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30. The relative values of the luminous units of the primaries are $l_{460} = 0.051$; $l_{530} = 1.000$, and $l_{650} = 0.814$. Matches were made by flicker photometry between the first two at 494 mμ, and for the second and third, at 582.5 mμ. The luminous units are within the range reported by Wright (*28*) for his normal subjects. The experiments were done with retinal illuminances of test wavelengths equal in all cases to 500 trolands as established by flicker photometry.
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Production of U.S. Scientists

Trends in the number of doctorates granted in the major fields of science and in the humanities.

Office of Scientific Personnel,
National Academy of Sciences–National Research Council

Recent events have focused attention on the subject of the production of scientists in the United States. Discussion relating to science production inevitably involves educational problems outside the field of science specifically and factors affecting education generally in the United States. The present article is intended to furnish up-to-date information with respect to the output of scientists by the United States universities during the past 20 years and to put this in the context of long-term trends in advanced education.

The main body of data for this article is the doctorate records file built up over the past decade by the Office of Scientific Personnel of the National Academy of Sciences–National Research Council. Through the cooperation of all the graduate schools in the United States which grant third-level degrees, and by means of funds furnished by the Office of Naval Research, the National Science Foundation, the Carnegie Corporation, and the Ford Foundation, a comprehensive and accurate roster has been produced of all persons who have earned the Ph.D. degree or its equivalent in all the science and nonscience disciplines in the United States universities since 1936. Data for the periods 1936–1945 and 1936–1950 have been published previously (*1*). The data are now available for the first 20 years of this survey: 1936 to 1955, inclusive. The data for 1956 and 1957 are being checked for completeness and accuracy and are not yet available for publication. In addition, the Office of Scientific Personnel has drawn upon data previously assembled by Douglas Scates from many sources, including chiefly the United States Office of Education. These data, covering the years 1885 to 1935, were published by the American Council on Education in 1951 (*2*).

In compiling data for the long time span indicated above, a number of difficulties necessarily arise concerning such problems as definition of a field or discipline, the development of new interdisciplinary fields into specialties which acquire significance in their own right, and the convergence of fields originally dissimilar. These problems, however, are of importance chiefly with respect to the finer subdivisions of any discipline and do not preclude a clear picture where only a gross breakdown of general fields is concerned. In the present article, emphasis is placed on gross trends in major fields, while certain problems with respect to the minor fields are noted in passing.

Trends

Figure 1 represents the over-all production of doctoral degrees in all fields, compiled for the 70-year span 1885–1955. Because the production of doctorates has roughly doubled in each decade since the earliest records were maintained, it is convenient to show this gross trend on a semilogarithmic scale. The result is an approximation to a straight-line graph because of the logarithmic increment on the vertical axis. In Fig. 1, a straight line has been projected through

This article was prepared by the staff of the Office of Scientific Personnel, National Academy of Sciences–National Research Council. M. H. Trytten is director.

the annual production data at a slope equal to a 7 percent per annum increment. The base period through which this line is drawn is the period 1936 through 1941, inclusive (the first six years covered by the doctorate survey of the Office of Scientific Personnel). An increment of 7 percent per annum, compounded annually, is closely equivalent to the "doubling every decade" approximation noted by a number of writers in earlier publications.

It can be seen from Fig. 1 that this 7 percent trend line yields a fairly close approximation for the whole 70 years of data accumulation, in spite of variations in definitions and methods of data collection. The two points in the curve at which production falls precipitously below the trend line are the periods of World War I and World War II. In each case, there is a postwar recovery which brings the production curve back to the long-term trend line.

In Fig. 1 the production of science doctorates has been plotted at twice the actual value in order to represent the data as superimposed on total production. This simple doubling formula could be used because, during the base period 1936–1941, the science and nonscience fields were equal. As any line separating these two general fields is necessarily somewhat arbitrary, it is important that the definition used here should be clearly understood. On the one side are those fields which are almost universally accepted as the natural sciences, including physics, chemistry, geology, biology, and the medical sciences (only third-level degrees are considered; not included are the M.D., D.D.S., and D.V.M. degrees). Also included here are mathematics and engineering. The remainder of the disciplines form the more heterogeneous group, including the social sciences, the arts, and the humanities. Somewhat arbitrarily perhaps, psychology, anthropology, and geography have been included in the latter group. An earlier attempt to split these fields into their natural science and social science components was found unsatisfactory because of varying opinions as to what constitutes natural and social sciences and the lack of information with respect to fields of specialization of the individuals in the several groups.

Figure 2 presents the data from the Office of Scientific Personnel doctorate survey for the years 1936–1955 for these two general fields, in linear rather than logarithmic form to facilitate direct reading. It can be seen here that the 7 percent per annum trend line, based on the first six years, simultaneously graduates both production curves. The significant fact for present consideration is that the curve for natural sciences has reached a plateau while that for other fields is still rising. Also, the natural sciences

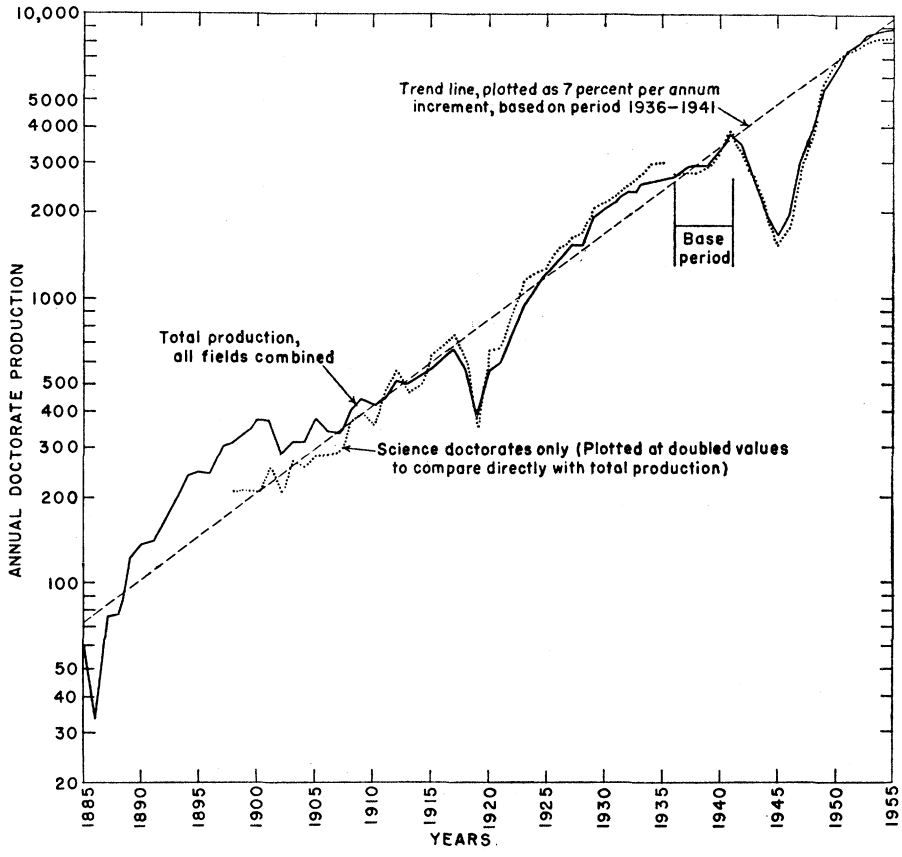

Fig. 1. Production of doctorates in United States universities, 1885–1955, plotted on logarithmic scale for straight-line projection.

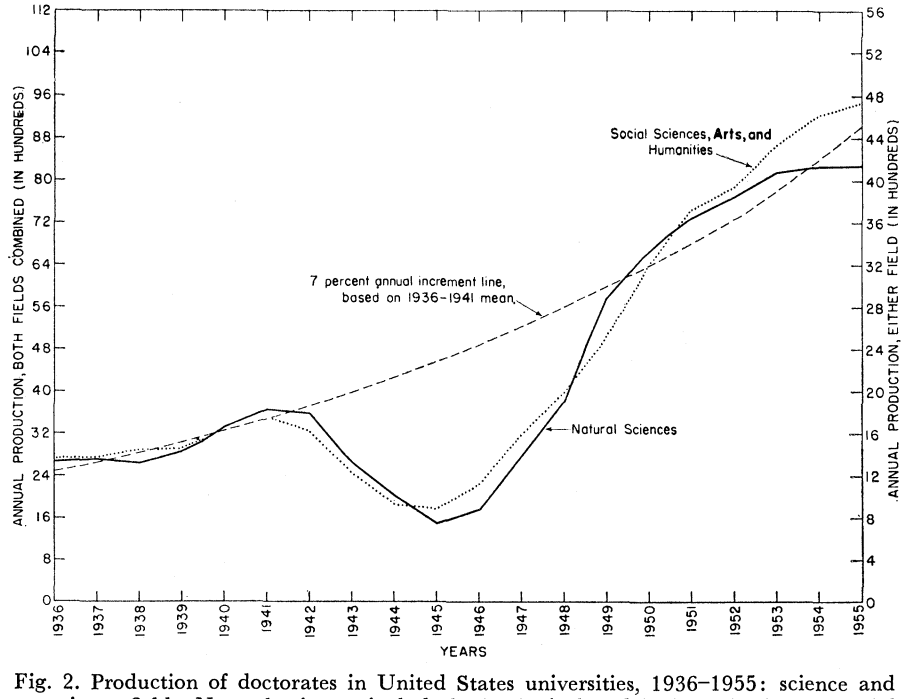

Fig. 2. Production of doctorates in United States universities, 1936–1955: science and nonscience fields. Natural sciences include both physical and biological sciences; social sciences, arts, and humanities are combined and include geography, psychology, and anthropology. The scale at left is for total production, all fields combined. The scale at right is for either field taken separately.

have dropped below the long-term trend line, while the social sciences, arts, and humanities group is above the line. In general it can be seen that the response of the latter group to the war emergency was somewhat less sharp and the post-war recovery less rapid. At least one of the factors involved in this differential response is the fact that members of the latter group are older and that, for this group, there is typically a much longer time span between the granting of the bachelor and doctoral degrees. The typical B.A.–Ph.D. time interval for the natural sciences is four or five years; in the other fields it is approximately twice this time.

Figure 3 breaks down the data of the natural science field into physical science and biological science components and presents each production curve with its corresponding 7 percent per annum projection based on the first six years. Again the definition of the disciplines included within each major grouping is important in interpretation. The physical science group includes mathematics, physics, astronomy, chemistry, geology, and engineering. The biological sciences include biochemistry and the medical sciences but do not include any portion of the fields of psychology and anthropology.

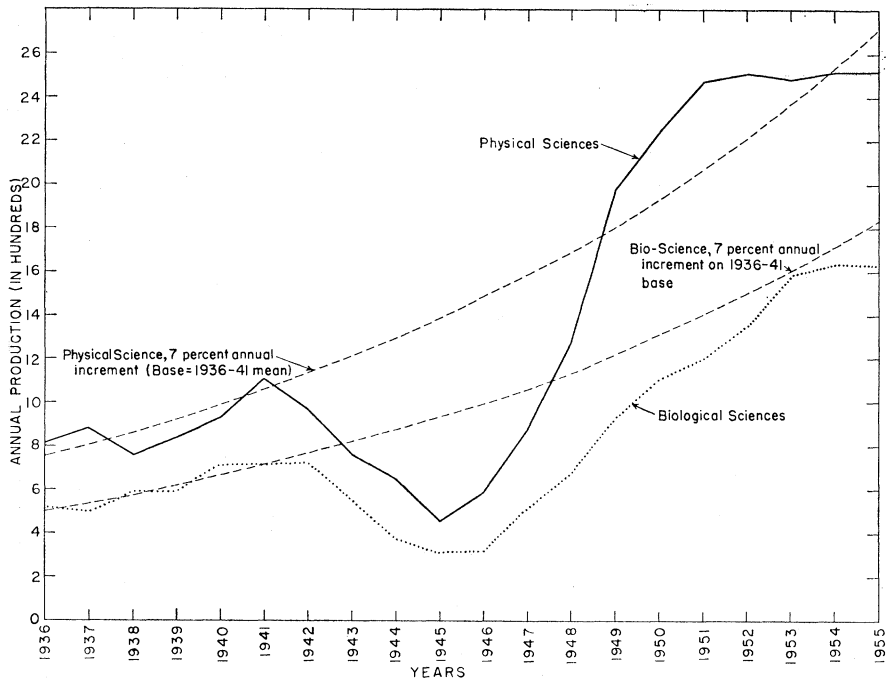

Fig. 3. Production of doctorates in United States universities, 1936–1955: biological and physical sciences. Physical sciences include geology and engineering; biological sciences include biochemistry and medical sciences but not anthropology or psychology.

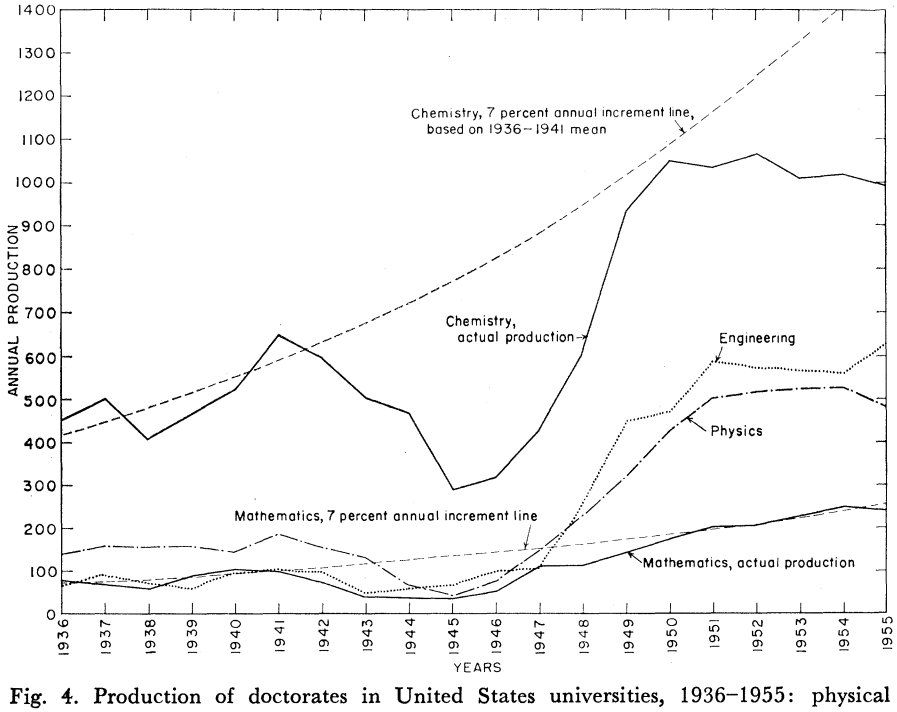

Fig. 4. Production of doctorates in United States universities, 1936–1955: physical sciences.

A phenomenon somewhat similar to the general difference between the science and nonscience fields mentioned earlier is apparent in the two graphs of Fig. 3. That is, the physical science group responds somewhat more sharply and quickly to the war period and to post-war recovery. Of particular importance at the present time is the fact that this group as a whole reached a plateau in 1951 and has continued on what is practically a dead level ever since. The biological science group, recovering somewhat more slowly, never quite reached its long-term trend line but struck a plateau two years later than the physical science group. This may be due to the fact that the bio-science group is, in general, composed of a somewhat older group of people and that there is a greater time lag between the granting of the bachelor's and doctor's degrees than is true for the physical science group.

Figure 4 gives a further breakdown of the physical science field. Omitted from this graph, in order to avoid overcrowding, is the curve for geology, which in general runs somewhat below that for mathematics. While geology includes some specialists who are more closely related to the bio-sciences than to the physical sciences, a preponderance of the members of this group are felt to belong properly in the physical science group. Biophysics, a very small group, is included in this tabulation with the biologists rather than the physicists.

The most striking feature of Fig. 4 is the fact that the largest field, chemistry, has never returned to its 7 percent trend line and has actually been on the decline most of the time since 1950. The second striking feature of this graph is that engineering has come up from being the smallest field in 1936 to being the second largest since 1948. Rather interesting is the fact that the upward trend in engineering as a Ph.D. field began during World War II and continued uninterruptedly until 1951. The relation of chemistry to engineering is of some im-

portance here. Although the depression in the chemistry figures can be attributed in part to a shift of some people from chemistry to chemical engineering (one of the largest components of the engineering group), the downward trend in chemistry over the past six years cannot be attributed to this source, as engineering itself has been on a plateau since 1951. Although the graduating 7 percent curves are omitted for physics and engineering, to avoid cluttering the chart, some interesting facts about them should be noted. In engineering, during the first six years, the production rate is almost exactly equal to that in mathematics. The mathematics trend line will therefore suffice as a close approximation to that for engineering. It is readily seen, therefore, that engineering has for several years produced twice as many doctorates as the 7 percent per annum increment would have led one to predict on the basis of the 1936–1941 figures. In physics, the trend line, if introduced, would have shown that the actual production exceeded expectations from 1950 on, but that the recent decline has brought the actual and projected figures almost exactly together.

Figures

Table 1 includes the actual figures for the fields included in the natural science group. Table 2 depicts the major fields within the social sciences, arts, and humanities groupings. Because of the large number of fields, only those with a production figure of over 700 within the 20 years covered by this study have been included in this table. Fields not tabulated include the following (20-year production totals are in parentheses): anthropology (484), geography (469), law and jurisprudence (344), international relations (291), linguistics (104), home economics (93), library and archival science (71), statistics (62), writing and journalism (38), and miscellaneous other fields not readily categorized (137).

Table 3 gives summary figures for the physical science and bio-science subgroups and for the natural science group as a whole. It also includes the summary figures for the fields of the social sciences, arts, and humanities group, with breakouts of certain significant components of this group. Psychology has been included as a separate group because of the fact that it has had a phenomenal growth during the past 20 years, its expansion bearing certain resemblances to that of engineering, but undoubtedly having

Table 1. Number of doctor's degrees awarded in major fields of the natural science group during the period 1936–55.

Year	Mathematics	Physics, astronomy	Chemistry	Engineering	Geology	Biochemistry	Biology	Medical science
1936	78	141	451	67	72	8	479	22
1937	73	160	501	90	54	21	466	9
1938	61	154	405	65	69	108	446	25
1939	90	156	467	59	59	116	456	16
1940	102	144	525	95	63	128	551	28
1941	97	185	649	106	67	104	580	29
1942	75	154	597	76	66	136	559	28
1943	41	130	502	47	41	114	423	15
1944	40	63	469	60	18	97	251	28
1945	38	43	290	65	24	72	220	17
1946	53	71	319	100	37	30	266	19
1947	116	148	424	115	61	42	458	18
1948	117	224	604	251	67	90	563	20
1949	143	319	932	445	121	123	773	33
1950	174	421	1,050	469	129	127	926	48
1951	204	499	1,033	585	148	140	1,004	49
1952	204	519	1,061	569	149	151	1,134	59
1953	226	523	1,006	563	167	179	1,353	45
1954	247	527	1,017	560	161	200	1,352	85
1955	240	481	993	624	175	210	1,311	105
1936–55	2,419	5,062	13,295	5,011	1,748	2,196	13,571	698

Table 2. Number of doctor's degrees awarded in major fields of the social sciences, arts, and humanities group during the period 1936–55.

Year	Sociology	Economics	History	Political sci.; public admin.	Education	Foreign languages	English	Speech	Philosophy	Religion, theol.	Business, commerce
1936	34	98	130	47	333	177	142	12	55	80	18
1937	53	107	144	56	349	169	160	21	42	77	13
1938	48	124	159	50	360	170	159	20	43	81	13
1939	57	106	164	49	361	158	159	15	55	88	24
1940	50	117	164	68	456	179	172	24	51	81	17
1941	74	151	185	63	468	181	191	39	53	101	21
1942	62	134	168	60	479	150	177	33	46	138	23
1943	44	80	120	41	385	114	120	20	30	102	17
1944	33	59	58	33	305	70	68	13	36	105	17
1945	30	54	68	20	284	71	73	19	26	132	12
1946	45	80	117	35	337	71	113	22	26	88	14
1947	76	135	168	55	445	120	164	37	40	136	18
1948	70	142	145	88	665	135	164	65	51	155	25
1949	98	185	224	108	817	158	177	45	61	185	39
1950	131	248	270	136	1,009	213	236	72	92	182	55
1951	142	295	341	139	1,116	202	297	94	87	184	64
1952	147	303	296	133	1,319	178	263	106	89	176	83
1953	183	293	350	150	1,426	202	332	123	110	161	85
1954	198	341	366	150	1,518	215	344	138	86	178	89
1955	188	359	333	182	1,584	216	327	130	99	186	96
1936–55	1,763	3,411	3,970	1,663	14,016	3,149	3,838	1,048	1,178	2,616	743

Table 3. Summary figures for the science and nonscience subgroups and the doctorate population as a whole.

Year	Physical sci., engineering, geology	Biology, medicine, biochem.	Natural sci., medicine	Psychology	Social sci., (including psychology)	Education	Arts, humanities	Social sci., arts, humanities, psychology, educ.	All fields
1936	809	509	1,318	110	458	333	531	1,322	2,640
1937	878	496	1,374	113	507	349	524	1,380	2,754
1938	754	579	1,333	119	525	360	529	1,414	2,747
1939	831	588	1,419	116	530	361	546	1,437	2,856
1940	929	707	1,636	125	576	456	575	1,607	3,243
1941	1,104	713	1,817	112	631	468	639	1,738	3,555
1942	968	723	1,691	125	588	479	640	1,707	3,398
1943	761	552	1,313	86	399	385	444	1,228	2,541
1944	650	376	1,026	67	277	305	343	925	1,951
1945	460	309	769	58	243	284	368	895	1,664
1946	580	315	895	82	398	337	370	1,105	2,000
1947	864	518	1,382	118	594	445	560	1,599	2,981
1948	1,263	673	1,936	169	650	665	679	1,994	3,930
1949	1,960	929	2,889	269	943	817	771	2,531	5,420
1950	2,243	1,101	3,344	342	1,210	1,009	792	3,011	6,355
1951	2,469	1,193	3,662	483	1,500	1,116	1,090	3,706	7,368
1952	2,502	1,344	3,846	580	1,541	1,319	1,063	3,923	7,769
1953	2,485	1,577	4,062	653	1,733	1,426	1,198	4,357	8,419
1954	2,512	1,637	4,149	665	1,831	1,518	1,277	4,626	8,775
1955	2,513	1,626	4,139	728	1,904	1,584	1,249	4,737	8,876
1936–55	27,535	16,465	44,000	5,120	17,038	14,016	14,188	45,242	89,242

quite different causes. The field of education has been included as a separate field because of its overwhelming magnitude, representing as it does almost one-third of the total social sciences, arts, and humanities composite. The field of social sciences has been here defined to include geography, archeology, anthropology, sociology, economics, statistics (other than mathematical statistics), history, political science, and public administration. In the arts and humanities subgroup have been included business and commerce, international relations, area studies (only one case in 20 years), linguistics, all languages and literature (both English and foreign), speech, writing and journalism, library science, law, home economics, arts, music, architecture, philosophy, religion, and theology. The segregation of any particular field into one or the other of these two general categories—social sciences or humanities—may be rather arbitrary. It does not appear, however, that the shift of any field about which there is disagreement from one to the other of these two categories would profoundly alter the general trend of the data.

New Procedure

The figures and tables here given raise many questions regarding reasons for various trends and changes in trends and regarding educational policies and actions at local, state, and national levels that might bear on these production figures. For answers to most of these questions, more data are required. For example, information on trends in the demand for Ph.D. degrees and on kinds and levels of support available for students in the various fields is needed. More information with respect to the individuals included in the doctorate records is also needed. To meet this latter need, a change was made at the beginning of 1957 in order to secure much more information regarding the educational experience, age, marital status and dependents, and future employment and educational plans of each new recipient of the doctoral degree. With the accumulation of these data, it should be possible to answer many questions raised by the present study. The new data-collection procedure instituted in 1957 should also make it possible to process the data more rapidly and to bring production curves up to date more quickly in the future. Additional papers dealing with significant aspects of doctorate production and related questions will be published from time to time as appropriate. A fourth volume of the "Baccalaureate Origins" series (see *1*) is scheduled to appear in the late spring or early summer of 1958. When it is available, it will extend the data here presented through the calendar year 1956.

References and Notes

1. *The Baccalaureate Origins of Science Doctorates Awarded in the United States 1936–1950* (Office of Scientific Personnel, National Research Council, Washington, D.C., June 1948); *Baccalaureate Origins of Science Doctorates Awarded in the United States 1936–1950*, Office of Scientific Personnel, National Academy of Sciences–National Research Council, Publ. No. 382 (Washington, D.C., 1955); *Baccalaureate Origins of Doctorates in the Arts, Humanities, and Social Sciences Awarded in the United States 1936–1950*, Office of Scientific Personnel, National Academy of Sciences–National Research Council Publ. No. 460 (Washington, D.C., 1956).
2. D. E. Scates, B. C. Murdoch, A. V. Yeomans, *The Production of Doctorates in the Sciences: 1936–1948*. A report of a project sponsored by the Manpower Branch, Human Resources Division, Office of Naval Research (American Council on Education, Washington, D.C., 1951).

C.-G. Rossby, Leader of Modern Meteorology

The sudden death of Carl-Gustav Arvid Rossby at his office in Stockholm, Sweden, on 19 August 1957, at the age of only 59, ended the career of a man who had shaped the development of modern meteorology in America as it rarely has fallen to the lot of one man to do in any scientific field.

Carl Rossby arrived in this country on a Scandinavian-American fellowship in early 1926, a young man of 27, bursting with that keen enthusiasm for his chosen work which has proved so stimulating to great numbers of students and professional colleagues and to many others who have been associated with him. Besides his training in theory at the University of Stockholm and three years of practical experience in forecasting in the Swedish Weather Bureau, Rossby had behind him the benefit of a year's sojourn at the Geophysical Institute in Bergen, during the early period of the creative development of the polar front theory by the Norwegian meteorologists under the inspiration of V. Bjerknes. In addition, he had made an extended visit at the Geophysical Institute in Leipzig.

At the time of Rossby's entry on the American meteorological scene, the science in this country was coasting along on the long-spent momentum gained from such American pioneers in the field as Ferrel, Abbe, and Bigelow. Professional activity in the science was limited to the Weather Bureau (primarily agricultural), the Navy, the Signal Corps of the Army, and the geography departments of a few universities. Professional training in modern meteorology did not exist; a career in the field could be entered upon only through one of the afore-mentioned Government services or as an adjunct to the study of geography and climatology in a few universities. Meanwhile, the first strong stirring of civilian and military aviation was beginning to call for a new deal in American meteorology and weather forecasting. Conditions were ripe for the incendiary spark which was Carl Rossby.

My friendship with Carl began in the Weather Bureau in Washington during 1926, where he was enthusiastically promoting the discussion and synoptic application of the new polar front theory of weather map analysis (which, up to that time, had been practically unheard of in this country), and attempting model tank experiments to prove the practical validity of the theory. His genius for stimulating creative scientific activity was quickly recognized, and he was selected, in 1927, by the Daniel