letters

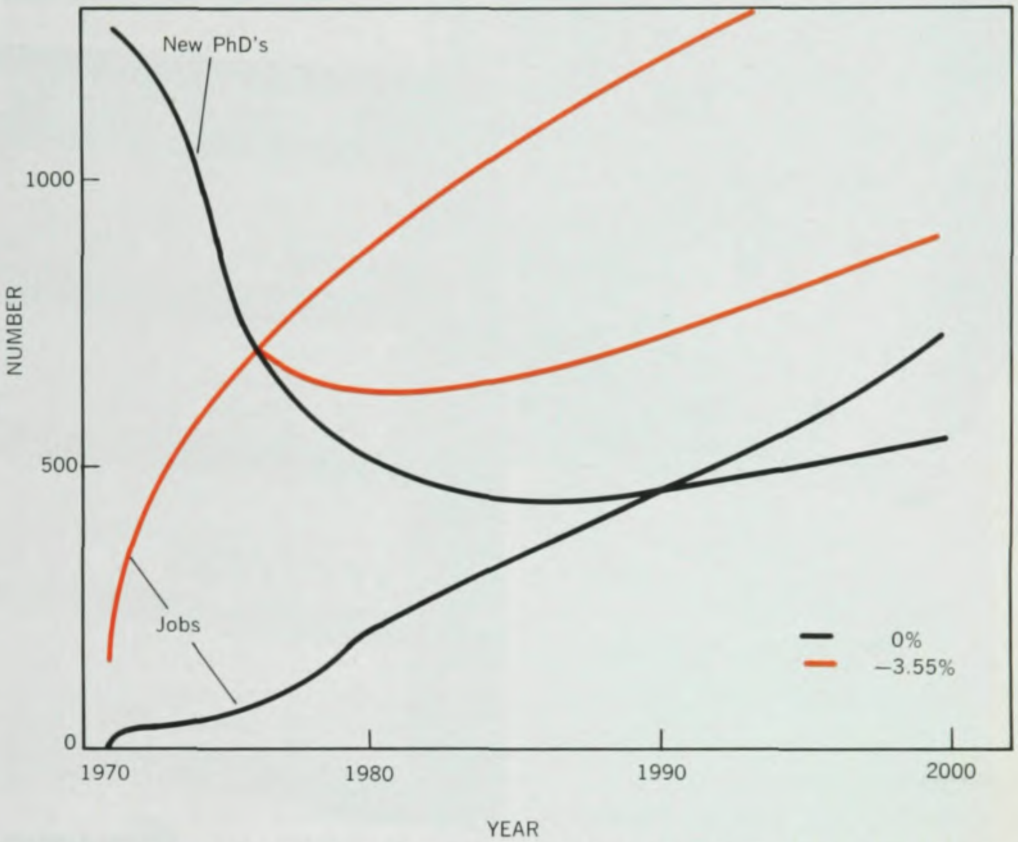
Modeling PhD production 1960–2000

Most physicists, particularly the younger ones, are sadly agreed that the days of plentiful money and jobs are gone and not likely to return. There is far less agreement, however, on how we, as a profession, should react to the present and future dilemma. Should we cut down on graduate-school admissions to reduce the number of unemployed new PhD's? Or should we recruit more actively, since large graduate-level faculties cannot be justified without sufficient students?

To answer questions such as these is difficult because we have no clear visualization of the interactions involved in the growth of the physics population. It is now well known that Allan Cartter,[1] in several farsighted publications, predicted the current glut on the PhD market. His results were obtained by comparing projected college enrollments with projected PhD production figures. The former quantity is not difficult to estimate from the known present age distribution of those who will populate colleges in the 1980's (or birth-rate predictions, for the 1990's students) plus an idea of what fraction of a given group will enter college. The latter projection, however, is more difficult to make reliable for any period farther in the future than about ten years. The reason is simply that the probability a student will enter graduate school depends on how worthwhile a PhD appears to him while he passes through high school and college. The extent to which the current gloomy market will depress the future influx of new physics students is difficult to assess, but such an estimate is essential to any insight into our future.

Most of those who predict PhD production for the remaining years of this century have assumed very little relationship of supply to demand. It is now becoming clear, however, that diminishing demand does lead to decreased enrollment, as emphasized recently by Lincoln Moses[2]; undergraduate enrollment in physics reached a maximum value about 1968 and has declined since.

In an attempt to understand the essential features of the complex interrelationships that are involved here, we have constructed a simple mathematical model of the growth of the US physics population.[3] To be sure, the model is oversimplified, and we are aware of many shortcomings that could be remedied in a more detailed calculation. In the spirit of the phenomenologists' art, however, we wish to present a "bare-bones" model that keeps the physics of the problem simple, and is at least qualitatively credible. Figure 1 shows our final conclusions. We hope our findings will stimulate controversy, because that will lead to better models and a clearer understanding of the alternatives before us.



Predictions for PhD production and available jobs, for budget growth rates of 0% (black curves) and 3.55% (color) Figure 1

Doctoral physicists, unlike angular momentum, energy and charge, are not conserved. Their number diminishes from retirements, deaths, and emigrations, and is replenished by immigrants and new PhD's. That is:

$$\Delta N = -\delta_r - \delta_d - \delta_e + \delta_i + \delta_n \quad (1)$$

where ΔN is the annual change in the total number of PhD physicists and the δ_α refer respectively to these five sources. The calculation we wish to present here is based on building a model for each of these effects. The resulting formulas were then fitted to experimental data for the years 1960–1970 to obtain best values for the parameters involved, from which we are able to make projections into the future.

The first two sources of change are relatively easy to describe, and we omit the details here. The heart of our model is its description of the number of new PhD's. Why do people go to graduate school in physics? Few of us, if pressed, could give a more satisfactory reason than that we like the field. But why did so many like the field in the "good" years of the early 1960's? Our model assumes that the determining factor is simply the ratio of demand to supply, as in so many other economic matters. This does not necessarily imply that anyone goes into physics for pecuniary reasons; the ample financial support of the good years may have been an effect, rather than a cause, of the same "mood of the

times" that made so many of us like the field.

We assume that the demand for physicists is reflected in the number of jobs available. This quantity is easy to calculate if there are more people than jobs, but it is more difficult to define in the converse situation. Our model assumes full employment in 1955—that is, 5000 physicists and 5000 jobs—as an initial condition. (The number is based on the American Science Manpower listing.) The number of jobs available changes for two reasons. First, changes in the budget will increase or decrease the total support. Some increase in the budget is essential to cover inflation and (we hope) give everyone his annual raise. We call the fractional increase required for this purpose r. If the budget increases by more than r, the remaining money can support new jobs; if by less than r, some jobs will be eliminated. (One could call this cannibalization.) The second source of new jobs is from deaths and retirements. Since the average physicist at death or retirement is presumably earning considerably more than a starting salary, he can be replaced by more than one new job. The exact number is, of course, conjectural; we define it by saying that each death or retirement produces one *new* job. Thus in year Y the change in J, the number of available jobs, is given by

$$\delta J(Y) = \delta_r(Y) + J(Y-1) \times \left[\frac{D(Y)}{D(Y-1)} - 1 - r\right] \quad (2)$$

where $D(Y)$ is the dollar supply in year Y. To describe the latter quantity we have used the figures given for total federal expenditures for research and development for the period 1955–1970, but it should be emphasized that only the fractional change in $D(Y)$ is important to the model. Using equation 1 and the boundary value J (1955) = 5000, we can calculate the demand for physicists through 1970 if we know the value of r. Our best fit to the data, to be described shortly, yields $r = 0.0355$, and the results corresponding to this value are shown in figure 1. Also shown there are the experimental values for the total number of physicians N, revealing that during this period demand exceeded supply by as much as 70%. The fact that the ratio has essentially dropped to unity in 1970 is evidence that this model is quantitatively quite satisfactory.

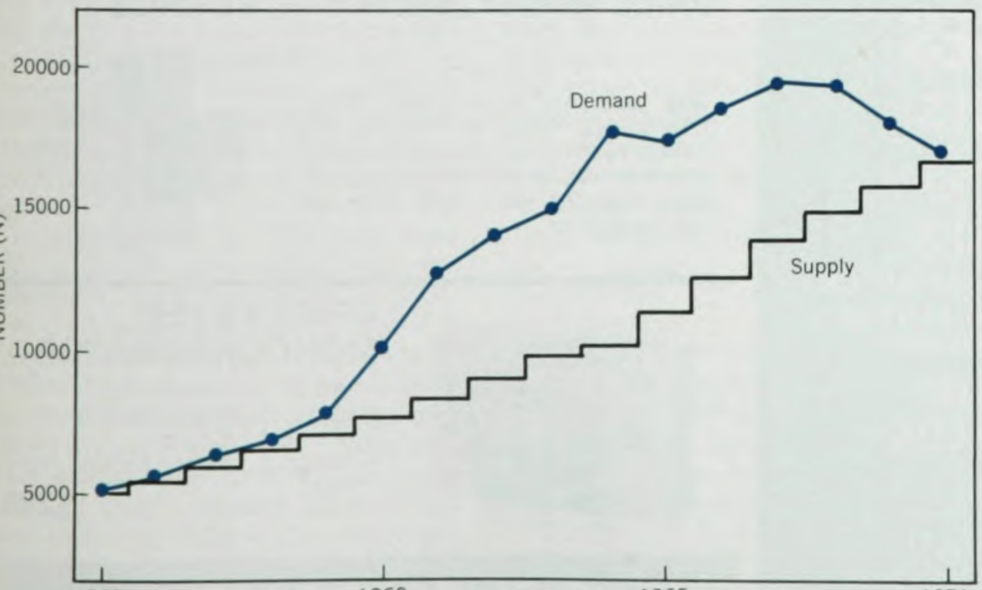
Using this model for the demand for physicists, we may now attempt to describe the production of new PhD's. The decision to go to graduate school is made, on the average, about six years before the successful candidate gets his degree. We neglect any dependence of the fraction who finish on the economic situation. Then the number of PhD's awarded in the year Y can be assumed proportional to some power of the demand/supply ratio six years earlier.

$$\delta_n(Y) = \beta\{J(Y-6)/N(Y-6)\}^{\alpha} \quad (3)$$

(Time delays of 4 to 5 years were also tried, but the 6-year figure produces substantially better agreement.)

Finally, we must describe the emigration and immigration of physicists to and from other countries and other fields. This quantity is assumed to be proportional to the number of open jobs, assuming that there is a one-year time lag

$$\delta_e(Y) - \delta_i(Y) = \gamma[N(Y-1) - J(Y-1)] \quad (4)$$



Comparison of the supply of PhD physicists with our model of the demand for them during the period 1955–1970. Figure 2

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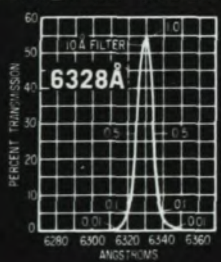

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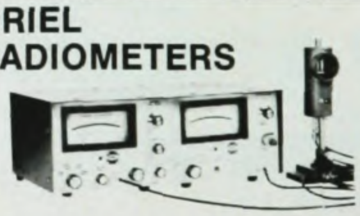

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The net effect of these two terms turns out to be quite small.

These four equations, plus the retirement rates projected above, can be used to predict the number of new PhD's and the total number of physicists for the period 1960–1970 as a function of the four free parameters α, β, γ and r. According to time-honored phenomenological methods, we have used a minimization routine to find the values of these constants that produce the best agreement (in the least-squares sense) with the experimental data. The best values are $\alpha = 1.39$, $\beta = 690$, $\gamma = 0.0252$, and $r = 0.0355$. A comparison of the experimental values of N and δ_n with the results obtained using these parameters is shown in figure 2. Considering the simplicity of the model, we feel the fit is quite good.

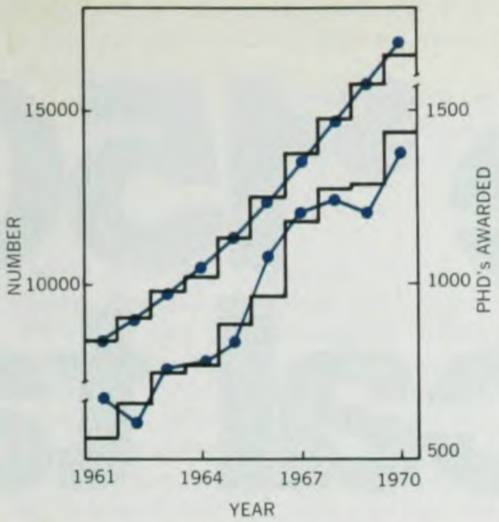
What does this model predict for our future? The answer depends, of course, on the budget. We have investigated a number of possible growth rates; in this letter we shall show the results of only two, zero growth and 3.55% ($=r$) growth, which (hopefully) are reasonable bounds on the true figure.

The number of new PhD's produced is determined primarily by the value of β; when supply and demand are in balance, we can expect to award about 690 degrees per year. This figure represents roughly the number of jobs that can be supported by the salaries freed through death and retirement. Our model predicts that the PhD output will fall to this figure by the late 1970's, as shown in figure 3, and not increase much above it thereafter.

The implication of this result for graduate education in physics is profound: *We must plan to exist on a graduate enrollment of about one-half that of the peak years of the last decade.* Such a cutback will necessitate considerable rethinking of policies on course offerings, teaching assistants, and many other related matters. Moreover, fewer students require fewer faculty, depressing demand still further.

A rapid decline in PhD production will, of course, lead to considerable improvement in the job market. The degree of this improvement is shown in figure 3 by the number of job openings predicted for each of the two growth rates. With reasonable budget growth (about 2% per year) those of today's seniors who go on to graduate school can expect a seller's market by the time their PhD's are awarded or soon thereafter.

If present trends continue as indicated by this analysis, then the job crisis will correct itself. Everything possible should, of course, be done to ease the difficulties it is now causing; but we should also devote more effort to planning what happens afterward. Unless some means of stimulating demand for PhD physicists, other than a rising budget, can be developed, we are facing a serious decline in graduate enrollment in physics.



Comparison of the predictions of our model with the experimental values for the total number N of physicists and the number δ_n of new PhD's awarded per year. Because of the six-year time lag built into the model, the data from 1955–1960 must be used as initial conditions. Figure 3

References

1. Allan M. Cartter, Proc. Am. Stat. Assoc., 1965 edition, page 70. See also Dael Wolfle, Charles M. Kidd, Science **173,** 784 (1971).
2. L. E. Moses, Science **177,** 494 (1972).
3. N. W. Dean, IS-2985.

NATHAN W. DEAN
Iowa State University

Racial statistics decried

I just received the APS-AIP Questionnaire and want to voice my objections to Question 32 of that questionnaire.

Question 32 reads: "Race or Ethnic Groups: Please check the race or ethnic groups which apply to you." It then proceeds to list nine categories of "race or ethnic groups": White, Black, Oriental, Other Asian, American Indian, Mexican-American, Puerto-Rican, Other Spanish Speaking, Other (specify).

As a matter of very deeply felt principles, I respectfully refuse to answer Question 32. By the same principles, as a member of the American Physical Society, I urge you take measures toward permanently removing answers to Question 32 from each questionnaire returned.

The last time I had to answer questions regarding my race was in Nazi-occupied Poland. On the basis of my own and other people's experiences