I misused the concept of marginal utility then so did one of its originators, E. Bohm-Bawerk, who also applied it to income as well as to single goods (*2*). The only assumption in Bohm-Bawerk's treatment is that there exists for the individual a hierarchy of wants, and sensible people satisfy their most pressing wants first, whether in alternative uses of a single commodity or in alternative uses of income. The modern textbook definition as the "partial derivative of a hypothetical utility function" requires the assumption of cardinally measurable utility and some specific utility function, both of which are at best heuristic analogies, and at worst unscientific pretentions. But if one wants to assume cardinal utility, then I confess that I find the "Bernoulli hypothesis" very convincing.

The simple argument was this: if marginal benefits of physical growth decline while marginal costs rise, there will be an intersection beyond which further growth is uneconomic. The richer the society (the more it has grown in the past), the more likely it is that marginal benefits are below marginal costs and that further growth is uneconomic.

The best attack on this argument is not to question the shapes of the curves, but to argue that the curves themselves continually shift apart so that the intersection always stays ahead of us, and thus growth remains economic. But there are physical limits to efficiency (how far down cost curves can be shifted), and I suspect that our rush toward growth-permitting technologies (for example, fission power) is more likely to push the cost curve up than down, once all costs are counted. Also our efforts to push the benefit curve up by creating new wants too rapidly and too artificially are, in my view, more likely to pull down the benefits curve than to push it up. Probably Hueckel would dismiss these claims as personal value judgments. But they are not value judgments, they are personal judgments of fact. What in fact are the real costs and benefits at the margin? We do not measure costs of growth in our social accounts—or rather we do measure them, but count them as benefits. Deciding just what is a cost and what is a benefit involves value judgments, but is also in large part a judgment of fact. That the properly accounted marginal benefits of growth in the United States are below the properly accounted marginal costs, or at least soon will be if physical growth continues, is a judgment I consider reasonable, though it cannot be conclusively demonstrated. But neither can the contrary proposition be conclusively demonstrated, yet Hueckel and other growth economists accept it as the only conceivable possibility.

Hueckel says that even granting the diminishing marginal utility of income, my argument still runs into the grave problem of "identifying the point at which . . . society moves from the classification of 'poor' to 'rich.' " If we cannot distinguish poor from rich, then what is the justification for growth in the first place?

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Hueckel's discussion of some crucial issues in the "limits to growth" debate is more careful and sophisticated than most, but it still begs too many important questions to be persuasive.

First, Hueckel argues as if ecology had never been discovered. Suppose, for example, that it does become economically and technologically feasible to extract metals from seawater and ordinary rock. What would the ecological consequences be of processing (in an extremely energy-intensive fashion) the huge volume of materials needed to supply our current demand, much less the expanded demand he envisions? After all, the ecological problems and costs of exploiting the relatively high-grade Western coal and oil-shale resources have provoked considerable controversy (and even some loose talk about the necessity for "zones of national sacrifice"). In the past, the scale and intensity of human economic and technological activity has been below the threshold that would cause serious ecological degradation,, and technological development could therefore proceed unimpeded. Now, there is little or no slack in the ecosystems important to human well-being, and every technological "solution" seems inevitably to create additional problems.

Second, Hueckel appears to overlook the enormous planning and management problems attached to continued growth. Starting from our already high level, the implications of future growth are daunting, not only in terms of the quantities involved (for example, the construction of as many as 900 nuclear power plants in the next 25 years), but also in terms of our ability to orchestrate the work of innovation, construction, and environmental management to form a reasonably integrated, safe, and harmonious whole (unlike the present situation, in which undesirable social and ecological "side effects" abound and thorny safety issues remain unresolved). Technology cannot be implemented in a vacuum. In fact, something like the ecological "law of the minimum" applies: the factor in least supply governs the rate of growth in the system as a whole. Where, for instance, shall we find the staggering amounts of capital we will need to build all those nuclear power plants *and* exploit offshore oil *and* create new coal mines *and* so on?

Third, ironically, economist Hueckel neglects important political-economic issues. For example, the market price mechanism handles modest incremental change with relative ease, but it tends to break down when confronted with genuine scarcity (for example, famine) or marked discrepancies in supply and demand (for example, monopolies and cartels). Nor does it deal appropriately with common property resources. Moreover, discounting can make ecologically priceless future resources (like a breathable atmosphere) effectively worthless to today's economic decisionmakers. Furthermore, although letting the market take its course can adjust supply and demand most of the time, the social consequences are often so painful that governments will usually go to considerable lengths to avoid it. Including the social costs of production in market prices, as Hueckel and others suggest (although the practical difficulties of doing so are substantial), would remedy some of the defects of the market alluded to above, but only by increasing the painfulness of the market's impact on individuals. The critical question therefore is, Do we have the political will to reform the market if this will involve personal sacrifice? or, more colloquially, Who will bell the environmental cat?

This by no means exhausts the issues Hueckel has failed to consider—thermodynamic limits to technological advance, limits to the invention and application of knowledge to human problems, and many other questions only hinted at above (for example, the social and political implications of accepting the "Faustian bargain" of modern technology) that I have discussed in detail elsewhere (*1*). Hueckel has considered technology and the market price system in artificial isolation from ecological and other practical realities. His optimism about future economic and technological growth would therefore appear to be ill-founded.

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Hueckel criticizes the Meadows-Forrester assumption that, with continued economic growth, "world resource usage will approach the corresponding U.S. rate." Hueckel promotes instead the sound theoretical economic position that the technology employed to achieve a given end will reflect the "prevailing structure of the relative prices of those inputs [capital, labor, and resources]." It would seem to follow that poor countries characterized by surplus labor, few natural resources, and a scarcity of machine capital would be utilizing labor-intensive, resource-saving technology.

Hueckel uses the examples of 19th-century England and 19th-century United States to bolster his contention. At that time, appropriate technologies were in the initial evolving state in both countries. Hueckel ignores the fact that today's nonindustrialized country *imports* technology along with a host of social images reflecting what is the appropriate salary and lifestyle of an employee in the modern sector. The despair of development economists is that, lacking indigenous technologies, underdeveloped countries are forced to "select" the capital-intensive, labor-saving technology which appropriately enough reflected the then optimal input mix of the Western countries creating it.

The continuation of this practice seems certain for as long as the most promising students from underdeveloped countries are sent abroad for a postgraduate education in the "most advanced" technologies. Attempts are now being made to create research institutes in underdeveloped countries themselves, but whether these centers will come up with technologies that will weaken the relationship between economic growth and increased use of nonrenewable resources is a question open to much debate, as is the question of how soon such innovations would be dispersed in the field. The lag time between innovation and widespread acceptance is also a crucial factor in forecasting the West's needs in a time of changing resource prices.

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Hueckel states that "the high pressure [steam] engine was cheaper to build but apparently was more extravagant in its fuel requirements." High pressure steam means high temperature steam which gives a greater thermodynamic efficiency according to the following relationship.

$$\text{Efficiency} = \frac{\text{Inlet temperature} - \text{Exhaust temperature}}{\text{Inlet temperature}}$$

A high pressure steam engine delivers more power for less fuel than a low pressure engine. In addition, a high pressure engine probably produces more power per unit weight, which would mean that less material would be required for its construction.

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Although much of my article was devoted to the question of physical limits to economic growth, of the letters printed here, only Edens' is explicitly concerned with that issue. Ironically, Edens accuses me of "an overly narrow time perspective" and then raises the same issue as that raised by Mishan—that the development of the modern industrialized nations has depended upon the availability of fossil fuels—an issue which I criticized in the article as "the result of a lack of sufficient [historical] perspective."

The past two and one-half centuries clearly have been unique in human experience; but, as I argued in the article, Edens' "dynamic factor" in past growth has not been society's dependence upon fossil fuels but rather society's ability "to advance its technological knowledge to the point where those resources could be employed for the satisfaction of human wants." It is, after all, that knowledge that makes a given material useful to society; and the fact that terrestrial deposits of those materials might some day be exhausted does not necessarily imply that economic growth must stop, only that knowledge must continue to advance. The fact that past technological change has not been random and capricious but rather has occurred in a systematic manner in response to market forces causes me to take an optimistic view of the probability for future advances in knowledge.

Clearly if we confine the discussion to our own planet [a constraint which O'Neill (*1*) argues is unnecessary], no one can deny that there is a physical limit to energy and mineral use—a point made by Daly and others elsewhere (*2*) and suggested by Ophuls' reference to "thermodynamic limits." That, however, is an obvious and rather uninteresting statement; the relevant question is whether society is now sufficiently close to that limit to warrant concern, and it is here that I must respectfully disagree with my critics. As Brooks and Andrews have noted (*3*), "the literal notion of running out of mineral supplies is ridiculous. The entire planet is composed of minerals, and man can hardly mine himself out."

Of course, those authors warn that the effort to obtain those resources might involve costs in the form of pollution, changes in land use, changes in the international distribution of wealth and power, or other disturbances which society is unwilling to bear—a fact of which I am quite aware, in spite of Ophuls' charge that I argue "as if ecology had never been discovered." Indeed, I find such a charge surprising, particularly in light of his reference only two paragraphs later to the very policies I proposed to reduce environmental damage. He criticizes those policies on the ground that they do the job "only by increasing the painfulness of the market's impact on individuals"—a rather perplexing criticism, since the external costs of production, of which pollution is only a part, are already borne by individuals. The effect of "including the social costs of production in market prices" simply would be to monetize those costs and to reallocate them so they are borne by those individuals who consume the goods and services whose production is causing the pollution. If the policies can be enforced efficiently, there would be little increase in the total cost borne by society. Obviously such a reallocation would involve personal sacrifice for some, but that sacrifice would be compensated by a cleaner environment. Ophuls questions society's "political will to reform the market if this will involve personal sacrifice." Is it any more likely that society would have the "political will" to undertake policies deliberately designed to stop economic growth? I doubt it.

I certainly agree with Ophuls that there are certain circumstances under which the market will fail to yield the desired allocation of resources. Indeed, his examples of "common property resources" and "discounting" are precisely the issues I treated in the last section of the article. He is quite right to include cartels in this category as well, though it is important to realize that even the strongest such organizations must be concerned with the degree to which consumption of the product declines as price rises—a fact of which the OPEC (Organization of Petroleum Exporting Countries) is becoming increasingly aware.

In the final analysis, however, the problems raised by Ophuls and Daly are contained in the question of the desirability of further growth. While certainly an important issue for national debate, this question is clearly more difficult to settle since, as Daly puts it, the problem is to evaluate "the real costs and benefits [of growth] at the margin." Unfortunately, in spite of Daly's efforts to devise one, there does not exist a generally accepted nor scientifically defensible standard with which to measure those magnitudes. Consequently, whether one labels these evaluations "personal judgments of fact" or value judgments makes no difference; the crucial point is that reasonable individuals can legitimately differ over their evaluations of the costs and benefits of growth. This is the meaning of my sentence of which Daly quotes only a part at the end of his letter. Obviously there is no problem in distinguishing for ourselves " 'poor' from 'rich' " and thus (in Daly's scheme) the point at which further growth becomes "uneconomic." But it is, in my view, the height of arrogance to presume to make that judgment for an individual other than oneself.

One final point of clarification is necessary in response to Leighly. He is quite right to expect a priori that the high pressure steam engine was more economical in fuel use—a point which historians of technology have noted (*4*). The difficulty arises in the details of the early 19th-century engine. Watt's low pressure engine employed a separate cylinder in which the steam was condensed to form a vacuum below the piston, the power being supplied by the operation of the atmosphere (or of steam at atmospheric pressure) above the piston. The early high pressure engines dispensed with the condenser and used steam at pressures around 50 pounds per square inch, venting it directly to the atmosphere. It appears that, in the early years of the engine's development, the sacrifice of the vacuum in the condenser reduced the fuel economy relative to the standard low pressure engine (*5*), although the new, high pressure engines could be considerably smaller per unit of power produced, as Leighly notes. One would expect that the best features of both engines would be combined. This occurred in Cornwall in 1812; and for the next three decades Cornish engines, operating with high pressure steam and a condenser, were widely renowned for their economy of fuel. This event is yet another example of technological advance conditioned by resource availability, for Cornwall was a county with abundant tin and copper (thus requiring steam power for mining operations) but peculiarly lacking in coal or wood for fuel.

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Traditional Tobacco Substitute

I agree with Julia F. Morton (Letters, 16 May, p. 683) that more land should be made available for food crops by eliminating the growing of tobacco. However, we already have a much more suitable alternative than cabbage, lettuce, or papaya leaves, and one which would not make use of food or food-producing materials. I am referring to corn silk, a traditional substitute for tobacco. It should be allowed to dry before harvest, of course, so that its role in seed fertilization would be over.

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Filming of Behavior

The article "Anthropological film: A scientific and humanistic resource" by E. Richard Sorenson (20 Dec. 1974, p. 1079) deserves comment, first because of its relevance not alone to anthropological research but to all behavioral research, and second because Sorenson does not mention very exciting ongoing research in the field of human ethology.

I agree completely with Sorenson about the urgency and need to record human behavior on film, but I would add that his argument holds for many other species as well, particularly those which are endangered by extinction, either through man's wanton slaughter or through the destruction of their habitats. Indeed, students of animal behavior have long recognized the usefulness of motion picture films for the documentation and analysis of behavior patterns. To this end the *Encyclopaedia Cinematographica* was established by G. Wolf, director of the Institute for Scientific Films in Göttingen, West Germany. Each film depicts a single type of behavior and is accompanied by a short descriptive publication. Leslie P. Greenhill at Pennsylvania State University is the director of the American Archive of the *Encyclopaedia Cinematographica.* Films on animal and human behavior are available.

In addition to the film studies which Sorenson mentions, the reader should be aware of the important studies of human ethology by I. Eibl-Eibesfeldt and his coworkers in the Research Unit for Human Ethology, a division of the Max Planck Institute for Behavioral Physiology, Percha, West Germany. They are filming rituals and unstaged social interactions, such as play, greetings, courtship, and child-parent relationships. They are particularly interested in similarities and differences in these behavior patterns in different cultures. By studying populations of cultures which have had minimal contact with outsiders they have attempted to capture on film behavior patterns in their purest form. This is exactly what Sorenson is arguing for. The films are published in the Human Ethological Film Archive of the Max Planck Association (*1*), and descriptions of the film studies are to be found in such journals as *Anthropos, Current Anthropology, Homo,* and *Zeitschrift für Tierpsychologie.*

Undoubtedly there are also other groups active in this exciting area of research. Let us hope that Sorenson's timely article will serve as a rallying point to bring together persons working in human ethology and focus their attention on the urgent need for film documentation of behavior.

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