postdocs before finding permanent spots. This success may be due to the cultural milieu of their work at LLNL. The environment at Livermore is more akin to what existed at several technical universities and institutions during the late 1940s and early '50s than to most current graduate education: Important problems with practical applications are posed and are expected to be solved in real time and within budget. This is an attitude that strikes a responsive chord in industry recruiters!

In addition to the national laboratories of the Department of Energy, the Department of Defense has many research facilities scattered about the nation. Any of these could be approached by a major research university and possible joint programs explored. There are also excellent private research facilities, some of which are already open to graduate students on an informal basis. We suggest a vetting of the best staff at these laboratories by the faculty of a school so that the staff can act both as instructors in formal courses on site and as research advisers—the model at LLNL.

If students are immersed in PhD research outside the academic setting, we believe that they will more easily appreciate the breadth of career opportunities that await them. It is recognized that half of those graduating from our law schools do not practice law; it is less well known that for years at least half of those trained as scientists and engineers have found jobs other than as scientists and engineers.

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The Sky is Falling! (Well, Part of It)

Regarding the three letters by Moti Segal and Rodney Kubesh, Michael Kelly and John Kepros on how an increase in the greenhouse effect might alter the heights of atmospheric layers (December 1994, page 15): Back in 1989 Ray Roble and Bob Dickinson of the National Center for Atmospheric Research, in Boulder, Colorado, investigated "global cooling" in the upper atmosphere.[1] They predicted that a doubling of the CO_2 and CH_4 concentrations at 60 km height (as expected within the next 50 years) would cool the mesosphere by up to 10 K. In the thermosphere the predicted cooling is greater, about 50 K. The resulting thermal contraction would reduce the air density at 300 km by about 40%, leading to increased orbital lifetimes of satellites.

Using simple physics, I estimated that the cooling would cause a drop of 15–20 km in the height of the ionospheric F2 layer (the layer that has the greatest electron concentration and is the most important for radio communications).[2] Better calculations with the NCAR thermospheric global circulation model gave similar results.[3]

These predictions are theoretical: What of the data? The ionospheric layers have been routinely sounded since 1931, though precise measurement of the height of the F2 peak is difficult. At middle latitudes by day, the peak typically lies at about 250 km at solar minimum and 350 km at solar maximum, though its height may vary by up to 100 km with time of day, latitude, and solar and geomagnetic activity. Given this variability, detecting a progressive decrease of the layer height would be difficult, but it should be possible. In Germany, Jürgen Bremer[4] has detected a drop of 8 km in 33 years, consistent with my theoretical prediction.

Of course more observations over longer time scales are needed to confirm the trend, together with further studies of whether global cooling in the upper atmosphere is indeed a reliable indicator of "global warming" lower down.

References

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Was PT's Environment Issue Misaddressed?

The November 1994 PHYSICS TODAY special issue on physics and the environment arrived, and I was delighted to find we were addressing one of the most important issues facing our survival. Now I was to learn what the world of physics, my field, had to say. First I learned that we were not even going to mention nuclear power: Fuel cells are the future. Then I get a dissertation on the nitrogen cycle, which, if it goes unchecked, will be a major problem in a few thousand years. Well, if the

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oceans keep rising at current rates, in a few hundred years most of the farmland will be underwater, so who cares? Next we consider clouds and then deep water currents, which are pertinent and very interesting.

Of course the big problem, which goes unmentioned, is how are we going to generate power in the 21st century without producing greenhouse gases and other pollutants? Certainly fuel cells are not going to be able to generate large quantities of energy, and where is all the fuel for the fuel cells coming from? The article suggests biomass, solar and wind power. A quick calculation of the usable solar power input to the Earth indicates we are now consuming power at about the same order of magnitude as we receive it. Since there is no thought of serious population limitation at this time, we can expect the power demand to rise according to the estimated population growth. Therefore we need a clean energy source, or a drastic reduction in our standards of living will result.

I am disappointed at PHYSICS TODAY for treating such a serious problem so lightly, especially when the issue was titled as it was. Let us try again soon.

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THE GUEST EDITOR OF THE NOVEMBER 1994 ISSUE REPLIES: My goal for the special issue on physics and the environment was to show where physicists might contribute to the generation of new knowledge. The five articles I commissioned dealt with open questions in environmental science (the nitrogen cycle, clouds, deep ocean currents) and in technology (fuel cells for mobile and stationary power, industrial restructuring to retain materials longer within the industrial system). Opportunities for physicists to contribute in these areas are abundant.

For the answer to Lewis Hollander's question about the source of fuel for fuel cells, I refer him to Sivan Kartha and Patrick Grimes's reply to Gary W. Harding's letter in the March issue (page 11).

As for the scale of our future energy needs, Hollander's "quick calculation" is off by a factor of 10 000. The solar flux of 1350 W/m^2 is intercepted by the Earth at a rate of 1.7×10^{17} W; 65% of this energy flow, 1.1×10^{17} W, is absorbed, not reflected, and thereafter drives the Earth's chemical and thermal processes. By comparison, humans consume commercial energy at a rate of 1×10^{13} W (roughly 2 kW per capita). It follows that solar energy (as photovoltaic photons, photosynthesized biomass, wind or heat) is sufficiently abundant to meet all global commercial needs. As with nuclear fission and fusion, important uncertainties surround the economic, social and environmental costs of today's and of future technologies. By not explicitly highlighting nuclear energy (which I acknowledged in the introduction to the special issue has "the potential . . . to loosen at least a few of the environmental constraints" on our energy-consuming activities), I was implicitly advocating that the efforts of physicists should be distributed across all the energy sources, including fossil fuels, and energy efficiency.

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Triggering Mosquitoes and Initial Butterflies

I thoroughly enjoyed Paul Nahin's letter (March, page 132) in which he relates Lorenz's butterfly from chaos theory to Lord Kelvin's mosquito, of whom it was said, "if all the matter in the Universe were reduced to its ultimate atoms and equally divided through all space, the disturbance caused by the beating of the wing of [this] mosquito would bring about everything that we find in the material Universe today." However, I believe there is an important distinction between the two insects.

A uniform mass distribution filling all of space is a mechanically unstable configuration. Kelvin's mosquito is the *trigger* that perturbs this configuration and sends it irreversibly on its way. Lorenz's butterfly, on the other hand, makes up part of the *initial conditions* that must be exactly (and impossibly) specified before the evolution of a chaotic system can be predicted. Kelvin does not address the issue of sensitivity to initial conditions. Thus we need both creatures: the mosquito to precipitate the formation of a lumpy universe, and the butterfly to beat its wings so that we arrive at our present configuration, as opposed to one in which Earth orbits a black hole in some distant galaxy.

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Corrections

May, page 19—The yellow band corresponds to CDF's results, the blue to D0's and the green to the overlap.

April, page 105—Jerome Wiesner was born on 30 May 1915. ■