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, plausable 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 contin-