MIT PHYSICS

GRADUATE ALUMNI

Graduate Record vs Achievements

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SINCE 1930, when Karl T. Compton became president of the Massachusetts Institute of Technology, about 500 graduate students have been awarded doctoral degrees in physics by MIT. This corresponds to more than a twentieth of the total output of ScD's and PhD's in physics in the United States during these thirty years. In connection with the Institute's Centennial Celebration this year the administration has instituted a number of historical surveys of students and alumni. Because the doctoral alumni in physics since 1930 constitute a large enough sample for statistical validity and because records of these alumni are fairly complete and uniform in quality throughout the period, a detailed study of this group was authorized.

Available Data

SINCE 1933 the MIT Physics Department has kept records of all its graduate students on a standard form, which provides a detailed history of his work as a graduate student. In addition, the Admissions Committee of the Department has kept records (except for the years 1942–48) of its ratings of applicants for admission to the graduate school in physics, and the Department has recently sent out questionnaires to its alumni, from which we have learned the present status of more than 70% of these men. The volumes of *Science Abstracts, Section A, Physics,* were searched to record all papers there included which were written by any of them. Another indicator of their professional progress and standing as physicists is their election as fellows of the American Physical Society (70 of the 500 are now fellows) and their listing in *American Men of Science* (216 are listed in the 1955 edition). A small number (16) of these men are also listed in *Who's Who* and a still smaller number (6) are members of the National Academy of Sciences. All four indicators were recorded.

Before listing the other data recorded, it is appropriate to describe the steps in the progress toward the doctorate of a typical physics graduate student at MIT. His application for admittance, with letters of recommendation, is rated (on a scale from 1 to 9) by an Admissions Committee of the Department, and usually only the ones with ratings higher than 5 (about half of them) are admitted. About half of these come to MIT; the others decide to go elsewhere. (Questionnaires sent, in several years, to these "no-shows" have provided fairly complete data as to where they went and why they decided not to come to MIT.)

Those who do come take graduate subjects for the first year or two; in some cases the Admissions Committee has decided the student is deficient in one or more undergraduate subjects, which may be made up either by examination or by attending the appropriate class. The amount of course work is measured in "hours"; a usual graduate subject counts twelve hours and a full load of four subjects per semester thus corresponds to about fifty hours per semester or about 100 hours per full-time year. Teaching and research assistants usually register for between 30 and 36 hours per semester.

More than three quarters of the graduate students in physics at MIT go directly for the doctor's degree, bypassing the master's thesis. Since 1945, every candidate for the doctor's degree has been required to take a

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qualifying examination. Since 1950 this has had to be taken during the first term of his candidacy. Those who fail the first time have one more try during the next semester; those who fail the second time must change to candidacy for the master's degree, or cancel their graduate registration in physics.

No later than the beginning of the third year of his doctoral candidacy, the student must take the general examination, with both written (since 1950) and oral parts; here again the student has one more try if he fails the first time. Before this time the student has usually passed reading examinations in two foreign languages and has started some research work, preparatory for his doctoral thesis. To start research under the supervision of a faculty member the student signs up for six or more hours of special-problem work for a semester or two, under a faculty supervisor of his choice. When the research appears promising he requests approval of his thesis topic and, if approved, signs up for thesis work. Students are urged to start a special problem not later than their second year of graduate work so they can be given individual attention as early as possible. When their thesis research is completed and their thesis is written, they take an oral thesis examination and, if this is passed, they are awarded the doctor's degree, either the PhD or the ScD, according to their choice. No definite number of graduate subjects in physics is required of the doctoral candidate; he takes enough courses to pass his qualifying and general examination. He is required, however, to take and pass at least three single-semester courses in some department other than physics for a minor. Most physics doctoral candidates (90%) have taken their minor in mathematics, though some (5%) took theirs in electrical engineering and a few chose economics or chemistry or biology or another engineering subject.

Since 1945 most physics graduate students have had either teaching or research assistantships or fellowships (such as the NSF fellowships) during most of their stay in graduate school. The assistantships, which involve about fifteen hours a week of work teaching or in the laboratory and which thus reduce the maximum number of subjects the student can take from four to three a semester, have (previous to 1945) had statistically no effect on the length of time the student takes to get his degree. Because no specific number of courses in physics have been required and because few full-time students have taken more than two courses per term after their first year (the remaining time being spent on a special problem or in thesis), the slight handicap the assistantship causes, in reduction of available class hours, seems to have been compensated by the gain in experience acquired by teaching or assisting in a research project. The records of the past five years, which will be discussed later, may indicate a change in this regard.

In the last few months the more informative of the data regarding the progress of the student toward his advanced degree have been recorded on punched cards for more rapid analysis, two cards being produced per student. Thus we have, in accessible form, the following data on each student who was admitted to the graduate school in physics and who attended for at least one semester (the data on applicants not admitted or on those admitted who did not come is on hand but is not on cards):

> The student's name, birth date, and the college from which he received his bachelor's degree; the numerical rating of his application by the Admissions Committee (admission evaluation $= E_a$) and the undergraduate subjects in which he was judged deficient; his first semester cumulative rating $= G_1$ (an average grade on the subjects he has taken, 5.0 corresponding to straight A, 4.0 to B average, 3.0 to C average, and so on) and his final cumulative rating (the average grade for all his graduate work, including thesis); the total number of hours of course work taken, the total number of special problems and of thesis. If the student was a master's candidate, the general field of his thesis and the name of his faculty supervisor were recorded and the date of granting of the degree. If he was a doctor's candidate, his minor department, the outcome of his qualifying and general examinations, the general field of his thesis, his faculty supervisor, and the date of granting of the degree were all punched. Data on assistantships and fellowships, number of terms, which term, etc., are included, as well as the data on papers published and professional status mentioned earlier.
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> In addition, for the roughly two thirds of the alumni who answered, some of the data from recent questionnaires concerning present status have been punched, including present income, employer (whether academic, industrial, etc.), the fraction of time spent in basic or applied research, administration, etc.

A great deal of statistical analysis will be necessary before all useful conclusions can be drawn from this mass of data. Presented here are some results of general interest, which are mainly concerned with the men who obtained a doctor's degree.

Chronological Survey

FIRST, we discuss the figures on the student's progress through his graduate years in physics at MIT. Initially, of course, he applies for admission and is either admitted or rejected. Detailed analyses have been made of the admission records for the years 1934–42 and also for 1951–55. These showed, among other things, that the ratio of admissions to rejections was roughly constant over the periods of study, and also that the fraction of the admitted students who actually come to MIT increased slightly from the first to the second periods. For example, in the 1934–42 period, 679 applications for admission to the graduate school in physics were received; 377 (55% of the applications) were admitted and 148 (40% of those admitted, 22% of those applying) registered as graduate students at MIT for at least one semester. In the three years 1951, 1954, and 1955, a total of 592 applications were received; 323 of these (55%) were admitted and 152 (47% of those admitted, 26% of those applying) came to MIT. On the basis of these percentages, in the decade 1930–39 about 800 applied for admission to the graduate school in physics; about 450 were admitted and 173 actually attended for one or more semesters; in the decade 1940–49 about 1500 applications were received; about 800 were admitted and 368 came; in the decade 1950–59 about 1900 applied; about 1000 were admitted and 506 came.

About a quarter of these graduate students who did come had taken their undergraduate work at MIT and about a twelfth of them came from foreign universities. Most of the rest came from smaller colleges throughout the US (alumni of 236 different colleges and universities have attended). In order to see whether students from the larger universities with active graduate departments in physics were better prepared than students coming from small colleges, it was desirable to divide the US institutions into two groups: universities with a reputation of activity in physics ("our competitors") and all the others (which would include large universities not very active in physics, as well as the smaller colleges). The results of several surveys of students, admitted but not coming to MIT, were used, in lieu of opinion surveys, to achieve this dichotomy. In the fall, for several years, those applicants who had been admitted the previous spring but who had not come to MIT were sent questionnaires which asked, among other things, what graduate school they had gone to. Seventy percent of the questionnaires were returned answered, so the results are statistically meaningful. It turned out that most of them had gone to a few other institutions: 80% of those answering had gone to one or another of twenty universities. These universities (U. of California—Berkeley, UCLA, Caltech., U. of Chicago, Columbia, Cornell, Harvard, Johns Hopkins, U. of Illinois, U. of Indiana, U. of Michigan, U. of Minnesota, NYU, Ohio State, U. of Pennsylvania, Princeton, U. of Rochester, Stanford, U. of Wisconsin, Yale) have therefore been designated in this study as our "major competitors." Of those applicants who were admitted to MIT, 40% chose to come to MIT; 50% * chose one or another of the twenty (to which, of course, they had also applied). In the opinion of these applicants and their advisers, these twenty are "in the same league" as MIT.

Reciprocally, alumni from these twenty universities applied for admission to the graduate school at MIT and about 40% of those admitted came. If the presence of an active (and well-known) graduate school of physics has any effect on the training of undergraduates in physics, then the students who came from these 20 universities to do graduate work at MIT should be better prepared scholastically than the students from other US colleges and universities. In our first table we have therefore divided the students into those coming from MIT (about 25%), those coming from "our major competitors" (the twenty universities—about 20%), those coming from all other US colleges and universities (about 47%), and those coming from foreign universities (about 8%).

Table I summarizes the general progress of the students who entered the Institute graduate school to major in physics. The table is divided into five-year time periods according to the year the student began his graduate work. The top rows, dividing the students according to their source, as just discussed, compare their average grades for their first graduate year. Students from MIT have a slight edge, probably because they are accustomed to our ways of doing things. Students from "our major competitors" do about as well; their undergraduate training seems to have prepared them adequately; likewise for the foreign students. The students from the other US colleges (the majority of whom come from small colleges) do not do quite so well, though between 1930 and 1949 the difference is probably not statistically significant; up to about 1950 the students coming from small colleges seem to have been nearly as well prepared for graduate work in physics as were those from the larger universities (the twenty listed above).

The difference shown in the 1950–54 columns, however, is probably significant. It may be that the rapid advance in physics has left the smaller colleges somewhat behind; their graduates are now not quite so well prepared for graduate work as are those who did their undergraduate work at an institution which had active research and graduate work in physics. In recent years, for example, MIT (along with other universities) has included some quantum mechanics in its undergraduate instruction; students coming from colleges where this is not the case are under some handicap during their first graduate year. The disadvantage does not, as yet, seem to last beyond the first year, however; the average grades for the students' full graduate term show a considerably smaller difference. Students from the other colleges take a fraction of a year longer, on the average, to obtain their graduate degrees; otherwise their handicap is not, as yet, large or permanent.

The next set of rows of Table I shows the results of the doctoral examinations. Roughly two thirds of those entering try them and most of those trying them pass, if not on the first try then on the second try. About two thirds pass the first time; most of those taking it the second time pass. This does not mean that the examinations are not a major barrier to the too-easy obtaining of a doctor's degree, however. Only about a sixth of the students entering come just for a master's degree; another sixth come expecting to get a doctor's degree but are persuaded by their course grades or by discussions with faculty and with other students that they cannot pass the general examination and so do not take it. Some, of course, drop out because of other reasons. The endeavor, on the part of the faculty, has been to discourage as soon as possible those who cannot make it so that they do not waste their time. Of course, the best solution would be not to admit anyone

* The reasons for their not coming to MIT were quite varied, of course. Many of them were related to financial assistance; another school offered them a better assistantship, or made the offer sooner than did MIT, for example.

who cannot pass the examinations and achieve a graduate degree. The columns labelled *NF* indicate that we are not completely successful in this respect.

The rest of the table is subdivided into columns for those who did obtain the doctor's degree (*D*), for those who obtained a master's degree only (*M*), and those who left the graduate school without obtaining any graduate degree (*NF*). The differentiation in the average first year's grades shows that course grades have separated off the *NF* fraction (a student must maintain an average grade of 3.5 to continue in the graduate school). An improvement in admission procedure might be able to reduce the number of *NF*'s. This question will be discussed later.

Comparison of the fractions from MIT, from "major competitors," etc., between the columns is another way of comparing the capabilities of students with different backgrounds. Those coming from the smaller US colleges have a somewhat larger fraction drop out without obtaining a degree, though this difference seems to have vanished in the last five years reported. The difference, of course, could be caused by a difference in effectiveness of the admission procedure; it may be more difficult to pick the promising students from the smaller colleges, and the admission procedure may have finally equalized its discrimination about 1950. The large increases in the *M* column for other colleges in the last two five-year periods is caused by the special master's degree program for Naval officers which was inaugurated just after World War II.

The rows giving the average fraction of his graduate term the student spends as teaching or research assist-

Table I. Where they came from, their length of stay, their first graduate year's grade, and their record in the qualifying and the general doctor's examination

Yr. Entered Grad. Work at MIT	'30–'34		'35–'39		'40–'44		'45–'49		'50–'54	
	No.	Gr. 1st Yr.	No.	Gr. 1st Yr.	No.	Gr. 1st Yr.	No.	Gr. 1st Yr.	No.	Gr. 1st Yr.
Total no. entering	72	3.89	101	4.07	74	3.66	294	4.10	261	3.97
No. coming from MIT	29	4.03	22	3.89	17	3.81	62	4.40	86	4.35
No. from major competitors[1]	14	3.83	17	4.28	13	3.68	63	4.05	41	4.40
No. from other US colleges	26	3.70	55	4.03	40	3.59	143[5]	3.92	110[5]	3.46
No. from foreign universities	3	3.77	7	4.56	4	3.78	26	4.52	24	4.27
No. taking qualifying exam			(was not given)				209		192	
No. passing qualifying exam							201		177	
No. taking general exam	42		60		42		201		169	
No. passing general exam	41		59		39		198		163	

	D[4]	M	NF	D	M	NF	D	M	NF	D	M[5]	NF	D	M[5]	NF
Number	39	18	15	56	16	29	35	9	30	191	51	52	151	60	50
Fraction from MIT	0.33	0.50	0.47	0.21	0.25	0.21	0.26	0.45	0.13	0.22	0.20	0.17	0.34	0.27	0.38
Fraction from major competitors[1]	0.23	0.17	0.13	0.18	0.12	0.17	0.17	0.33	0.13	0.26	0.06	0.21	0.20	0.03	0.16
Fraction from other US colleges	0.36	0.33	0.40	0.48	0.63	0.62	0.54	0.22	0.64	0.40	0.68[5]	0.62	0.35	0.65[5]	0.36
Fraction from foreign universities	0.08	0	0	0.13	0	0	0.03	0	0.10	0.12	0.06	0	0.11	0.05	0.10
Av. 1st year grade	4.3	3.6	3.0	4.5	4.1	3.3	4.4	3.2	2.9	4.4	3.9	3.2	4.1	4.1	3.4
Av. no. yrs. grad work	4.1	2.3	1.8	4.3	1.7	1.5	4.6	4.3	0.8	3.7	2.0	1.3	4.5	2.0	1.7
Av. fract. time teaching ass't[2]	0.37	0.11	0.47	0.26	0.09	0.49	0.35	0.10	0.52	0.15	0.03	0.29	0.15	0.10	0.24
Av. fract. time research ass't[2]	0.10	0.14	0.14	0.12	0.04	0.18	0.13	0.03	0.35	0.61	0.19	0.22	0.73	0.24	0.65
Av. no. hours courses	185	102	99	151	101	84	125	89	59	134	111	74	162	148	83
Av. no. hours special problems[3] & thesis	134	75	35	120	65	22	102	64	9	121	53	22	183	61	42
Fraction taking math minor	0.90			0.66			0.88			0.78			0.89		
Fraction taking EE minor	0			0.20			0.06			0.15			0.06		
No. also taking MS	7			6			1			10			12		

[1] The 20 large universities to which students, admitted to MIT, go if they don't choose to come to MIT.
[2] The teaching assistantship and research assistantship both allow student to take ¾ of maximum class work.
[3] Special problems, research preparatory to thesis.
[4] D = those who obtained a Doctor's degree; M = those who obtained only a Master's degree; NF = those who left without obtaining a graduate degree.
[5] Includes *10 (45–49)* and *19 (50–54) US Naval Academy Graduates who came to take a special master's degree curriculum.*

ant are also of interest. The fractions for *RA* are considerably greater in the later periods than in the earlier ones; there was less money for research assistantships before 1946. The fact that, between 1930 and 1945, the *NF*'s spent more of their time as assistants than the *D*'s is in part a reflection of the inaccuracies of the admission procedure, which is responsible for the *NF*'s, and in part a result of the fact that teaching assistantships come early in the student's career. In general, a student has a teaching assistantship, if he has one at all, during the first year or two of his graduate years; during the last two years, while working on his thesis, he usually received no financial support in the years before 1945; nowadays he is usually awarded a research assistantship. Those students who were admitted but never completed their graduate work (*NF*'s) received their quota of teaching assistantships. Since they usually left before they got well into thesis research, the time they spent at MIT was more financed, on the average, than were those who stayed on to complete their thesis. This is still true for teaching assistantships in the decade 1945–54. Since the war, however, research assistantships have been available for most students, so most doctoral candidates have *RA*'s while they are doing their thesis research. In fact at present, on the average, during about 90% of the doctoral candidate's time he is a research or teaching assistant. The table does not include special fellowships, such as the Woodrow Wilson or NSF, since they have become important only during the past six or seven years.

The fact that a student is a teaching or research assistant during most of his graduate career does not necessarily extend the duration of his graduate work. In the period 1945–49 the *D*'s were assistants for three quarters of their stay, nearly twice the fraction of time spent as assistants by *D*'s before the war, yet the mean time taken to get the doctor's degree decreased somewhat, from 4.2 years to 3.7 years. Many of the students who returned for graduate work, just after the war, were older men, more anxious to finish their studies and get out, than were the prewar graduate students. This is reflected in the lower values of mean time spent, mean hours of class and research work, for 1945–49 compared with the years 1930–39. The fact that the postwar students had assistantships most of the time did not slow down their progress toward a degree and a job. The war years, 1940–44, were exceptional ones, and the few students entering then often had their careers interrupted, which accounts for the average length of their graduate stay being longer and the average hours of class and research being shorter than before or after the war.

In the years 1950–54 the full effects of the more generous financing of graduate students in physics begin to be apparent. The average post-1950 doctoral candidate is taking half a year longer to get his degree than previous students did. He is not taking more course work; he takes longer to finish his thesis. These are the facts. Why the student takes longer now, whether it is that the amount of work required to complete a doctor's thesis is increasing ("physics is getting harder") or whether, with the present nearly complete financing of the better graduate student he finds it easier to stay on ("the students have it too easy"), are questions this table does not attempt to answer. They will be returned to again.

Later Accomplishments

TO follow the later careers of the MIT graduate alumni in physics, we will concentrate on those who obtained doctor's degrees, and will reclassify them according to the year during which they were awarded the doctor's degree. Table II lists them by year of granting of degree, giving the number listed in the 1955 Edition of *American Men of Science*, the number who were fellows of the American Physical Society in 1959 (to be raised from membership to fellowship requires nomination and election by a committee of the Society), the number of papers in physics they published (i.e., those listed in *Science Abstracts, Section A, Physics*), and their average total yearly income (i.e., their salary plus consulting fees, if any).

Four fifths of the older alumni are now listed in *American Men of Science* and about two-thirds of them are now fellows of the APS. The proportion is smaller for the younger alumni; it takes time for such recognition to be granted. The approximately 500 alumni have been responsible for more than 2500 published papers, which must be partly responsible for the recently increased size of *The Physical Review*.

The average total income shown is somewhat larger than the mean salaries of all physicists in the US, as reported in *Physics Today* and in various governmentally supported surveys. This may be because the figures here reported are for total income, or it may be because more MIT alumni go into industrial jobs (though the reported *total* incomes of those who now have teaching positions are not much less than the averages given), or it may be because the MIT alumni are able to obtain better positions, on the average, than other professional physicists. The steady increase of present income with time since the doctor's degree was granted is probably chiefly caused by the fact that a larger fraction of the older men have changed over from research to administrative positions, as we will shortly see.

The last column, the average time the members of each group stayed in graduate school, again exhibits the increase noted in Table I. Here the increase occurs after 1955. This table lists the students according to date of granting of the degree; Table I lists them according to date of start of graduate work, an average of about four years earlier.

Table III lists some of this same data in different form, and includes data on the present employers of the alumni, together with their fields of research. The figures on the school from which they got their bachelor's degree parallel Table I (allowing for the difference between year of entrance and year of leaving graduate

Table II. Doctoral alumni in physics by year of granting of degree, their publications, their standing as professional physicists, their present total yearly income, and the mean time taken to get the degree

Year	No. Granted Degree	No. Now in Amer. Men of Sci.	No. Now APS Fellows	Total No. Papers* in Sci. Abst.	Mean No. Papers* per Man	In 1st 10 Yrs. No. Publishing More Than 2 Papers*	In 1st 10 Yrs. No. Publishing More Than 5 Papers*	Mean Yrly. Income at Present	Mean No. Yrs. as Grad. Stud.
1935	8	7	6	41	5.1	6	6	$27 400	3.4
36	14	12	3	107	7.6	5	4	23 150	4.3
37	10	7	2	80	8.0	7	7	17 500	3.6
38	12	10	5	76	6.0	7	7	21 205	3.6
39	7	5	2	76	10.0	4	4	18 000	3.9
35–39	51	41	18	380	7.45	29	28	21 400	3.78
1940	9	7	4	72	8.0	7	6	30 200	3.0
41	8	8	3	94	11.8	6	7	23 200	3.4
42	10	9	2	53	5.3	4	4	12 700	3.4
43	10	6	4	69	6.9	6	6	17 600	3.7
44	10	8	3	132	13.2	7	7	17 900	4.3
40–44	47	38	16	420	8.94	30	30	20 700	3.58
1945	1	1	0	14	14.0	1	1	—	5
46	2	1	1	9	4.5	1	1	—	7.0
47	18	14	6	180	10.0	11	10	16 500	4.2
48	36	28	10	267	7.4	24	17	13 500	3.6
49	37	23	3	277	7.5	23	18	18 600	3.6
45–49	94	67	20	747	7.95	60	47	16 300	3.84
1950	40	23	14	218	5.5	22	15	15 100	3.8
51	33	21	2	155	4.7	23	12	15 900	3.9
52	28	12	0	117	4.2	17	5	13 100	4.2
53	31	7	0	112	3.6	17	7	13 800	3.6
54	38	3	0	135	3.6	20	8	11 500	3.9
50–54	170	66	16	737	4.33	99	47	13 800	3.89
1955	29	3	0	78	2.7	11	5	11 500	4.4
56	29	0	0	65	2.2	8	3	11 300	4.5
57	22	0	0	30	1.4	3	—	10 900	5.1
58	26	0	0	28	1.1	5	—	8 600	4.3
59	29	1	0	25	0.9	2	—	8 800	4.8
55–59	135	4	0	226	1.67	29	8	10 300	4.62
35–59	497	216	70	2510	5.06	247	160	14 600	4.04

* Only papers abstracted in *Science Abstracts, Section A, Physics*, are counted.

Table III. Doctoral alumni in physics, by year of granting of degree, their origin, publications and standing as physicists, their employer and their field of research, then and now

Yr. of granting of doctor's degree		1935–39	1940–45	1945–49	1950–54	1955–59
No. granted doctor's degree		51	47	94	170	135
Fraction with BS from MIT		0.25	0.27	0.23	0.26	0.36
Fraction with BS from our "major competitors"		0.25	0.18	0.25	0.19	0.20
Fraction with BS from other US colleges		0.44	0.43	0.39	0.43	0.37
Fraction with BS from foreign universities		0.06	0.12	0.13	0.12	0.07
Mean no. papers* pub in 5 yrs. after deg.		2.6	1.6	2.9	2.7	—
Mean no. papers* pub in 1st. 10 yrs. after deg.		3.2	4.6	6.7	—	—
Mean no. papers* pub up to 1960		7.5	9.0	8.0	4.3	1.7
Fraction who have published more than 2 papers in 1st 10 yrs.		0.57	0.64	0.64	0.59**	—
Fraction who have published more than 5 papers in 1st 10 yrs.		0.37	0.53	0.50	0.28	—
Fraction who have published more than 10 papers in 1st 10 yrs.		0.04	0.11	0.26	0.08	—
Fraction now in *Amer. Men of Science*		0.84	0.81	0.71	0.39	0.03
Fraction now fellows of APS		0.35	0.34	0.20	0.09	—
Fraction now in *Who's Who*		0.20	0.11	0.01	—	—
Fraction now employed by:	Government	0.08	0.12	0.07	0.22	0.18
	Armed Services	—	—	0.01	0.03	0.04
	Industry	0.42	0.51	0.44	0.43	0.36
	Academ. Institutions	0.45	0.28	0.43	0.30	0.39
	Other (self, etc.)	0.05	0.09	0.05	0.02	0.03
Fraction of their time spent in:	Basic Research	0.16	0.30	0.33	0.40	0.56
	Applied Research	0.13	0.21	0.18	0.22	0.22
	Teaching	0.13	0.13	0.21	0.11	0.12
	Admin. of Research	0.40	0.27	0.18	0.12	0.03
	Other Administrative	0.13	0.06	0.02	0.05	0.01

		1935–39 Thesis	1935–39 Now	1940–45 Thesis	1940–45 Now	1945–49 Thesis	1945–49 Now	1950–54 Thesis	1950–54 Now	1955–59 Thesis	1955–59 Now
Fraction who did (are doing) research in field of:	Nuclear, Exper.	0.10	0.06	0.25	0.21	0.12	0.11	0.28	0.16	0.20	0.14
	Nuclear, Theor.	0.06	0.06	0.03	0.10	0.10	0.04	0.17	0.09	0.09	0.10
	Solid State, Exper.	0.06	0.10	0.17	0.21	0.18	0.31	0.18	0.22	0.18	0.19
	Solid State, Theor.	0.06	0.06	—	0.07	0.03	0.04	0.03	0.03	0.12	0.10
	Cos. Ray, High En. Particl.	0.03	—	—	—	0.07	0.06	0.09	0.06	0.13	0.13
	Acoustics	0.10	0.06	0.03	0.03	0.12	0.04	0.04	0.01	0.04	0.02
	Electronics	0.16	0.13	0.17	0.03	0.14	0.04	0.05	0.08	0.04	0.07
	Plasma Physics	0.06	0.10	—	0.03	0.06	0.04	0.05	0.07	0.03	0.03
	Spectros., Atomic Phys.	0.16	—	0.10	0.03	0.09	0.07	0.08	0.03	0.09	0.05
	Other	0.21	0.43	0.25	0.29	0.09	0.25	0.03	0.25	0.08	0.17

* See footnote on Table II.
** Papers counted to 1960, which is less than 10 years after degree granted.

school). The rows on publications display these data in a different form from that of Table II, as is the case with the listings in *American Men of Science* and fellowship in the American Physical Society.

The figures on present employment show few trends, except for the fact that more of the younger alumni are in government laboratories than their older colleagues. When the older ones left MIT there weren't many government laboratory positions open. The fraction now in academic institutions has varied somewhat but it seems to oscillate about 0.4; a bit less than half of our alumni are now in a college or university. That they do other things besides teaching in these academic jobs is seen from the next set of rows.

These next rows indicate the average fraction of the man's working time now spent in the activities listed (the category "other" which includes writing, marketing, consulting, etc., makes up the difference between the figures shown and 1.00). We see that, although about 0.4 of the men are in academic institutions, only about a third ($=0.12/0.4$) of their time is spent in teaching. This fraction remains about the same for all age groups. However, in the case of research, on the one hand, and administration, on the other, we see a trend, as we go to the older groups, away from basic research and into administration. The changes are complementary; what time is lost to basic research has gone into time spent in administration.

Finally, the fields of their thesis research and the fields of their present research (if any) are listed in the last set of rows. All the fields listed have been active at MIT over the thirty-year period under study, with a few interruptions. The category "other" includes research in classical physics, in biophysics, in chemistry, in engineering, etc. We note that many alumni have changed their fields (at least a third of them). More did theses in experimental nuclear physics, for example, than are now doing research in experimental nuclear physics. Similarly with acoustics and electronics. On the other hand, fewer did theses in experimental solid-state physics than are now doing research in this field. This does not mean that these men should have been advised to do their thesis research in another "more appropriate" field. Experience in research carries over from field to field; the thesis is simply an exercise for the student in the ways of research and a demonstration that he has mastered these ways.

Achievement and Scholastic Record

It is, of course, hoped that study of these data will provide guidance in improving the quality of our future alumni and of our future entering graduate students. As a beginning we might see whether the "best" of our alumni were in any way different from the others while they were graduate students; we might separate our records according to some "quality rating" of the men, and then work backward to see what the "best men" and the "worst men" did while they were in graduate school. Of course there is no objective index of the quality of a physicist but we can devise an index which may bear some relationship to the man's research productivity and to his standing among his professional colleagues. The index we have chosen is obtained by the following formula:

> I_p = "Productivity Index" = (Number of papers reported in *Science Abstracts, Section A*, the man has published in the first 10 years after leaving graduate school) *plus twice* (the number of times his name appears in the following four lists: *American Men of Science*, *Who's Who*, Fellowship list of APS, Fellowship list of the National Academy of Sciences).

The index might be called an "achievement rating" or "research index", though the more neutral term "productivity index" has been chosen for it. It checks with subjective rank-order tests of individual alumni. The distribution of values of the index, for the graduate students entering before 1950, has a slight peak at about 3, tailing off very slowly for high indices, with a mean of about 7 and a standard deviation of about 6. The mean value of the index, of course, goes down for the group which entered after 1949, but if the index for the group entering in the years 1950–54 is multiplied by 2, the resulting distribution corresponds quite closely to that for all the earlier groups. Thus we have a crude criterion for separating the more from the less productive of the men who entered the MIT graduate school in physics between 1930 and 1955.

Table IV gives the results of the analysis. Each five-year group has been divided into three classes, according to their "productivity index"; the first class ($I_p = 0$ or 1) having published at most one paper and not being listed even in *American Men of Science;* the second class ($I_p = 2$–10) being the "run-of-the-mill" of each five-year group, with a moderate number of publications and some recognition; and the third class ($I_p > 10$) being the exceptionally productive ones. The behavior of each of these classes, while at MIT, is shown for each of the five-year groups listed in Table I.

The top rows deal with the groups as a whole. We see that the ones with higher I_p in general had higher course grades at the end of their first year of graduate work, though the differentiation is not marked. A detailed statistical analysis of the 50–54 group showed a correlation index between I_p and mean first-year grade (G_1) of 0.26, a definite, though not very complete correlation.* (This will be discussed more fully later.)

The "preadmission evaluation" (E_a) is the numerical rating mentioned earlier, given the student's application by the departmental admissions committee, on the basis of which the applicant is admitted or not. Ordinarily, before 1940, only applicants with a rating of 4 or better were admitted; since 1950 the limit has usually been higher than this, 5 or 6; admission records for the years 1940–50 are incomplete, so they have not been recorded.

We see that there is some correlation between the

* Correlation index between two random variables x and y, each having standard deviation Δ_x and Δ_y, is defined as $[(xy)_{av} - (x)_{av}(y)_{av}]/(\Delta_x\Delta_y)$. It equals 1 only for perfect correlation, is zero when there is no correlation, and is negative for negative correlation.

Table IV. Separation of students according to "productivity index" I_p, explained in text, comparing grades, present activities, duration of stay in graduate school, and time spent as teaching or research assistant

Year entered grad. work at MIT	30–34			35–39			40–44			45–49			50–54		
"Productivity Index" I_p	0–1	2–10	>10	0–1	2–10	>10	0–1	2–10	>10	0–1	2–10	>10	0	1–4	>4
Number	20	46	6	36	56	9	26	40	8	92	161	41	102	131	28
Preadmission eval. E_a	4.80	5.36	6.67	4.95	5.90	6.67	—	—	—	—	—	—	6.19	6.45	6.96
Mean 1st yr. grade G_1	3.60	3.94	4.00	3.56	4.35	4.55	3.46	3.65	4.62	3.64	4.25	4.60	4.00	4.27	4.50
Fraction now doing research	0.30	0.38	0.33	0.45	0.55	0.78	0.60	0.39	0.60	0.40	0.68	0.87	0.61	0.63	0.95
Fraction now teaching	0.10	0.23	0.30	0.11	0.27	0.56	0.30	0.22	0.40	0.08	0.26	0.42	0.12	0.17	0.24
Fraction now in administration	0.60	0.62	0.90	0.43	0.51	0.33	0.30	0.44	0.60	0.55	0.31	0.29	0.30	0.26	0.05
No. obtaining doctor's deg.	5	28	6	11	36	9	4	23	8	24	128	39	35	88	28
Preadmission eval. E_a	5.2	5.4	6.7	5.9	6.6	6.7	—	—	—	—	—	—	6.5	6.8	7.0
First yr. av. grade G_1	4.3	4.5	4.0	4.4	4.6	4.6	4.3	4.4	4.6	4.4	4.3	4.6	4.3	4.5	4.5
Av. no. yrs. Grad Work	4.2	4.2	3.3	6.1	3.8	4.4	4.5	4.5	4.9	4.4	3.9	2.8	5.4	4.3	3.4
Av. hrs. Course work	170	192	143	156	140	169	132	126	118	162	137	109	197	157	135
Av. hrs. SP + thesis	126	139	115	136	116	122	68	114	88	181	120	83	246	172	138
Av. terms TA	1.2	2.8	4.8	1.4	2.3	3.1	3.0	3.1	3.6	1.0	1.3	0.6	2.1	1.3	0.8
Av. terms RA	0	0.8	1.6	1.2	0.9	1.3	0.3	1.3	1.5	4.7	4.7	6.0	6.2	7.0	6.3
No. obtaining MS deg. only	7	11	0	6	10	0	4	5	0	39	12	0	33	27	0
Preadmission eval. E_a	4.6	5.3	—	5.5	5.2	—	—	—	—	—	—	—	5.8	5.3	—
First yr. av. grade G_1	3.4	3.8	—	3.9	4.3	—	3.5	3.5	—	3.9	4.0	—	4.1	4.2	—
Av. no. yrs. grad. work	2.6	2.1	—	2.2	1.5	—	4.0	4.4	—	2.0	1.9	—	2.1	1.9	—
Av. hrs. Course work	84	110	—	90	85	—	90	90	—	117	90	—	149	150	—
Av. hrs. SP + thesis	66	77	—	80	52	—	73	60	—	53	55	—	62	57	—
Av. terms TA	0	0.5	—	0.8	0	—	1.0	0.8	—	0.2	0	—	0.5	0.2	—
Av. terms RA	1.1	0.9	—	0	0.2	—	3.5	1.2	—	0.5	1.8	—	1.2	0.7	—
No. leaving with no grad. degree	8	7	0	19	10	0	18	12	0	29	21	2	34	16	0
Preadmission eval. E_a	4.7	5.0	—	4.2	4.3	—	—	—	—	—	—	—	6.2	6.5	—
First yr. av. grade G_1	3.3	2.7	—	2.9	3.7	—	3.3	2.3	—	2.7	3.9	4.0	3.4	3.3	—
Av. no. yrs. grad. work	1.9	1.9	—	0.9	1.5	—	1.0	0.8	—	1.3	1.3	1.9	1.5	2.4	—
Av. hrs. Course work	95	101	—	83	86	—	63	53	—	69	74	132	76	99	—
Av. hrs. SP + thesis	39	30	—	23	21	—	9	8	—	26	17	5	31	69	—
Av. terms TA	1.8	1.7	—	0.3	1.2	—	1.2	0.3	—	0.7	0.8	2.0	0.5	1.5	—
Av. terms RA	0.3	0.9	—	0.7	0.1	—	0.4	0.1	—	0.2	1.1	0	1.9	2.9	—

judgment of the admissions committee and the "productivity" of the man after he left graduate school. In every five-year group reported, the average E_a is higher for the classes with higher I_p. The correlation is positive though not very marked. (A detailed analysis of the 1950–54 group established a correlation index of 0.14.)

There also seems to be some difference between the I_p classes in regard to their present activities. (It should be pointed out that the sum of these three fractions in each column dealing with their present activity usually adds up to more than unity; many men both teach and do research, for example.) More of the "more productive" ($I_p > 10$) alumni are doing teaching, for example, and they changed from research to administration later in life. Perhaps these statements should be reversed, to say that those alumni who chose to continue research rather than take an administrative position were the ones who turned out more papers and got elected fellows of the APS, and thus achieved a higher I_p. The figures in the table, of course, do not indicate which way of stating the facts is more "correct".

The rest of the table divides the classes into those who were granted doctor's degrees, those who obtained only a master's degree, and those who left without obtaining a graduate degree (NF). It is not surprising to see that, for most of the five-year periods, all those with high I_p obtained a doctor's degree. A doctor's degree is today almost mandatory for a professional career in physics (the two NF's with $I_p > 10$ in 1945–49 obtained their doctor's degrees elsewhere after leaving MIT, so they are not really exceptions).

Achievement and Graduate-Work Duration

PERHAPS the most unexpected interrelation which comes to light is the fact that the *more productive* alumni took *less time* to complete their graduate work. This is particularly noticeable in the latest group (1950–54), for which we had previously noted an increase in mean stay. Now we see that the *less productive* men have been *almost entirely responsible* for this increase; the average and the most productive men took no longer to get their degrees than did the prewar graduate students. This less productive class took nearly twice as long to complete their thesis research (and in doing so pre-empted as many terms of assistantships) as did their more productive colleagues. (Incidentally, it will be noted that the average number of terms of assistantships adds up to more than twice the number of years of graduate work for the class $I_p > 10$ after 1945; this is because better students are occasionally given an extra summer term of RA, making three terms of assistantship for some years.)

To follow up this negative correlation between length of stay in graduate school and productivity we have grouped all the alumni who have been awarded doctor's

Table V. Separation of doctoral alumni according to the length of their term as graduate students, comparing their standing as physicists, their publications, and the time spent as teaching or research assistants

Duration of grad. work in years	2	3	4	5	6	>6
No. taking this long	50	122	114	38	18	20
Fraction of the whole	0.14	0.33	0.32	0.10	0.05	0.06
No. now fellows of APS	14	18	19	3	1	2
Fraction of them now fellows of APS	0.28	0.15	0.17	0.08	0.06	0.10
No. who pub. >5 papers in 1st 10 years	22	39	30	12	2	3
Fraction of them who pub. >5 papers in 1st 10 yrs.	0.44	0.32	0.26	0.32	0.11	0.15
Av. no. hrs. they took of special problems	20	30	36	32	28	45
Av. no. hrs. they took of thesis	61	72	100	113	117	107
Sum	81	102	136	145	145	152
Av. no. terms of TA	0.7	1.5	1.9	1.8	2.3	2.1
Av. no. terms of RA	2.0	2.8	3.6	4.6	6.0	2.7
Av. no. terms of assistantship	2.7	4.3	5.5	6.4	8.3	4.8
% of time with assistantship	68	72	69	64	69	30

degrees between 1935 and 1954, inclusive, according to the duration of their graduate work, in Table V. The fraction of each of these groups who are now fellows of the APS or who published more than five papers in the first ten years after graduation decreases steadily as we move to the longer-staying groups. More than twice as many two-year men published more than five papers than did the five- or six-year men; more than three times as many of them are fellows of the APS. The single departure from the monotonic negative trend of the indices with length of stay is for the more-than-six-year group, where the averages are thrown off because of two "productive" men who interrupted their graduate work; "duration of graduate work" (defined as the difference between leaving and entering dates) in these two cases was considerably greater than the actual time spent as a registered graduate student. In general, it would seem that discouraging long theses (by limiting financial assistance) would discourage only the less productive students.

Of course, we must first see whether a particular field of physics requires more thesis time than others; if this were true, discouraging extended thesis registration would discourage these fields. To investigate this point the doctoral alumni are grouped according to the subject of their thesis in Table VI, for the period before 1945 and for the two five-year periods since. Nuclear experimental research (neutrons, nuclear energy levels, etc.), solid-state theoretical, physical electronics (experimental), and atomic experimental (spectroscopy, etc.) take longer than average. There seems to be an indication that the new fields in physics present more opportunities for short theses than do the older fields. The average duration of thesis research in electronics and in atomic experimental research has been steadily increasing since 1935. Plasma physics and elementary-particle physics were relatively new subjects in 1950; in both fields the mean stay in graduate school was shorter than the usual stay during this period. In spite of these minor differences, however, it does not appear that any one field would be unduly handicapped if graduate students were discouraged from staying longer than four years. Perhaps a few more students would be persuaded to take theses in the newer fields of physics, and a few less would take their theses in the well-established fields. This would not necessarily be detrimental to the development of physics; the well-established fields are more supported by industry than are the newer fields. Research would still be done in the older fields by some of our alumni, only it would be done after they have completed their theses and obtained positions in industrial or governmental laboratories.

Incidentally, the rows giving the fraction of each category who have published more than five papers display

Table VI. Duration of graduate work versus number of papers and present standing as physicists for different research fields of thesis

Yr. of Entrance		Nucl. Exp.	Nucl. Theor.	Solid State Exp.	Solid State Theor.	Acous.	Cos. R; H. En. Part.	Electronics	Plasma	Atom. Exp.	Atom. Theor.
	Number	20	10	18	6	8	—	23	6	18	19
1930	Av. yrs. grad. work	4.7	4.3	4.4	4.0	4.0	—	3.3	3.8	5.0	3.8
thru	Av. hrs. SP+thesis	135	110	123	101	106	—	119	142	141	89
1944	Fract. now fel. APS	0.30	0.50	0.22	0.83	0.13	—	0.17	0.50	0.17	0.37
	Fract. publ. >5 papers	0.35	0.50	0.28	0.50	0.25	—	0.09	0.17	0.22	0.21
	Number	39	22	29	13	9	19	15	13	15	9
1945	Av. yrs. grad. work	4.0	3.3	3.9	3.8	3.7	3.4	3.5	3.2	4.5	3.3
thru	Av. hrs. SP+thesis	133	107	124	120	101	83	144	96	164	87
1949	Fract. now fel. APS	0.12	0.09	0.03	0.23	0	0.26	0.13	0.23	0	0.22
	Fract. publ. >5 papers	0.39	0.55	0.20	0.31	0.22	0.42	0.27	0.62	0.20	0.22
	Number	37	23	20	14	6	16	9	10	13	5
1950	Av. yrs. grad. work	4.5	3.9	3.9	5.2	3.5	3.8	4.9	3.4	4.8	4.0
thru	Av. hrs. SP+thesis	198	156	162	236	144	138	211	167	206	159
1954	Fract. now fel. APS	0	0	0	0	0	0	0	0	0	0
	Fract. publ. >5 papers	0.03	0.22	0.10	0.14	0.33	0.12	0.11	0	0.15	0
	Number	96	55	67	33	23	35	47	29	46	33
1930	Av. yrs. grad. work	4.4	3.7	4.1	4.5	3.7	3.5	4.7	3.4	4.8	3.7
thru	Av. hrs. SP+thesis	159	132	135	166	114	108	145	130	165	99
1954	Fract. now fel. APS	0.11	0.14	0.07	0.24	0.04	0.14	0.13	0.21	0.07	0.27
	Fract. publ. >5 papers	0.24	0.40	0.19	0.27	0.26	0.29	0.15	0.31	0.20	0.18

some interesting variations. There is some indication that the "newer" fields provide more opportunity to publish than do the older fields and that the theorists are more prone to publish than are the experimentalists (at least in nuclear and in solid-state physics, though not in atomic physics).

The Admission Problem

As demands for trained physicists increase and as graduate work in physics increases in popularity, it becomes more important to choose graduate students so that nearly all of those admitted obtain a doctor's degree within a reasonable time and become contributing members of the profession of research physicists. Since such an ideal admission procedure seems at present impossible, we should alternatively arrange it so that the admitted students who cannot "make the grade" are spotted as soon as possible and are persuaded to change to more appropriate work before they have wasted too much of their time and self-respect trying to attain a goal unsuitable for them. To admit selectively and to "weed out" early, we must find indicators having high correlation indices with the quality we wish the applicant or student to have.

The present admission procedures are far from perfect, and it is difficult to see how they can be markedly improved. The correlation index between admission rating E_a and first-year grades is fairly high, 0.42. Using the 1950–54 group as a measure of the effectiveness of our admission rating, a student entering with an E_a of 5 would be expected to have a first-year average grade $G_1 = 3.7 \pm 0.5$; one with $E_a = 6$ would expect a $G_1 = 4.0 \pm 0.7$; one with $E_a = 7$ would predict $G_1 = 4.4 \pm 0.5$; with $E_a = 8$, a $G_1 = 4.5 \pm 0.5$; and one with the high value of $E_a = 9$ would be expected to have $G_1 = 4.8 \pm 0.2$. This is not bad as a prediction, but it would save student and faculty time if it were better. The admission committee has found that letters of recommendation from the professors of physics and mathematics who knew the student's undergraduate work are more useful in arriving at an admission score than are the student's undergraduate grades. It may be that a more specifically-worded request for a letter of recommendation (asking about the student's originality and motivation and requesting detailed comparisons with other students who have come to MIT, for example) would improve these letters as indicators. We should avoid, however, the over-organized forms, such as those used by the NSF; we find them less useful on the whole.

The chief question, however, is whether this correlation is meaningful, whether in fact the first year's average grade is a good measure of the student's ability to obtain a doctor's degree or of his productivity as a research physicist after graduation. The correlation index between admission rating and productivity index I_p is 0.14, quite low, lower than the correlation between first-year grades and I_p, which is 0.26, as mentioned earlier. The E_a's for those students who drop out without obtaining a degree are lower than those for those who obtain doctor's degrees, as Table IV shows, but the differences are smaller than the standard deviation of the E_a's in any group.

Table VII. Students entering between 1950 and 1954 divided according to preadmission evaluation; their scholastic record

Preadmission evaluation E_a		5 or less	6	7	8 or more
Number		14	61	91	40
Mean 1st yr. grade G_1		3.69	4.07	4.40	4.50
Fraction taking qual. exam		0.50	0.79	0.97	0.83
Fraction passing qual. exam 1st time		0.36	0.54	0.76	0.75
Fraction taking exam who failed to pass		0.29	0.31	0.22	0.09
Fraction granted Dr. deg.	D	0.36	0.61	0.72	0.84
Fraction granted MS deg. only	M	0.36	0.10	0.13	0.03
Fraction leaving without degree	NF	0.28	0.29	0.15	0.13

Table VII shows the record of those students entering between 1950 and 1955, when divided according to their preadmission rating E_a. Those students with the higher rating tend to have higher first-year grades (but not much higher); more of them pass the qualifying examination the first time; fewer of them fail after two tries; more of them are awarded doctor's degrees and fewer stop at the master's degree. This indicates that the Admission Committee's rating is a fair prediction of the applicant's ability to succeed in graduate work. An indication that the prediction is not perfect is evidenced by the last row of the table. While nearly a third of the students who entered with the low preadmission rating of 5 left without getting an advanced degree, as large a fraction as a seventh of those with the highest E_a (7 or more) dropped out also. It may be that roughly half of the NF's are not particularly lacking in ability, but lack motivation toward a career in physics; our preadmission evaluation may not take motivation sufficiently into account. Indeed, it may be difficult to forecast the permanence of motivation in graduate school from the student's undergraduate interests, on which the E_a is based. The fraction of NF's may represent in part the propensity of young people to change their goals for a career.

It is to be hoped that the grades on the newly modified qualifying examination will be useful in spotting, early in their graduate career, those who will not be able to obtain an advanced degree. The new form of examination has not been in effect long enough to have amassed complete information as yet. Preliminary data, from the students entering from 1955 to 1959, appears promising. For example, the correlation index between grades on the qualifying examination and first-year course grades is 0.56, between qualifying grades and number of papers published to date is 0.44. Both of these are larger than the indices mentioned in the previous paragraph. Although it does not "weed out" the failures before they arrive, if the qualifying examination is taken in the student's first graduate year, the failures will have only lost one year or less. This is better for the student and more efficient for the department than waiting till the general doctor's examination to eliminate these men.