How physicists can contribute

Concerned physicists can lend their particular skills to the common problems by direct research, by teaching courses in environmental physics, or by joining interdisciplinary centers.

Marvin L. Goldberger

It is part of the folklore of physics that physicists can not only do anything, but that they can do it better than anyone else. This modest appraisal is a direct outgrowth of their stunning performance during World War II, in which the development of radar and the invention of nuclear weapons were unmistakably physicists' accomplishments. In the past 25 years physicists in general (and many of those who were involved in the radar and bomb projects) have played anomalously important roles as advisors to the government and industry on problems quite outside their technical specialities. One should not then be too surprised that a number of physicists have become seriously involved with environmental problems.

Here I shall describe some of the present activities of physicists in environmental problems and consider new roles they may take up in the future. As I see them, the new roles would include direct research and development, education of young physicists for environment work, and participation in multidisciplinary teamwork.

Stanford study

Let me first describe my own involvement in this kind of effort. I am an otherwise mild-mannered theoretician who works in elementary-particle physics, and I have no background in environmental problems. I have, however, been active as a consultant to the Government, and, as a member of the President's Science Advisory Committee from 1965 through early 1969, I had an opportunity to be exposed to the early expressions of environmental concern transmitted to the incoming Nixon administration by various pre-inaugural task forces.

As a result of this exposure, Gordon MacDonald (also then on PSAC and now a member of the three-man Council on Environmental Quality) and I organized a study held at Stanford, during August 1969, sponsored by the National Academy of Sciences. We brought together an interdisciplinary group that addressed the general question of what institutional innovations were needed to produce effective means for preserving and enhancing the physical environment. In addition, to provide a focus to the activity, we studied in detail a particular environmental problem—the issues raised by a proposal to construct a major jet airport near Everglades National Park in south Florida.

This study involved a number of physicists, almost all of whom were totally inexperienced in working on environmental questions. The single most important technical contribution in connection with the Everglades Jetport problem was made by two young particle physicists, John Harte and Robert Socolow of Yale. I think it is fair to say that their contribution played an important role in the ultimate decision by the Government to forbid the proposed jetport development. Needless to say, their analysis of the threat to the water supply of western Florida posed by the jetport and associated commercial development bore little relation to their normal field of interest in elementary-particle physics. (Since then, both Harte and Socolow have continued their work on the environment—Socolow by full-time research and Harte by teaching an undergraduate course entitled "Environment: a scientific approach." They have collaborated on a book, "Patient Earth," which will be published next spring. See the box on page 28.)

The other outputs of the Stanford 1969 study included the suggestions for the creation of national environmental laboratories and of a large analytical "Institute for Environmental Studies." My own active involvement in environ-

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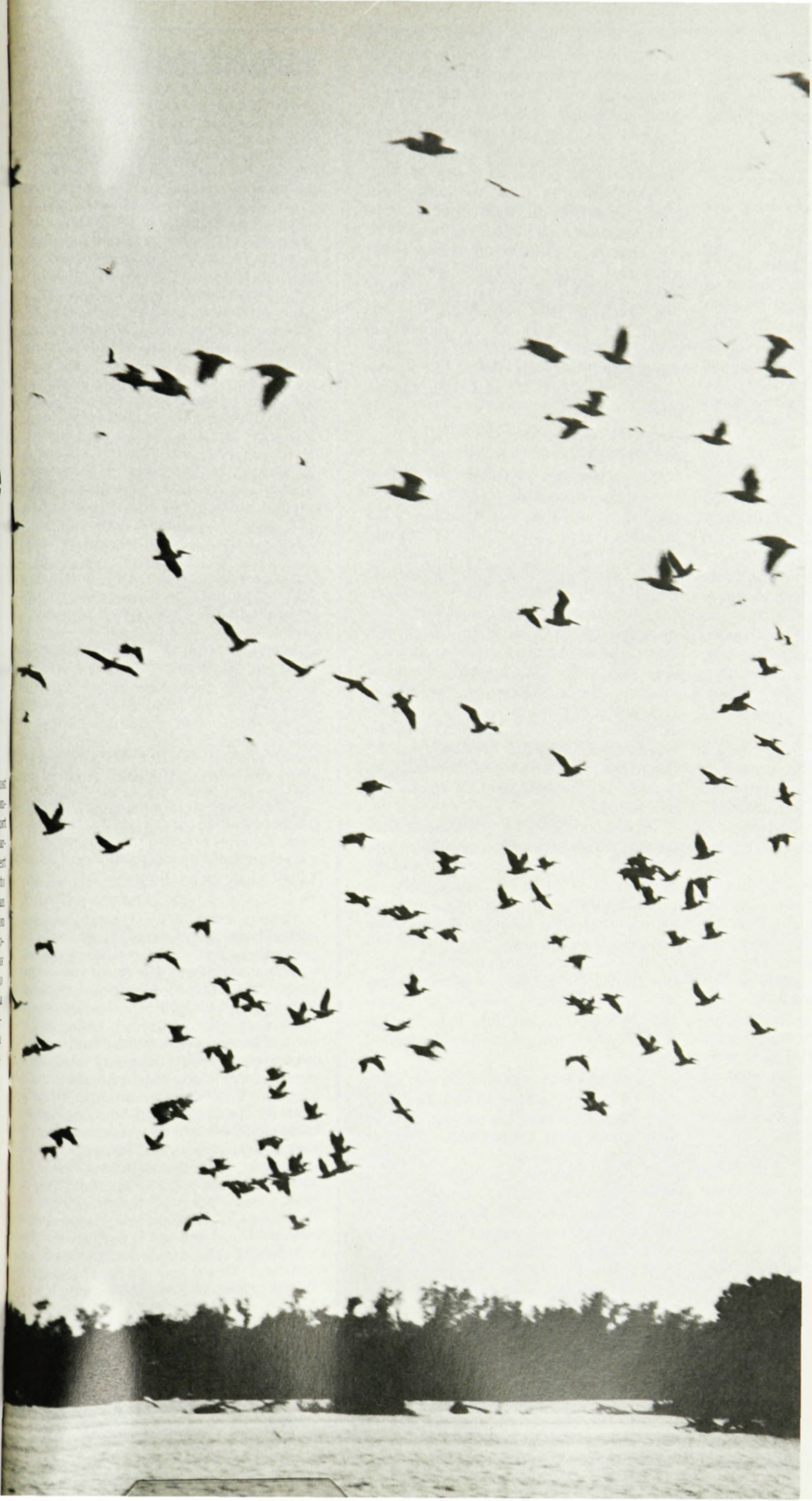

FLORIDA DEPARTMENT OF COM

White pelicans over Florida's Everglades National Park. Physicists led the fight to save the park when it was threatened by the development associated with a major jet airport.

mental issues has been through this summer study and, more recently, as a member of the Princeton University Council on Environmental Studies, and finally as a new member of the Sierra Club.

Confronting the crisis

Even so limited an involvement has convinced me that we are facing a crisis of alarming proportions in the form of environmental problems, and it has made me skeptical about some of the popular remedies. We are now being bombarded almost daily with staggering statistics. No pollutant worth mentioning involves fewer than millions of tons or volumes less than cubic kilometers. This leads some to the belief that what we are facing are purely technical problems, because they are so quantitative, and that what we must do is to redirect and reorient science towards these particular problems and all will be solved. Economists appear particularly prone to this kind of snap judgment when they extoll the "Green Revolution" in agriculture without considering the much broader implications of such technological fixes. In that particular instance, the fertilizers needed pose a critical problem of eutrophication of streams and rivers (that is, they are rich in dissolved nutrients but have seasonal oxygen deficiency), which has no simple technical solution.

We begin to see that many deeper problems lie in the social, economic, political and psychological pressures that drive our society and its structures into an increasingly hopeless morass of over-production and over-consumption of resources.

How should universities, and in particular university physicists, respond to these pressing problems? It is important to recognize at the outset that there is no single discipline, not even physics, that stands out as the natural one for future environmentalists. Real environmental problems are truly multidisciplinary. This raises two serious issues for universities. The first comes from the experience with previous attempts to train Renaissance Men or Generalists, which resulted only in the production of Superficialists. The second is that problem-oriented rather than discipline-oriented research is a foreign element in universities, by and large. Nevertheless, we need people who can solve problems.

Physical scientists are frequently confronted with the accusation that "their science," and the technology derived from it, enables the exploding population to destroy the environment. This, together with the exploitation of scientific developments by the military, has led to a widespread antipathy towards science in young people. The situation is exceedingly unfortunate. Even though science alone may not provide all needed solutions it is only through imaginative utilization of science and technology that many of the present problems can be solved.

There are at least three distinct routes that physicists interested in working on environmental problems or in making a contribution to their solution might take. The first and most obvious is to get physicists involved in research projects that bear directly on actual situations and require the development of instrumentation to be used in monitoring, studying and enhancing the environment as well as in theoretical analysis of technical problems. Many such activities can be carried out at universities as part of academic course work.

Involvement

For example, last year George Reynolds at Princeton taught an undergraduate course on air pollution. He discovered that much of the instrumentation currently being used in measurements involving ionization gauges is based on 1920's theory and technology. Clearly environmental problems need research on small mass spectrographs, laser light-scattering devices for measuring particulate distributions, chemical kinetics, the development of sensors, techniques of data processing, measurements bearing on the complexity of the carbon-dioxide cycle, atmospheric diffusion studies, aerosol behavior and gas-particle interactions, just to mention a few items.

Much work needs to be done in connection with water pollution, solid-waste disposal, recycling of raw materials, utilization of infrared technology in satellite photography for earth-resource surveys and crop management. There are many unexplored areas in theoretical and experimental meteorology, thermal pollution, electrical power transmission, and energy resources. I personally feel that the time may be ripe for a crash program on controlled fusion.

Many of these activities are very appropriate for university physicists, many can be carried out in industry and in existing national laboratories. One of the recommendations of our 1969 summer study was the establishment of a major national facility directly concerned with environmental research and perhaps a different center to deal with the important area of monitoring the environment—we cannot begin to restore and enhance the environment unless we know the present state and the manner in which it is changing. These new institutions do not yet exist, but I am sure they will soon. It is obvious that physicists' inventiveness, their capability in dealing with large quantities of data and their ability to design sharply

Patient Earth

To study the effect of a nuclear powe station on a lake one should understan something about the way radioactiv waste builds up in a lake and about th thermal distribution in the water. To di cuss the pros and cons of land develop ment in Florida's Everglades one needs t know the science governing salt-water er croachment into that fresh-water are An examination of the Department of th Interior's helium conservation prograr requires a little knowledge of the concep of entropy.

Two assistant professors of physics a Yale, John Harte and Robert Socolow have edited a collection of essays on top ics such as these, to be published b Holt, Rinehart and Winston next spring The book, *Patient Earth*, consists mainl of ten case studies describing enviror mental problems in contemporary Amer can society and four extensive scientifi supplements. The authors claim in thei preface that: "These are all stories o positive accomplishments, and they ar told by authors who have been directl involved in the problems. We have se lected the case-study approach becaus it begins to do justice to the intellectua complexities of environmental problem and because it leads the reader into th real world . . . Here and there throughou the book we show the reader how to d "back-of-the-envelope" calculations which give an approximate answer an point the way to a more refined calcula tion."

This approach is similar to that of th undergraduate course Harte teaches a Yale, one of a series of innovative an experimental interdisciplinary course called "College Seminars."

Cayuga Lake. This typical case-stud in the book follows the history of a pr jected lake-side nuclear power station.

When, in 1967, the New York Stat Electric and Gas Corporation announce its plans to build a nuclear power statio on the shores of Cayuga Lake, N.Y., local Citizens Committee, inspired by group of Cornell University staff mem bers, demanded environmental safe guards. They drew attention both to the thermal pollution and the buildup o radionuclides to be expected in the lake. Currently the building project lie dormant, the plans having been in definitely postponed in 1969. There fol lows a description of the stratification o the lake in its normal state and ar extract from one of the Citizens Com mittee's position papers, both taken from "Nuclear Power on Cayuga Lake," by Alfred Eipper, in *Patient Earth*.

"During summer months the lake is thermally stratified; the upper layer (epi limnion) and lower layer (hypolimnion) differ so much in temperature—and hence in density—that they do not mix, even under the influence of strong winds.

During the period of stratification (May to November) temperatures in the epilimnion range from 50 to 73°F; temperatures in the hypolimnion range from 40 to 43°F, just above the temperature at which water reaches its maximum density (about 39°F). The epilimnion layer becomes thicker as summer progresses, usually extending to depths of 35 to 50 feet below the surface. In autumn this layer begins to cool and subsequently to increase in density. This process continues until late October or November, when the density of water in the epilimnion has increased to a point where it is near enough that of the hypolimnion that the next strong wind causes the two layers to mix. The lake then becomes essentially the same temperature throughout and remains so (generally without ice cover) until May, when warming and density reduction of the surface layer reaches a point where stratification is re-established.

"During the period of stratification, biological production, particularly of single-celled algae, is largely confined to the epilimnion, where light is available in combination with nutrients and warmer temperatures. Dead plant cells and planktonic animals sink to the hypolimnion. While stratification persists, there is no source of additional oxygen for the hypolimnion. Animals confined to the hypolimnion—such as lake trout—use the oxygen there in respiration, and additional oxygen is consumed by bacterial decay of the dead plant and animal matter continually sifting down from above. Thus, oxygen in the hypolimnion decreases throughout the summer until that time in the fall when the epilimnion cools to the point at which winds can mix the entire lake again and rejuvenate oxygen supplies in the deeper water . . . "

Predicted effects of power-plant operation on the stratified lake:

"1 The onset of thermal stratification will occur earlier in the spring and, because volume of the epilimnion will be increased during the course of the summer, stratification will extend longer into the fall.

2 The length of the growing season for plants and animals in the upper layer will, therefore be extended.

3 Water brought up from the lower layer and flushed into the surface where most biological production (growth and reproduction of plants and animals) takes place, will contain nutrients previously unavailable to plants in the lighted portion of the upper layer.

4 A longer growing season and more nutrients in the surface layer of the lake will result in greater capacity for biological reproduction.

5 Prolonged stratification will extend the period of oxygen depletion in the large underlying layer of cooler water, where trout live, during the summer. Thus oxygen levels will become lower than they do at present, before being replenished by the delayed fall mixing of the upper and lower layers."

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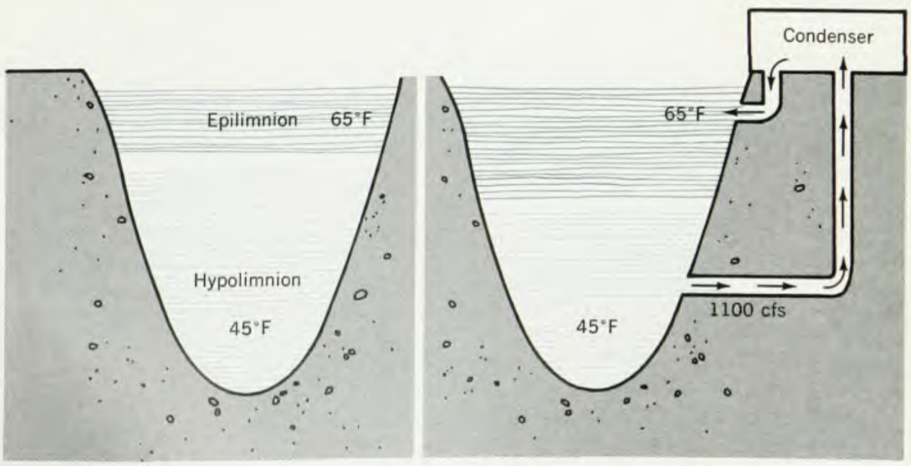

Cayuga Lake, as it is now and as it would be if used for power-station cooling. The relative volume of the two layers would change, but not their temperatures.

Proposal for a junior-senior curriculum

Earth physics
Elastic modes of the earth
Density-pressure versus depth
Seismic-wave propagation
Thermal balance
Tides
Earth-Moon dynamics
Global circulation
Geomagnetism
Ionospheric physics
Van Allen belt

Fluid dynamics
Shock waves
Turbulence
Hypersonic flow
Rockets

Plasma physics
Plasma frequency
Alfvén Waves
Stability
Fusion reactors

Astrophysics
Stellar structure
Stellar evolution
Radio sources
Synchrotron radiation
Stromgren sphere
Energy sources
Virial theorem—clusters
Fermi mechanism
Supernova physics
Neutron stars

Low temperature
Superconductors
Adiabatic demagnetization

Miscellaneous
Signal-to-noise
Radar
Coherent optics
Electron optics
Lasers
Reactor physics

focused research programs will make them vital members of such activities.

Training

The second way in which physicists can be useful is in the training of people who would like to specialize in environmental problems. To be most effective in this arena, we must modify our methods of teaching physics. As the field has progressed, and as the greatest demand for PhD physicists has been in colleges and universities (with solid-state physics the notable exception) there has been a distinct tendency towards specialization and, in particular, away from applied physics. These trends must be reversed if physics is to play the necessary and appropriate role in the education of environmentalists.

There are some who point to grave dangers in such a redirection of physics away from its traditional area of pure exploration of the fundamental laws of nature; they say that applied science is the job of engineering schools. I am aware of these dangers, but nevertheless I have become convinced of the need for a specific modification of the undergraduate curriculum in physics. My uneasiness in making this suggestion comes from the fact that the traditional style of physics education has produced a large number of extremely versatile and valuable members of society. A change in style does not come with any guarantee of the same success. On the other hand an argument can be made that the "unreasonable effectiveness" of physicists in the past is explained by observing that a great many very smart people went into the field at the appropriate time. I believe one can no longer count on that in the future; I am therefore willing to try a modification of the ancient process, one that I think will not disrupt the past traditions and has some positive virtues.

There have been two significant contributions to introductory physics course work in universities over the past few years. These are the Feynman lectures and the Berkeley physics program. They are both two-year courses, and both go a long way towards satisfying a basic need in undergraduate education: *excitement*. Kids entering college want immediate contact with new concepts, things they have heard of—such as relativity and quantum mechanics—and expect to find in college courses. I do not necessarily advocate slavish devotion to either Feynman or the Berkeley series. What is important, I feel, is to concentrate the basic theoretical development (most appealing to students at that stage) during the first two years, teaching simultaneously (and largely in the physics course) the necessary mathematics.

Then one is faced with the last two years. What is done at present, to a greater or less extent, is to ignore essentially everything in the introductory course (this is particularly true for the more customary one-year introduction to physics) and start all over again giving finer derivations and so on. My proposal for those two years is to teach applications of physical principles to a wide range of problems, developing and deepening the theory as one goes along and as it is needed.

I am not prepared to outline a detailed curriculum, but I can give some examples of what such a program might involve. See the box on this page. (I should say that Edward Purcell, when exposed to my idea some years ago, responded with enthusiasm and a number of specific suggestions that are incorporated here.)

My firm conviction is that people coming through this curriculum, or the one that would evolve after much more thought or a real trial, would be far better prepared than current students for addressing the serious problems of application of science and technology to social problems or for going directly into industry. I am also confident that those students who want to pursue traditional graduate training in physics would not be harmed; indeed, they would profit from the experience of seeing physics in action. Finally this curriculum change might have the effect of reversing the trend away from physics that we have experienced in recent years, a trend perhaps in part associated with the growing abstraction of the field and a feeling of its irrelevance.

Multidisciplinary teams

The third role for physicists is perhaps the most important although it is difficult to describe or measure. The most effective attacks on environmental problems will almost surely be carried out in problem-oriented centers whose personnel will consist of scientists, doctors, lawyers, economists, ecologists, sociologists, geographers, political scientists, architects, psychologists, and so on. The creation of a major center of this type was proposed by our 1969 study, and the prospect for its creation seems excellent at the moment. There should, in my opinion, be smaller versions at universities to form the glue for any serious effort in environmental education programs. A physicist working with this type of operation may use his specialized knowledge, but it is also quite likely that he will never write down the Schrödinger equation or Maxwell's equations or operate any experimental equipment. What he will contribute is a style of research, an openmindedness and a confidence in Man's ability to solve problems. These attributes are the result of training and successful research in physics. A physicist is not frightened by complexity; he knows how to isolate parts of a problem, and he knows how to utilize computers instead of worshipping them. I believe that there is a physics style of making models and developing phenomenological descriptions that can be very useful in environmental and social problems.

Physicists can make a contribution to environmental problems through any or all of these three routes—by actual research and development, by education, and as participants in a multidisciplinary team. Such activities are not for everyone, nor are all physicists likely to be effective or happy working on them. I believe there is a need however, and I hope that in the future many physicists will turn their talents toward this important problem of our times. □