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POSTWAR GROWTH IN THE LENGTH OF ASTRONOMICAL AND OTHER SCIENTIFIC PAPERS

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The average length of scientific papers has increased by 13% to 115% (average 64%) since World War II in a wide range of English-language journals published in the USA, UK, and Japan in the fields of mathematics, physics, and chemistry as well as astronomy. The average length of letters and other short communications has also increased, by 26% in the last ten years and 76% in the last 20. Journals published in different countries and different disciplines show somewhat different patterns of growth. Changes in some journals are closely contemporaneous with changes in editorial policy or larger-scale events like wars. No two people who have examined the data have perceived the same pattern of probable causes. Suggestions include social phenomena (increases in publishing budgets and the ease of manuscript preparation, declining skills in the use of the English language, and publish-or-perish pressures in the direction of longer papers) as well as genuine increases in scientific content, perhaps even more rapid than the increases in length. The data set apparently constitutes a sort of Rorschach blot test of how one thinks science is changing and how it ought to change. The reader must, therefore, draw his own conclusions. If the sociological causes make a significant contribution to the increase in paper length, there is some hope that at least this particular aspect of the literature explosion can be controlled without detriment to scientific endeavor.

Key words: scientific literature—paper lengths—publishing policies—history of science

I. Introduction

Readers of PASP do not need to be told about the scientific literature explosion. Our desks are piled higher and deeper with more papers by more authors in more journals on more specialized topics than ever before. Several years ago, the editor of the *Astrophysical Journal* (Abt 1981) called attention to another aspect of the phenomenon: within the major American journals of astronomy and astrophysics there are now also more words per paper than ever before. The rise in mean paper length started shortly after the Second World War and has been monotonic and more than linear with time since, so that a typical 1980 paper is nearly three times wordier than a typical 1910–40 one. This is far from the only factor in the literature explosion; but it is not negligible either. If paper lengths in American astronomy had stayed at the 1950 level, we would, today, have only ten times as much to read as then, instead of 15 times as much per month!

I developed an interest in the phenomenon when Harris (1983) identified a similar trend in both European and American astronomical letters publications. Despite editors' avowed intent to favor short communications over long ones, the average letter is 30% longer today than it was ten years ago. In fact, the mean 1982–83 letter, at about 3100 words (or equivalent space in equations and figures) is a shade longer than the mean 1910–40 paper at 2900. One is left wondering (a) whether astronomers are different from other scientists in this logorrhea and

(b) whether average paper lengths could be correlated with any obvious properties of the science being presented or of the conditions of its publication.

The data assembled in section II, presented in section III, and discussed in section IV are the result of this wondering by the present author.

II. The Data Base

Table IA lists the journals and years examined for mean paper lengths. The number of papers in each sample is given in parentheses. Asterisks indicate years in which the sample does not include all the papers published that year (because the total number was much larger than needed to provide a statistically significant sample and the journal format made determination of paper and page numbers tedious). The U.S. journals are listed first, then U.K., and Japanese, in the order mathematics, physics, chemistry, and astronomy. Astronomy in the U.S. is represented by Abt's (1981) composite data on the *Astrophysical Journal* (*Ap. J.*), *Astronomical Journal* (*A.J.*), and PASP.

Table IB contains the same information for the corresponding letters sections and journals, plus *Physics Letters B*, published in English in Holland, in the same order, except that mathematicians do not seem to produce short communications.

The journals were chosen on the basis of colleagues' responses to the question: "What is the most prestigious journal published in your field in the U.S. (U.K., etc.)

TABLE IA

DATA BASE — MAIN JOURNALS

ANNALS MATH.	PHYSICAL REVIEW	J. AMER. CHEM. S.	AMERICAN ASTRON.	PROC. LON. MATH. S.	PROC. PHYS. S. LOND.	J. CHEM. S. LOND.	MON. NOT. R. ASTRON. S.	J. MATH. SOC. JPN	PROC. TH. PHYS.	BULL. CHEM. SOC. JPN	P. ASTRON. SOC. JPN
1900-02 (71)				1903-07 (148)		1898-1902 (655)					
1903-07 (93)				1908-12 (127)		1903-07 (892)					
1908-12 (104)			1910 (167)	1913-17 (139)		1908-12 (1253)					
1913-17 (128)	1913-17 (492)			1918-22 (127)		1913-17 (908)					
1918-22 (150)	1918-22 (428)	1920 (296)	1920 (175)	1923-27 (222)	1921-23 (76)	1918-22 (1000)					
1923-27 (189)	1923, 25-7 (661)	1925 (312)		1928-32 (231)	1924-28 (229)	1923-27 (1923)					
1928-32 (284)	1928-32 (1432)	1930 (334)	1930 (134)	1933-37 (257)	1929-33 (278)	1928-32 (1978)					
1933-36 (213)	*1933-37 (709)	1935 (459)		1943-47 (46)	1934-38 (436)	1933-37 (2058)					
1938-42 (305)	*1938-42 (696)	*1940 (416)	1940 (212)	1948-52 (187)	1939-43 (343)	1938-42 (1444)	1940-42 (31)				
1943-47 (254)	*1943-47 (323)	*1945 (430)		1953-57 (147)	1944-48 (384)	1943-47 (1303)	1947 (34)				
*1949-51 (184)	*1948-52 (790)	*1950 (327)	1950 (217)	1958-62 (175)	1950-52 (664)	1948-52 (4013)	1952 (48)	1950 (38)	1950 (78)	1950 (79)	1950-52 (92)
*1954-56 (121)	*1960 (534)	*1955 (382)		1963-67 (214)	*1955-57 (309)	1953-57 (4398)	1957 (48)	1955 (33)	1955 (84)	1955 (158)	1953-57 (90)
*1959-61 (109)	*1962, 64 (808)	*1960 (335)	1960 (369)		1961 (309)	1958-62 (4951)	1962 (116)	1960 (29)	1960 (173)	1960 (367)	1958-62 (137)
*1964-66 (107)	*1967-68 (492)	*1965 (428)			1967 (379)	1963-65 (3562)	1967 (109)	1965 (31)	1965 (172)	1965 (409)	1963-67 (174)
					*1968 (519)	1966 (1329)					
*1969-71 (94)	*1972 (515)	*1970 (456)	1970 (908)	1968-72 (325)	*1973 (497)	1971 (2230)	1972 (154)	1970 (34)	1970 (230)	*1970 (401)	1969-71 (104)
*1974-76 (91)	*1977 (497)	*1975 (403)		1973-77 (312)	*1978 (1200)	1972 (3071)	1977 (273)	1975 (47)	1975 (281)	*1975 (416)	1974-76 (132)
*1979-80 (68)	*1982 (417)	*1980 (436)	*1980 (1622)	1978-81 (184)	*1983 (471)	1977 (3294)	1982 (360)	1980 (48)	1980 (311)	*1980 (299)	1979-81 (148)
						1982 (4201)					

TABLE 1B
DATA BASE — LETTERS JOURNALS AND SECTIONS

PHYS. REV. LETT.	J. AMER. CHEM. S.	AP. J. LETT.	J. PHYS	PHYSICS LETT. B	MNRAS	PROG. TH. PHYS.	BCS JAPAN CHEM. LETT.	P. ASTRON. S. JPN
	1930 (16)							
	1935 (100)							
	*1940 (82)							
	*1945 (126)		1944-46 (22)					
	*1950 (252)		1950-52 (342)			1950 (76)	1950 (3)	1950-52 (12)
	*1955 (229)		*1955-57 (242)			1955 (67)	1955 (24)	1953-57 (8)
1963 (419)	*1960 (87)		1961 (48)			1960 (83)	1960 (81)	1958-62 (21)
*1968 (537)	*1965 (298)		1967-68 (166)			1965 (79)	1965 (172)	1963-67 (10)
*1973 (300)	*1970 (326)	1974 (300)	*1973 (153)	*1973 (300)	1971-74 (120)	1970 (116)	1970 (139)	1969-71 (17)
*1978 (300)	*1975 (324)	1978 (300)	*1978 (415)	*1978 (300)		1975 (147)	1972 (349)	1974-76 (20)
							1977 (436)	
*1983 (300)	*1980 (313)	*1982-83 (300)	*1983 (174)	*1983 (300)	1979-82 (170)	1980 (116)	1982 (433)	1979-81 (16)

that covers a broad range of topics?" The volumes included in the sample are those available in the UC Irvine (UCI) physical sciences library in a format that made it possible to enumerate pages and papers accurately without having to examine absolutely every page of every volume. This excluded some society publications for years when scientific papers, obituaries, meeting reports, and short news items were intimately intermingled and no table of contents or classified index was bound with the volume.

The data are less than perfect. Abt (1981) and Harris (1983) appear to have examined individual pages and included fractional parts appropriately. But in the present sample, a volume that consisted of X pages containing Y papers was recorded as having papers of mean length X/Y , even though bottom portions of some pages may have been empty. This introduces a discordance between journals that run papers together on the pages (e.g., letters to the editor in *J. Amer. Chem. Soc.*) and those that leave blank half pages (e.g., *Phys. Rev. Letters*) or full pages (e.g., *Mon. Not. R. Astron. Soc.*) between papers. Of the journals in the sample, only the *Ap. J.* (which switched from leaving blank pages to starting papers on either odd or even pages a few years ago, but which was correctly treated in the Abt sample) appears to have changed its policy on this over the period surveyed. Thus the blank-page problem should not affect conclusions on how paper length changed in a particular publication.

Most of the journals have changed their format at least

once during the survey period, sometimes drastically (e.g., splitting into sections by subdiscipline). Most changes were in the direction of larger pages, though a couple of U.K. journals simply used smaller type during the war. Paper lengths were normalized across all such changes in format by counting lines per page and words per line on pages of text before and after. This is not quite fair, as figures and equations will not necessarily scale in the same way. Where journals split or merged, a problem arose in how to weight the subsections, since organic chemistry papers, for instance, might be systematically longer or shorter than physical chemistry ones. The decision made was to include all the papers published in the subsections over the same length of time (e.g., January to March 1980), even if this resulted in counting, for instance, three volumes of *Phys. Rev. B* to one of *Phys. Rev. A*. Similarly, Abt (1981) included *Ap. J. Suppl.* and *Ap. J. (Letters)* with the main journal after they split off in 1954 and 1967, respectively. *Memoires Roy. Astron. Soc.* was merged into *M.N.R.A.S.* in 1977-78 as microfiche pages. Both have been left out.

A few format changes, associated with changes in editors, etc., were accompanied by large changes in the population of authors publishing and the kinds of papers published. This resulted in large sudden changes in mean paper length, which are, however, real and not an artifact of page size etc. The only question is whether, e.g., *Journal of Physics*, which is here assumed to be a direct continuation of its predecessor, *Proc. Phys. Soc. (London)*

should properly be regarded as “really” the same journal.

For each sample volume, numbers of items and the pages occupied were recorded separately for full papers and short communications (letters to the editor, notes, new compounds, etc.), ignoring obituaries, prize lectures, meeting reports, and the like. Dividing pages by papers and normalizing as described above yielded mean paper length as a function of time for the various publications. Finally, in order to facilitate comparisons among journals, mean paper lengths were normalized by taking ratios to the 1950 values for each publication. This was the year most of the Japanese journals began publishing and is early enough to catch most of the postwar rise. Most of the letters publications do not go back this far and were, perforce, normalized to 1980–83. The data for *Ap. J. (Letters)* and *M.N.R.A.S.* (pink pages) is that of Harris (1983).

During the early years of the century, when most journals were small, it was necessary to look at all volumes published and combine, e.g., 1908–12, to get a statistically significant sample. This binning can obscure interesting features in paper numbers and lengths associated with world events (wars, depressions). One representative journal is, therefore, presented in detail in section III. More recently, some journals have published thousands of papers per year, while a few hundred seemed enough for the present purpose. The asterisks in Tables IA and IB indicate years in which the number of papers examined and listed in the tables is less than the total number published, by a factor anywhere from two to ten.

III. Results

The raw data reveal a variety of phenomena not di-

rectly pertinent to the subject matter of this paper. Most of them are qualitatively not surprising. Physicists publish more than mathematicians (and not just because there are more of them). Chemists like to have lots of coauthors. The number of pages printed per year has increased enormously in the physics, chemistry, and astronomy journals since 1950, but much less in the mathematics journals. Changes in editorial policy and format can cause large changes in submission rates as well as in paper lengths. A 1930 issue of any journal differs from a 1980 issue in having a much larger fraction of authors whose names one recognizes, titles one can understand, and papers that one feels vaguely were seminal to something or other. And so forth. These peripheral points will not be discussed further here.

Table II shows mean pages per paper as a function of time for the journals listed in Table I. Virtually all columns show increases from top to bottom, occasionally monotonic (*Ann. Math.*), more often with bumps and wiggles (*Phys. Rev.*, *J. Phys.*). The five-year binning has obscured some structure that may be significant. Table III therefore presents the data in full detail for *J. Chem. Soc. London*, chosen because it contained enough papers each year to give meaningful numbers and because the UCI collection goes back to the beginning of the century. Asterisks in this table indicate years when page format changed. After the first such change, the pages-per-paper column gives first the raw number and then the value normalized to pre-1932 pages.

Table III shows very clearly the enormous drops in paper numbers associated with both World Wars. All U.K. journals show these; the U.S. ones show only a WWII effect. Paper lengths do not change systematically through the wars, which is itself interesting,

TABLE IIA

NUMBER OF PAGES PER PAPER VS. TIME — MAIN JOURNALS												
YEARS	ANN. MATH.	PHYS. REV.	JACS	AMER. ASTR.	P.LON. MATH.S	J. PHYS.	J.CHEM S.LON.	MNRAS	J.MATH S.JPN	PR.TH. PHYS.	B.CHEM S.JPN	P.AST. S.JPN
1898-02	8.11						10.00					
1903-07	10.32				16.45		10.07					
1908-12	9.30			2.72	19.11		9.28					
1913-17	8.20	10.35			17.12		9.95					
1918-22	10.15	11.27	4.58	2.48	16.02	6.66	8.52					
1923-27	12.43	10.06	3.52		16.50	9.03	7.72					
1928-32	12.44	9.71	3.11	3.77	16.78	11.56	7.45					
1933-37	17.46	8.15	3.07		17.19	10.50	6.77					
1938-42	15.93	8.63	3.09	2.95	20.78	9.88	7.92	5.61				
1943-47	16.73	9.77	3.18		20.83	10.21	8.08	9.21				
1948-52	16.80	9.05	3.48	4.76	16.26	8.82	8.58	11.48	7.58	10.79	3.24	7.59
1953-57	19.36	8.24	3.18		19.16	8.59	8.16	11.48	16.24	13.27	4.18	11.22
1958-63	22.94	8.38	3.59	5.78	19.75	8.46	8.04	14.46	14.93	14.06	4.34	13.58
1964-68	21.85	10.07	6.15		17.94	9.00	8.96	12.32	14.26	11.71	4.80	13.70
1969-73	25.29	11.65	6.03	6.78	16.54	10.57	10.97	12.20	17.35	13.41	5.02	14.06
1974-78	26.03	10.97	6.04		20.38	12.13	12.32	11.21	14.66	12.26	6.17	13.27
1979-83	26.93	13.64	6.34	8.67	25.20	11.15	15.88	12.95	16.29	12.96	6.86	14.49

TABLE IIB

NUMBER OF PAGES PER PAPER VS. TIME — LETTERS JOURNALS AND SECTIONS

YEARS	PRL	J.AM. CH.S.	AP.J. LETT.	J. PHYS.	PH.L. B	MNRAS	PR.TH. PHYS.	B.CH. S.JPN
1928-32		0.63						
1933-37		0.61						
1938-42		0.63						
1944-46		0.60		1.27				
1948-52		0.72		1.32			1.33	2.00
1953-57		0.97		2.18			1.63	1.25
1958-63	2.68	0.65		1.90			2.04	1.88
1964-68	2.88	1.20		2.37			1.85	1.47
1969-73	3.20	1.45	2.8	3.82	3.62	3.6	1.89	1.94
1974-78	3.39	1.44	3.3	4.79	4.03		2.12	2.54
1979-83	3.84	1.52	3.9	5.11	4.57	4.3	3.42	2.67

TABLE III

DETAILED DATA FOR J. CHEM. SOC. LONDON

YEAR	PAGES	PAPERS	PAGES/PAPER	YEAR	PAGES	PAPERS	PAGES/PAPER
1898	1038	103	10.18	1932	2880	457	6.23
1899	1166	120	9.72	*1933	1533	388	3.95/6.28
1900	1334	127	10.50	1934	1906	443	4.30/6.84
1901	1411	146	9.66	1935	1744	434	4.03/6.39
1902	1604	160	10.40	1936	1737	414	4.20/6.68
1903	1490	142	10.49	1937	1847	425	4.35/6.92
1904	1761	175	10.06	1938	1900	404	4.70/7.47
1905	1818	184	9.88	1939	1929	405	4.76/7.57
1906	1809	186	10.16	1940	1561	302	5.02/7.98
1907	2021	205	9.86	1941	863	159	5.43/8.63
1908	2188	222	9.86	*1942	737	174	4.24/8.76
1909	2133	236	9.04	1943	648	178	3.64/7.52
1910	2601	270	9.04	1944	664	189	3.51/7.26
1911	2270	259	8.76	1945	930	276	3.37/6.97
1912	2431	266	9.14	1946	1161	300	3.70/7.65
1913	2173	238	9.13	1947	1709	375	4.56/9.43
1914	2830	272	10.40	1948	2203	511	4.31/8.91
1915	1862	200	9.31	1949	3762	870	4.32/8.93
1916	1212	103	11.77	1950	3576	806	4.44/9.18
1917	960	95	10.11	1951	3368	839	4.01/8.29
1918	849	89	9.54	*1952	4901	987	4.97/7.90
1919	1392	139	10.01	1953	4028	866	4.65/7.40
1920	1486	182	8.16	1954	4552	961	4.74/7.53
1921	1990	243	8.19	1955	4292	908	4.73/7.52
1922	2806	347	8.09	1956	4988	971	5.14/8.17
1923	3249	400	8.12	1957	5099	1025	4.97/7.91
1924	2605	363	7.18	1958	4784	976	4.90/7.79
1925	2870	409	7.02	1959	4141	840	4.93/7.84
1926	3060	437	7.00	1960	5276	1022	5.16/8.21
1927	3068	414	7.41	1961	5563	1094	5.09/8.09
1928	3188	438	7.29	1962	5303	1019	5.20/8.27
1929	2868	400	7.17	1963	6079	1165	5.22/8.30
1930	2657	371	7.17	1964	6260	1200	5.22/8.29
1931	3174	462	6.87	1965	7536	1375	5.48/8.71

* Changes in page and/or type size. Pages/paper thereafter are corrected to the pre-1932 format.

since the youngest researchers were systematically removed from the publishing populations. The drop in paper length during the depression (common to several journals, but not universal) was a surprise to me. Data on journals published in Germany, where severe economic pressure set in earlier would be interesting in this context.

Figures 1 and 2 show mean paper lengths normalized to 1950 = 1.00 for the individual journals, for averages by country and discipline, and for the total main journal and letter samples. All journals were given equal weight in all years for which there is data on them (mostly because weighting by paper numbers would have disenfranchised the mathematicians and astronomers completely; in 1960, for instance, *J. Chem. Soc. London* published more papers—1022—than all the mathematics and astronomy journals put together—777). The letter

sample had to be fudged, since some did not exist in 1950. They were first normalized to 1980–83 = 1.00, the average calculated for each five year bin, and then the numbers all divided by the 1950 average value.

Increases in paper length between 1950 and 1980–83 range from 13% to 115%, with an unweighted average of 64%. This drops to 40%, however, if we set the Japanese baseline year at 1955, when the effects of the immediate postwar wood-pulp shortage had largely disappeared. The 13% minimum value belongs to *M.N.R.A.S.* and the 115% maximum to *J. Math. Soc. Japan*. After renormalizing the Japanese data, *J. Chem. Soc. London*, *J. Am. Chem. Soc.*, and the American astronomy journals tie at 82–85% for largest increases. Disciplinary and national averages are mathematics 77%, physics 27%, chemistry 93%, astronomy 82%, U.S. 65%, U.K. 45%, and Japan 85% (but only 20% after 1955). Every reader can surely find something in these numbers to support his most cherished preconceptions.

Among the letter sections and journals, ten-year increases range from 5% (*J. Am. Chem. Soc.*) to 38% (*Bull. Chem. Soc. Japan*) and 20-year increases from 40% (*Bull. Chem. Soc. Japan*) to 170% (*J. Phys. London*). The averages are 22% in ten years and 74% in 20 (vs. 15% and

FIG. 1—Changes with time in mean paper length for the twelve main journals surveyed, normalized to 1950 = 1.00. Circles and solid lines are mathematics journals; diamonds and uneven dashes are physics; triangles and short dashes are chemistry; and squares and long dashes are astronomy.

FIG. 2—Changes with time in mean paper length, averaged by country and discipline, normalized to 1950 = 1.00. Disciplines in the lower half of the figure are coded with the same symbols as in Figure 1. In the upper half, "Total" represents the average of the twelve main journals surveyed and "Letters" the average of the nine letters journals and sections.

29% for the associated main journals). Such a trend persisting over half a century would give us 12,000-word "letters", equivalent to the average 25-page *Annual Review* article.

No two journals or averages show precisely the same pattern. Some features that I think may be important or informative are: (a) the universality of postwar increases in mean paper length, (b) the very steep rise in letter lengths since 1960, (c) the differences among disciplines, (d) the differences among national averages, including the rapid Japanese decompression 1950–55 and the late, but nearly exponential, U.K. takeoff, and (e) the flattening in the astronomy curve 1960–75. The reader is invited to look for, and attempt to interpret, other trends.

IV. Discussion and Interpretation

Abt (1981) and Harris (1983) suggested several possible reasons for the increasing length of astronomy papers and letters. Two were intrinsic to the science being reported (a drop in the ratio of "discovery" papers to "modeling" papers; and a genuine increase in the per-paper content of new science) and one largely extrinsic and sociological (changes in editorial policy to exclude uninterpreted observational data). The scientific literature explosion as a whole might similarly have causes either in the nature of the science being presented or in the conditions under which it is published (or both). The point of trying to make the distinction is, of course, that the sociological factors can, and probably should, be changed to slow down the explosion, while the internal scientific ones probably cannot and should not be.

The present larger data set has been looked at by two professional historians of science (H1 and H2 below), the editors of two other journals (E and E'), and a distinguished colleague whose active scientific career spans about two-thirds of the period surveyed (C), as well as the present author (A). Each saw evidence for different sorts of causes for the increase in mean paper length. The qualifications of the first five to interpret such data are obvious from their background. A can claim no such special expertise. She has, however, at least seen the titles, authors' names, and lengths of most of the papers indicated in Table IA and IB and, in addition, has for the past decade been in the habit of writing out brief abstracts of the astronomical papers that appear in about two dozen physics, astronomy, and interdisciplinary journals. This has left some impression of how much that is new to the average reader appears in these current papers as a function of their length.

The following paragraphs present hypotheses and supporting data suggested by these five people. In general, H2 and E have perceived scientific factors, and H1, E', C, and A sociological ones.

One of the trends mentioned at the end of section III

looks to A like a possible confirmation of the discovery vs. modeling effect suggested by Abt and Harris. The rapid growth in astronomy paper length leveled off during the brief "gee whiz" discovery era from the identification of quasars (1963) through the microwave background (1965) and pulsars (1968) to the *Uhuru* X-ray sources (1971). Then rapid growth resumed, perhaps as Harris (1983) suggested, because astronomers turned from reporting to explaining. Hesitation in accepting this explanation comes from the fact that the leveling is a sum of increasing American paper length, constant *P.A.S. Japan* length, and falling *M.N.R.A.S.* length. This particular hypothesis cannot really be tested by comparison with the other sciences because mathematics operates rather differently (something brand new is at least as likely to appear in a long paper as in a short one), while physics and chemistry cover so much territory that eras of discovery in one subdiscipline will be cancelled by eras of development in others.

H2, along the same lines but more broadly, describes long papers as a signature of mature disciplines and suggests testing this by looking at the literature of newer ones like anthropology as well as at 19th-century trends in the physical and mathematical sciences. Given a long enough base line, one would expect cycles of long and short papers as new fields open up, mature, and taper off. Library resources currently available to the author do not permit carrying out these tests; the work involved is probably a couple of person-weeks. On this hypothesis, the current lengthening of astronomy, etc., papers is a natural, temporary phase, which can be expected to pass without any special effort on our part.

E believes that the dominant factor in producing longer papers is greatly increased scientific content. He regards the extreme pervasiveness of the phenomenon as evidence for this—all science is becoming increasingly complex and, therefore, needs more space for explanation. All the other factors discussed above and below are, on this hypothesis, secondary causes that have merely slowed or enhanced the basic growth. If this is so, then we must apparently resign ourselves throughout the foreseeable future to continuing increase in the length of papers that contain significant new results. The growth not only should not be stopped, but probably cannot be.

E notes as a specific example orbits of visual binary stars, which used to be published one by one. They now appear in sets of 3–30 (e.g., in *Astr. and Ap. Suppl.*) or as a couple of lines in an *I.A.U. Information Bulletin*, representing a ten-fold increase in content per paper. A would remark, however, that the current papers are generally shorter than the old ones, because (a) fewer of the raw data appear and (b) methods of orbit determinations have been standardized and no longer need to be described. This case is perhaps a better example of H2's

hypothesis than of E's, if the subfield of visual binary orbit determination can safely be called post-mature.

A is not entirely persuaded of the primary importance of increased scientific content as a cause of rising paper length, because what must really matter is not the absolute content but what is new to the intended reader. This affects how an author presents (or should present) his observational, experimental, or computational methods, the results, comparisons with previous work, and implications as well as introductory material. And the average modern paper is read by a much narrower, more specialized, and better prepared audience than were papers of earlier generations.

C, who also questions the primacy of increased content, suggests testing the relationship between length and content by giving a graduate class a recent journal issue and asking each member to rewrite one of the papers, giving the essential information in what he regards as the most concise possible form.

A suspects that the main causes of postwar paper lengthening are sociological and subject to modification: Authors basically want to write long papers rather than short ones (that's why editors of camera-ready conference proceedings give you a maximum number of pages to fill, not a minimum). Referees find it easier to ask for expansions of difficult points than to provide detailed recommendations on how to rewrite for clarity. And some of the external pressures that once opposed the trend have relaxed or shifted.

Why long papers? First, it's easier. Winston Churchill is supposed to have said that he would need a week to prepare a five minute speech on an important subject, but if you wanted an hour-long one, he was ready immediately. Second, they are rewarded. Methods of evaluating scientists for promotion and tenure have, in recent years, tended to attach high value to substantial papers in refereed journals (and also to letter publications, of which more later). Third, C suspects that postwar authors may have to use more words than prewar ones did to express the same quantum of thought because they have not learnt English grammar as thoroughly and systematically. A, in turn, believes (but does not have the data to prove) that the fraction of authors in the journals surveyed who are not native speakers of English has increased with time and wonders if this may also contribute.

E' points out the referees' effect with an extract from a typical, though composite, report: "This paper is too long. The authors should be more specific about their observational techniques. They should explain their statistical tests more completely. They should cite more previous work. They should discuss my theory. They should..."

What are the external pressures and how have they

changed? Some are purely mechanical. C points out that the work-per-page in preparing a paper for publication is a good deal less now than it was before the war when (particularly in Britain) diagrams were drawn by hand in India ink on Bristol board and most "manuscripts" really were written by hand. The advent of word processors and computer graphics is rapidly lightening the work-per-page still further. This may be ominous! H1 noted two other effects on ease of publication. First, budgets for the purpose have increased enormously since the war, lightening in another way the burden of producing long papers. In addition, teaching loads within science departments at large universities have dropped from a prewar norm of 3-4 courses at a time to 1-2 or even less, leaving more time for publishing research as well as doing it. This last is more important for physics and mathematics than for astronomy in the U.S. An examination of 322 institutional affiliations listed by *Ap. J.* authors between 1926 and 1933 (Vols. 64-78 apart from a few missing issues) shows 124 at Mount Wilson and another 94 at Yerkes Observatory—70% of the total. (The first 322 affiliations listed in 1980 spanned 124 different institutions and no one contributed more than 5% of the total.)

A believes that policies announced and enforced by journal editors can constitute an important source of external pressure on paper lengths. Several of the main journals show effects closely correlated in time with changes in editorial policy. The three Japanese publications in 1950 all had and enforced stringent length limits, which they attributed to extreme difficulty in getting enough paper to produce the journals (Japan imports all her wood-pulp). Almost 2/3 of the entire postwar growth in these journals occurred over the next five years, as those limits were gradually relaxed. Papers in these journals are rather short to this day—though not as short as American papers would be if we had to write them in Japanese! *Annals of Mathematics* is unique in showing an almost monotonic increase in paper length over the whole century. This apparently results from increasing editorial determination to publish only thorough discussions of fundamentally new ideas, which, in mathematics, means long papers (Rector 1984). Finally, within American astronomical journals one- and two-page papers have been nearly eliminated by a communal and editorial decision that observational data must be accompanied by interpretation to be publishable.

A also thinks it significant that letters have grown even more rapidly than standard papers. Some of the changes closely parallel changes in editorial policy. For instance, the mean paper length in *Phys. Letters B* rose from 3.6 pages in 1973, when the rule was "maximum length not to exceed three printed pages," to 4.6 in 1983, when instructions read "should normally not exceed four

pages." In *Prog. Theor. Phys.*, permitted letter length has nearly tripled since 1950, from 1000 words to 250 (roughly 11-word) lines. Mean letter length has increased by about the same factor, from 1.33 to 3.42 pages. *Ap. J. (Letters)* has maintained a nominal four-page limit which is, however, exceeded by a much larger fraction of published letters now than ten years ago (and the pages are bigger). *Phys. Rev. Letters* and *J. Amer. Chem. Soc.*, on the other hand, have held firmly by their length limits (3.5 pages and 1000 words, respectively), but the average letter has crept asymptotically toward the maximum allowed. Table IV shows the trends for *Phys. Letters B* and *Phys. Rev. Letters*. A has a strong impression that the high prestige associated with getting one's work into many of the letter publications has encouraged authors to push constantly at the length limits so as to squeeze in contributions that should really be full papers. This is not an original idea!

At the other end of the length spectrum, C points out that prewar publication of extended contributions quite often took place in journals like *Phil. Trans. Roy. Soc.* and in the form of books, both of which fall entirely out of the present data sample, but are clearly much less often utilized now than formerly. A is uncertain whether to attribute the change primarily to authorial inclination or editorial policy.

Editorial policies are obviously not formulated in vacuo but reflect the perceived wishes of the communities the journals serve. They therefore provide an indirect but effective way for scientists-as-readers to exert forces on scientists-as-authors to control paper lengths or other aspects of publication.

Finally, there are clear differences among countries and subjects. Within the earlier data, several averages show rises in mean length during the ebullient 20s fol-

lowed by fairly rapid falls during the depression. A suspects causes related to the economics of both doing and publishing research. The late, rapid rise in the U.K. curve looks to A like the result of social pressures of the "publish or perish" sort, which appeared later there, but are by now arguably even stronger than in the U.S., owing to government policies on the financing of science. E believes that the physics curve has grown more slowly than the others because of a trend toward splitting research results into small quanta so as to yield longer bibliographies.

It is left as an exercise for the reader to decide whether other differences among disciplines and nations are what he would have expected, based on knowledge of his colleagues. These expectations can be tested by collecting data on journals in other fields (geology, biology, electrical engineering...) and from other nations. The only research tools required are a large library and a strong index finger. At least the latter should probably be one's own.

V. Conclusions and Exhortation

What, if anything, we should think and do about the gradual increase in the length of papers in the physical sciences depends almost entirely on what we perceive to be the main causes. If, as E believes, the main cause is increased scientific content, then we should on the whole welcome the phenomenon as a sign of health in our endeavors, though still striving to write our own papers with the maximum possible clarity and conciseness. On this hypothesis, modest continued growth in mean paper length is probably unavoidable.

If, on the other hand, the current growth epoch is a natural phase coinciding with a particular stage of maturity in the physical sciences, as H2 suggested, then the

TABLE IV
CHANGES IN DISTRIBUTION OF PAPER LENGTHS IN TWO LETTERS JOURNALS

JOURNAL	YEAR	# OF PAGES	# OF PAPERS	YEAR	# OF PAGES	# OF PAPERS	YEAR	# OF PAGES	# OF PAPERS
Phys. Rev. Lett.	1973	1	1	1978	1	0	1983	1	0
		2	32		2	13		2	3
		3	174		3	157		3	42
		4	93		4	130		4	255
			300			300			300
Phys. Lett. B	1973	2	24	1978	2	13	1983	2	8
		3	127		3	78		3	46
		4	103		4	118		4	108
		5	35		5	71		5	80
		6	8		6	17		6	31
		7	3		7	3		7	20
			300			300		8	5
								9	2
									300

cycle will probably take care of itself, and mean paper lengths in due course drop without any special effort in that direction.

Finally, A believes that the absolutely universal nature of postwar paper growth, despite the very different kinds of things being done in the several disciplines, along with most of the other trends and correlations discussed above strongly suggests driving by forces external to the kind of scientific research being reported. This, in turn, provides some hope of moderating at least one aspect of the current exponential literature growth. Other aspects—appearance of new journals, numbers of publishing scientists, numbers of papers per author, and so forth—require separate investigation. Unfortunately, the sociology of publication, curricula vitae, and professional advancement is such that each author's doing what he

perceives as best for himself is unlikely to lead to the best possible result for the scientific community as a whole. Perhaps we need a sort of Social Contract among authors, editors, referees, readers, and sponsoring agencies. Most of us function in two or more of these capacities, and so have both opportunity and motivation to do something about paper numbers and lengths via private action in the mean time.

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