

Of physics and applied physics

The American Physical Society has recently discovered an interest in applied physics. The training of students in applied physics is seen as a remedy for the malaise of the physics education establishment occasioned by the vanishing demand for its product. I should like to offer the opinions that, firstly, education in applied physics cannot be carried out in the ways apparently envisioned within the councils of the Society, secondly, that in any case it is not a potential remedy for the above mentioned dilemma, and thirdly, that offering training in applied physics is a good thing to do for its own sake. The special knowledge which qualifies me to deliver weighty judgments on these points comes as a result of participating from its outset in Caltech's applied physics program, at both the graduate and undergraduate level. The program is now five years old.

Caltech's is by no means the only applied physics department in the country, nor is it the oldest, nor perhaps—who knows?—even the best. It recommends itself in that it appears to have succeeded in what it set out to do.

The program at Caltech arose in response to a felt need, though not the one cited above. At the graduate level, students in many parts of the campus were working on problems that simply did not fit under the titles that would appear on their diplomas. Thus, for example, one student whose doctorate was to be in Aeronautical Engineering was studying superfluid hydrodynamics. Another in experimental high energy physics was really involved in sophisticated applications of solid state physics to the making of detectors, and so on. At the undergraduate level, considerable student enthusiasm for learning the secrets of the solid state and related matters was not being met in a systematic way. And perhaps most important of all, faculty members were doing what they felt to be research in physics on many subjects from neutron diffusion to nonlinear optics under the designation of various engineering and other disciplines. Applied physics already existed at Caltech, it needed only to be named.

As Shakespeare has shown us, one can question the importance of a name, but the importance persists nevertheless. Thus a course in solid state physics will come out a little differently if it is called Electrical Engineering 152, than if it is



called Physics 152, and differently yet if it is called Applied Physics 152. Moreover, the creation of a new curriculum, without precedent or tradition, offers opportunities for innovation that would not otherwise be present. In any case, it was decided to institute an Applied Physics Option (read Department. The absence of departments at Caltech is not the Institute's only peculiarity. However, the lack of Department Chairmen is compensated by the existence of Executive Officers).

The formulation of the new option began with a leisurely debate among its putative faculty members that centered around the question: What is applied physics? Even during the period of debate, however, a small committee (Hans Liepmann of Aeronautics, Floyd Humphrey of Electrical Engineering and your humble servant, Physics) was busy hammering out the details of the new program. For if no one could define applied physics precisely, it was nevertheless easy enough to identify when one saw it, and it was not difficult to reach a consensus on most matters of curriculum.

The terms that arose in the debate should perhaps be mentioned, even if they led to no practical (one might say applied) result, except to bring together members of the new faculty for a number of entertaining and somewhat lubricated evenings. For some, applied physics was

physics without quantum mechanics. For others it was engineering with quantum mechanics. My own favorite was offered by Liepmann: it is research on a problem that arose outside of the field in which the research is being done. The reader is invited to make his own contribution. What we could agree on was this: the applied physics student should be educated in those areas of physics the results of whose research would be likely to be applicable elsewhere.

In the name of both fiscal and intellectual economy, most of the new curriculum was made up of courses that had already existed under some title somewhere in the Institute. Thus, for example an undergraduate thermodynamics course came from Mechanical Engineering, a graduate hydrodynamics course from Aeronautics, courses in optics, plasmas and semiconductors from Electrical Engineering, a solid state course from physics, and so on. These courses, along, generally, with the allegiances of the professors who normally taught them were borrowed, renamed (the courses, not yet the professors), and thus transformed. In some instances, where another option proved reluctant to part with a course deemed useful for the education of the applied physicist (such as, a course in classical mechanics and electricity and magnetism offered by Physics) the students are simply advised to take it where it remains, and the Applied Physics faculty helps to teach it from time to time.

Two brand new courses designed to be key elements in the new curriculum were invented however. These were an undergraduate course, called simply Applied Physics, and one at the first year graduate level called States of Matter. The undergraduate course was intended to parallel the conventional course in Modern Physics taught by most physics departments, except that it would replace emphasis on nuclei and elementary particles with applications to lasers, semiconductors and the like. States of Matter would cut across the traditional boundaries of such courses as Solid State Physics and Statistical Mechanics to include subjects like the liquid state, phase transitions, and perhaps other questions of clear importance but insufficient elegance and fashion to suit the taste of many pure physicists. Incidentally, a textbook arising out of this latter course has now been published¹ and the reader is mod-

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estly directed to it for further details.

These courses, and indeed, a number of other courses offered by Applied Physics have proved extremely popular, with enrollments that consistently outstrip the number of applied physics majors available to take them.

The question of whether faculty members participating in the new program were to change their titles was at first a delicate issue. It was felt by some that since colleagues in other disciplines would be more willing than those in physics to have themselves so identified, the program would slip out of the grasp of the physicists entirely if title changes were permitted. These fears, however, eased with time (although they were not entirely ill-founded) and it also became clear that changes in title were essential to the success of the program, a point we shall return to later. Title changes were therefore allowed, on a voluntary basis, and a goodly number of professors of applied physics (or of applied physics and something, or of something and applied physics) may now be found in the Caltech catalogue.

Let me not be guilty of circumlocution. The issue we were contending with was the snobbery and prestige of physics. Those are symptoms of what I think one should call the Arrogance of Physics. It is the feeling physicists have that in a fundamental way they understand everything. Add a few messy details and you get chemistry, a few latin names and you get biology, but at the core it all reduces to physics. By and large, only the physicist will walk fearlessly into any seminar, only the physicist takes all of science for his domain.

As with many myths, the Arrogance of Physics is based on partial truth, and serves a real purpose. The deep, subtle challenge of an Applied Physics curriculum is not to overcome the myth, but rather to make use of it. The ideal applied physicist would have that same arrogant confidence in his ability and knowledge. He would differ from the pure physicist in being willing to plunge in and use that ability when the problem demands it. Notice also the role the myth played in the history of the program at Caltech. The thrust to form the new option came not from physics, but from the other groups that were to participate.

The program has been a success by any reasonable academic standard. It claims its share of undergraduate majors, roughly 15 each year which amounts to about 8% of all students. Applications to the graduate program have run at about 65 per year, of whom roughly 8 or 10 are accepted and enroll each fall. The quality of these students in perhaps not as flashy as the best theoretical physics students, but compares well to the run of

experimental students in physics. Nine PhD's have already been graduated. Positions for graduates of the program have not proved difficult to find.

It is difficult to estimate to what extent the students who emerge are different from what they might have been had the Applied Physics Option not existed (as we have seen, the change was made in such a way that most of the professors, most of the courses and many of the students would have been at Caltech even had it not been done). From the beginning, the broad base and interdisciplinary nature of applied physics has been stressed in all decisions regarding curriculum. Nevertheless, the students, particularly graduate students do not lose all trace of their intellectual origins (the aforementioned Aeronautics student studying liquid helium, when asked a question, any question, would start by going to the blackboard and drawing an airfoil. A low temperature physics student would have drawn a beaker). We hope that together with the broad variety of subject matter to which we have insisted they expose themselves, the luster of the word Physics glimmering on their diplomas, and the resulting domain that they perceive to fall within their professional competence, we will also have left them with a new spirit in which to choose and approach the problems they will go on to attack. The resolution of the debate on applied physics should ultimately come to this: that the scientists we produce are Applied Physicists, and that applied physics is whatever it is they do.

Let us return now to the concerns of the American Physical Society in this matter. During the two decades that followed World War II, American higher education underwent a period of expansion which is both without precedent, and never to be repeated. At the end, some 40% of the college age population was in college, with many more in other forms of post-secondary education. The comparable figure is 8% in most of Western Europe, and in an earlier America.

In physics in particular, (and in other sciences as well) this rate of expansion joined smoothly onto a process that had been going on since the eighteenth century but could not persist much longer.² The population of the physics community increased at the rate of about 10% per year, a doubling period of about seven years. Roughly 60% of the new graduates went to meet the growing academic demands, the rest going principally into industry and government laboratories. The job has been done now, the demand has been met. We can congratulate ourselves.

The long period of expansion had an additional effect, however. We developed a style of academic research that required a high throughput of graduate students for fuel. We have become accustomed to those students, and finally



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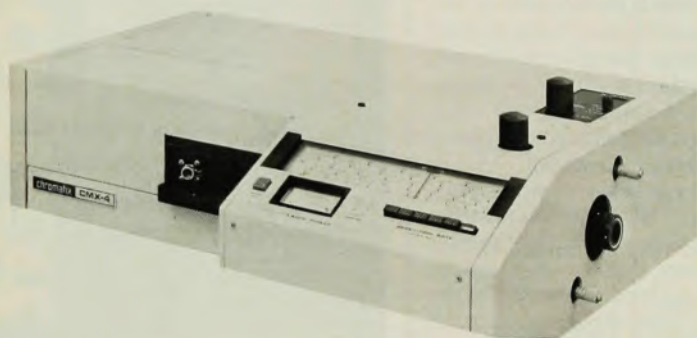


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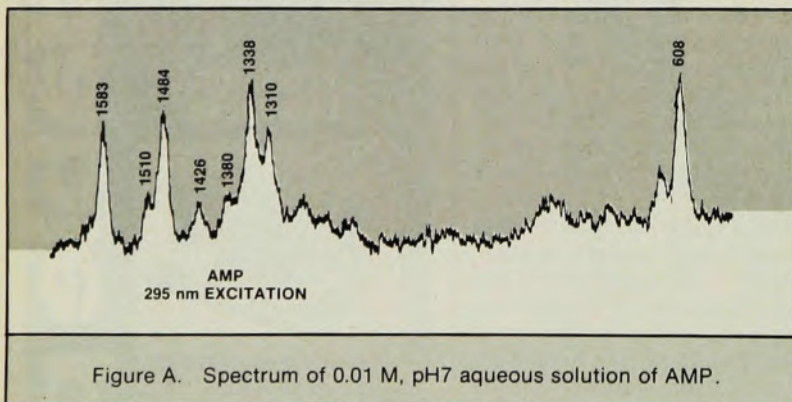


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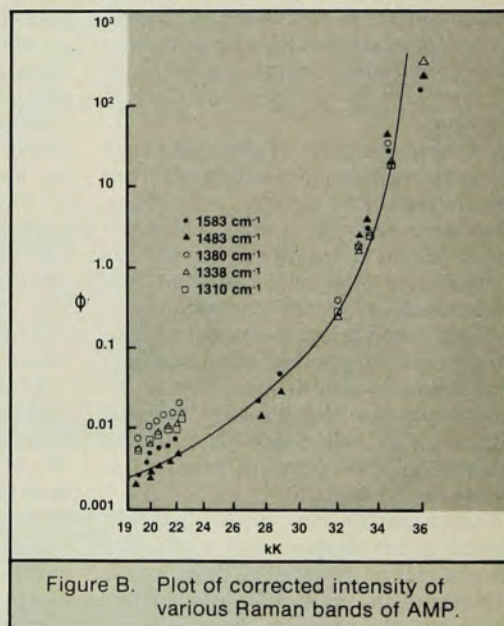


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dependent upon them. We need them in order to compete. This, I think, is the real dilemma that animates the American Physical Society's discovery of applied physics: if the universities can no longer absorb our issue, we will tailor our issue for other ends. The alternative, which is unthinkable, would be to do without all those students.

To see just how deep the dilemma is (and why applied physics is not the solution) consider for a moment that alternative. The PhD production rate needed for a stable physics population would be about three per university professor per lifetime—one to replace him (or her) when he (she) retires, the other two to go into nonreproductive jobs (industry, government laboratories, four year colleges, etc.). Assuming that by means of a resolute effort we could increase by a substantial factor the number of our (applied) physics graduates wanted by industry, that equilibrium ratio might increase, say, from three to four. That result would have no serious effect on the fundamental dilemma. The rate that we must decrease from is an average roughly fifteen PhD's per professor per career. What is needed is not curriculum reform, but a fundamental change in the system of academic research.

Even if we were willing to change the system, one might reasonably ask, what are we to do with the hordes of bright-eyed students who present themselves at our doorsteps each year, faces shining with the eager desire to learn physics? The question is a complex one that needs to be studied, although parts of the answer are easy to see. Graduate school is, after all, a kind of job. If the assistantships dry up, so will much of that eager desire. In any case, the point is that the system must change; that much is predictable from the inexorable mathematics of exponential growth. The only questions are, how? Into what? At the expense of whom? Those are questions we will not even begin to ask ourselves until we admit that change there must be.

Nevertheless, the education of students in applied physics is a worthy goal in its own right. I have avoided setting out in detail Caltech's curriculum in Applied Physics because it need not be copied. Each institution, deciding to initiate such a program, ought to build it (as Caltech did) around the particular predilections and strengths of its own faculty. However, on the basis of our experience, perhaps I can offer some suggestions for what ought not to be done.

Applied physics ought not to be presented offhandedly, as a sideline, by people who are physicists and would rather be doing pure physics. Here the matter of professorial titles enters. Applied physics students need Applied Physics professors whom they can copy,

with whom they can identify, by observing whose behavior they can learn what an applied physicist is and what one does. Otherwise applied physics just becomes second class physics, and the students we turn out will be neither very happy nor very good. The other side of this argument is that we are very good at training pure physics students (even if we train too many of them) and that kind of education should remain available and untampered with, both for the benefit of the students who remain dedicated to it, and for the future of our discipline.

To conclude then, let us by all means create the new discipline of applied physics. On intellectual, scientific and technological grounds it is more than justified. And let us face up squarely to the dilemma that disturbs all of us in the profession of academic physics. But let us not deceive ourselves into thinking that the first will resolve the second.

References

1. D. L. Goodstein, *States of Matter*, Prentice-Hall, Englewood Cliffs, New Jersey, (1975).
2. D. J. de Solla Price, *Little Science, Big Science*, Columbia University Press, New York, (1963).

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