

## SCIENTIFIC PUBLISHING

## SCIENCE IS BECOMING TRULY WORLDWIDE

Bulk of growth in scientific papers is in Europe and Asia; U.S. posts far more modest gains

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**T**O THE EXTENT THAT THE NUMBER of articles published annually in the scientific literature is a reasonably meaningful—if not strictly quantitative—measure of trends in the practice of science, the profile of scientific activity worldwide has changed dramatically over the past 15 years or so.

On a nation-by-nation basis, the long-

standing scientific dominance of the U.S. persists. But analysis of the source of published papers by nation indicates that other areas of the world are closing the gap.

Since the late 1980s, growth in the number of scientific papers published by scientists working in the U.S. has been spotty and limited. Since the mid 1990s, there has been no growth at all. Meanwhile, the

output of articles from Western European nations, combined, has surged past the U.S. total. And there have been really big absolute gains for Asia.

The U.S. accounted for only about 15% of the worldwide increase in the number of scientific papers between 1988 and 2001. Over this period, the U.S.'s share of articles declined in all of the natural sciences as well as in engineering and mathematics.

These are some of the major trends that can be confirmed and at least semiquantified by examination of National Science Foundation (NSF) and Chemical Abstracts Service (CAS) data on the output of scientific and technical papers. Analysis of the genesis of the papers published in ACS's own journals also shows a large increase in the non-U.S. contribution: It rose from 36% of the total in 1988 to 57% in 2001 and 60% in 2003.

**DATA SOURCES.** NSF data come from the foundation's latest and recently published biennial review, *Science and Engineering Indicators 2004*.

Most of the data concern the 1988 to 2001 period. They cover papers published in a steadily expanding set of the world's most influential scientific and technical journals—4,460 in 1988 and 5,262 in 2001—tracked by the Institute for Scientific Information's Science Citation Index and the Social Sciences Citation Index. The data were compiled by CHI Research, an intellectual property consulting firm based in Haddon Heights, N.J.

Data are presented on nine major disciplines. Included is chemistry, which is defined narrowly as the classic subdisciplines of analytical, applied, general, inorganic, nuclear, organic, physical, and polymer chemistry.

CAS data are based on the monitoring of a larger range of journals: about 8,000 in 1988 and about 9,000 currently. Again, coverage is very widespread.

The data from ACS's own journals have to be interpreted with care. They come from a program that has grown from 19 journals in 1988 to 31 today. Hence, the combined total of articles published in them largely reflects this expansion of coverage.

For all of these three data sets, a paper is assigned to a nation where the work was done and not by the nationality of the scientist or scientists who performed it.

**THE BROAD TRENDS.** In some cases, the corresponding totals and subtotals for papers from the NSF and CAS counts differ quite substantially in absolute terms. How-

## SCIENCE AND TECHNOLOGY PAPERS

U.S. is still dominant, but growth is slow

THOUSANDS OF PAPERS BY NSF COUNT	1988	% OF TOTAL	2001	% OF TOTAL	1988-2001 GROWTH	% GROWTH
<b>WORLD TOTAL</b>	<b>466.4</b>	<b>100.0%</b>	<b>649.8</b>	<b>100.0%</b>	<b>183.4</b>	<b>39%</b>
U.S.	177.7	38.1	200.9	30.9	23.2	13
Non-U.S.	288.8	61.9	448.9	69.1	160.2	55
Non-U.S./non-U.S.S.R.	257.1	55.1	428.8	66.0	171.7	67
<b>AUSTRALIA</b>	<b>9.9</b>	<b>2.1</b>	<b>14.8</b>	<b>2.3</b>	<b>4.9</b>	<b>49</b>
<b>CANADA</b>	<b>21.4</b>	<b>4.6</b>	<b>22.6</b>	<b>3.5</b>	<b>1.2</b>	<b>6</b>
<b>WESTERN EUROPE</b>	<b>143.9</b>	<b>30.9</b>	<b>229.2</b>	<b>35.3</b>	<b>85.3</b>	<b>59</b>
France	21.4	4.6	31.3	4.8	9.9	46
Germany	29.3	6.3	43.6	6.7	14.3	49
Italy	11.2	2.4	22.3	3.4	11.1	99
Netherlands	8.6	1.8	12.6	1.9	4.0	47
Spain	5.4	1.2	15.5	2.4	10.1	87
Sweden	7.6	1.6	10.3	1.6	2.7	36
Switzerland	5.3	1.1	8.1	1.3	2.8	53
U.K.	36.5	7.8	47.7	7.3	11.2	31
<b>EASTERN EUROPE</b>						
Poland	4.0	0.9	5.7	0.9	1.7	41
Russia	—	—	15.8	2.4	—	—
U.S.S.R.	31.6	6.8	20.1 <sup>a</sup>	3.1	-11.5	-36
<b>ASIA</b>	<b>51.7</b>	<b>11.1</b>	<b>113.6</b>	<b>17.5</b>	<b>61.9</b>	<b>22</b>
China	4.6	1.0	21.0	3.2	16.4	354
India	8.9	1.9	11.1	1.7	2.2	25
Japan	34.4	7.4	57.4	8.8	23.0	67
South Korea	0.8	0.2	11.0	1.7	10.3	1,332
Taiwan	1.4	0.3	8.1	1.2	6.7	472
<b>LATIN AMERICA</b>						
Brazil	1.8	0.4	7.2	1.1	5.4	308

**NOTE:** These data include papers on psychology, social science, health sciences, and professional fields. **a** Totals for former Soviet republics are Armenia, 152; Azerbaijan, 68; Belarus, 528; Estonia, 339; Georgia, 110; Kazakhstan, 116; Latvia, 157; Lithuania, 272; Moldova, 77; Russia, 15,846; Ukraine, 2,256; and Uzbekistan, 204. **SOURCE:** National Science Foundation, *Science and Engineering Indicators 2004*

## PAPERS ABSTRACTED BY CAS

Spectacular growth in Asia pushes it ahead of the U.S.

THOUSANDS OF PAPERS ABSTRACTED BY CAS	1988	% OF TOTAL	2001	% OF TOTAL	1988-2001 GROWTH	% GROWTH
<b>WORLD TOTAL</b>	<b>389.7</b>	<b>100.0%</b>	<b>606.7</b>	<b>100.0%</b>	<b>217.0</b>	<b>56%</b>
U.S.	106.7	27.4	139.3	23.0	32.6	31
Non-U.S.	283.0	72.6	467.4	77.0	184.4	65
Non-U.S./non-U.S.S.R.	232.5	59.7	429.8	70.9	197.3	85
<b>AUSTRALIA</b>	<b>5.0</b>	<b>1.3</b>	<b>8.7</b>	<b>1.4</b>	<b>3.6</b>	<b>72</b>
<b>CANADA</b>	<b>12.1</b>	<b>3.1</b>	<b>14.7</b>	<b>2.4</b>	<b>2.5</b>	<b>19</b>
<b>WESTERN EUROPE</b>						
France	16.8	4.3	24.7	4.1	7.9	47
Germany	29.2	7.5	42.3	7.0	13.1	45
Italy	9.3	2.4	17.8	2.9	8.5	92
Netherlands	5.7	1.5	8.6	1.4	2.9	50
Poland	6.8	1.7	9.6	1.6	2.7	40
Spain	5.4	1.4	12.3	2.1	6.9	127
Sweden	4.7	1.2	7.2	1.2	2.6	55
Switzerland	4.1	1.1	7.2	1.2	3.0	73
U.K.	21.8	5.6	30.3	5.0	8.5	39
<b>EASTERN EUROPE</b>						
Russia	—	—	26.7	4.4	—	—
U.S.S.R.	50.6	13.0	37.6 <sup>a</sup>	6.2	-13.0	-26
<b>ASIA</b>						
China	13.7	3.5	59.3	9.8	45.6	333
India	12.0	3.1	15.1	2.5	3.1	26
Japan	44.6	11.5	79.2	13.1	34.6	77
South Korea	2.2	0.6	12.6	2.1	10.4	591
Taiwan	1.4	0.4	6.0	1.0	4.6	330
<b>LATIN AMERICAN</b>						
Brazil	1.5	0.4	7.5	1.2	6.0	395

<sup>a</sup> Totals for former Soviet republics are Armenia, 371; Belarus, 1,433; Estonia, 333; Georgia, 374; Kazakhstan, 611; Kyrgyzstan, 55; Latvia, 371; Lithuania, 564; Moldova, 149; Russia, 26,747; Tajikistan, 25; Turkmenistan, 6; Ukraine, 5,875; and Uzbekistan, 662. **SOURCE:** Chemical Abstracts Service

## U.S. SCIENCE PAPERS BY TOPIC

Several disciplines show declines since 1995

THOUSANDS OF PAPERS BY NSF COUNT	1988	1991	1993	1995	1997	1999	2001
All topics	150.4	165.1	168.8	173.6	167.3	168.9	171.1
Clinical medicine	55.0	59.5	61.3	63.4	62.7	63.2	63.7
Biomedical research	27.5	31.2	33.1	35.0	33.7	33.4	34.0
Biology	12.9	13.9	12.7	12.7	12.0	11.3	12.5
Chemistry	13.2	14.7	15.1	14.9	14.4	14.5	14.3
Physics	18.0	20.5	19.6	19.7	18.0	18.1	17.7
Earth/space science	8.1	9.1	9.8	10.9	10.5	11.2	11.3
Engineering/technology	11.8	12.8	13.3	13.8	12.9	13.6	13.9
Mathematics	3.9	3.4	3.5	3.2	3.1	3.6	3.7

**SOURCE:** National Science Foundation, *Science and Engineering Indicators 2004*

ever, they reveal similar patterns of relative growth around the world.

For instance, they both trace a flattening of U.S. scientific publication, which, according to NSF, held at between 196,000 and 203,000 papers annually between 1992 and 2001. CAS puts the U.S.

total as peaking at 160,000 in 1996, followed by a dip and partial recovery to 151,000 by last year.

NSF is puzzled by this apparent disconnect between a stagnant output of papers in this country in recent years and increasing real R&D expenditures and

research personnel. The foundation will explore such issues as whether the lack of growth is real or an artifact of the indicators used. The issue of what happened to scientific publishing in the 1990s will also be looked into. The foundation says it will reveal its findings in *Science and Engineering Indicators 2006* as well as in special reports.

The overall NSF data, which also include the social and behavioral sciences, indicate a gain of 184,000—from 466,000 to 650,000—in the worldwide total of papers between 1988 and 2001. The U.S. accounted for 23,000, or a little under 13%, of this gain, moving up from 178,000 to 201,000, with almost all of this gain coming before 1992.

The CAS world total grew from 390,000 papers in 1988 to 607,000 in 2001. This was a gain of 217,000. The U.S. accounted for 33,000, or about 15%, of this increase—from just under 107,000 to just over 139,000.

Both NSF and CAS indicate a sharp decline in the number of papers from the republics of the former Soviet Union from 1988 to 2001—a drop of 13,000, or 26%, according to CAS and of 11,500, or 36%, by NSF's count.

This all means that the vast majority of the growth in papers over this period was in non-U.S./non-former Soviet Union areas of the world. According to NSF, this gain was 172,000, or 67%, from 257,000 to 429,000. The CAS count puts it at 197,000, or an even higher 85%, from 233,000 to 430,000.

According to NSF, the U.S.'s share of scientific papers fell from 38.1% of the worldwide total in 1988 to 30.9% in 2001. Over the same period, Western Europe's share rose from 30.9% to 35.3% while Asia's slice went up from 11.1% to 17.5%. The 1988 to 2001 gains of 85,000 papers for Western Europe and of 62,000 for Asia were both far larger than the 23,000 uptick for the U.S.

Both NSF and CAS reveal particularly strong percentage growth for Italy and Spain, as well as for China, Taiwan, South Korea, and Brazil.

Traditionally, CAS has pegged the U.S.'s share of papers lower than has NSF: at 27.4% in 1988 and 23.0% in 2001.

The biggest change in the CAS count has been in the total for the Asian Big Five—China, India, Japan, Taiwan, and South Korea—with a jump from a combined 19.0% of the worldwide total in 1988 to 28.4% in 2001.

The most spectacular absolute boost has been for China, with a gain, accord-

## TRENDS IN CAS ABSTRACTS

Less than a quarter of abstracted articles are now from U.S. sources

THOUSANDS OF CAS ABSTRACTS	WORLD	U.S.	NON-U.S.	% NON-U.S.
1982	381.3	103.4	277.9	72.9%
1983	371.4	100.4	271.0	73.0
1984	380.7	103.0	277.7	72.9
1985	380.1	102.6	277.5	73.0
1986	384.1	106.5	277.7	72.3
1987	386.5	107.6	278.8	72.2
1988	389.7	106.7	283.0	72.6
1989	397.2	110.9	286.7	72.2
1990	394.9	110.0	284.9	72.2
1991	453.6	132.3	321.4	70.9
1992	430.3	117.8	312.4	72.6
1993	448.7	126.2	322.5	71.9
1994	542.5	158.2	384.3	70.8
1995	563.0	152.2	410.8	73.0
1996	579.2	160.3	418.9	72.3
1997	585.5	151.6	434.0	74.1
1998	559.0	136.6	422.4	75.6
1999	591.1	141.3	449.8	76.1
2000	573.5	136.3	437.1	76.2
2001	606.7	139.3	467.4	77.0
2002	630.5	150.5	479.9	76.1
2003	646.9	150.9	496.0	76.7

SOURCE: Chemical Abstracts Service

## BREAKDOWN OF PAPERS IN ACS JOURNALS

Over the past 20 years, the non-U.S. share is up

PAPERS IN ACS JOURNALS	WORLD	U.S.	NON-U.S.	% NON-U.S.
1980	8,248	6,006	2,242	27.2%
1981	8,707	5,941	2,766	31.8
1982	9,043	6,304	2,739	30.3
1983	8,946	6,033	2,913	32.6
1984	9,928	6,546	3,382	34
1985	10,174	6,604	3,570	35.1
1986	10,492	6,825	3,667	35
1987	10,288	6,633	3,655	35.5
1988	10,875	6,926	3,949	36.3
1989	11,473	7,308	4,165	36.3
1990	12,351	7,729	4,622	37.4
1991	13,670	8,326	5,344	39.1
1992	14,432	8,407	6,025	41.8
1993	15,067	8,710	6,357	42.2
1994	15,750	8,600	7,150	45.4
1995	16,541	8,555	7,986	48.3
1996	18,503	9,192	9,311	50.3
1997	18,691	8,497	10,194	54.5
1998	19,254	8,737	10,517	54.6
1999	19,730	8,809	10,921	55.4
2000	20,915	9,005	11,910	56.9
2001	21,138	9,051	12,087	57.2
2002	22,511	9,306	13,205	58.7
2003	24,222	9,738	14,484	59.8

SOURCE: ACS Journal Publishing Group

## PAPERS PUBLISHED IN ACS JOURNALS

Their number almost doubled between 1988 and 2001

PAPERS IN ACS JOURNALS	1988	% OF TOTAL	2001	% OF TOTAL	1988-2001 GROWTH	% GROWTH
WORLD TOTAL	10,875	100.0%	21,138	100.0%	10,263	94%
U.S.	6,926	63.7	9,051	42.8	2,125	31
Non-U.S.	3,949	36.3	12,087	57.2	8,138	206
AUSTRALIA	165	1.5	280	1.3	115	70
CANADA	590	5.4	869	4.1	278	47
WESTERN EUROPE						
France	376	3.5	930	4.4	554	147
Germany	363 <sup>a</sup>	3.3	1,203	5.7	840	231
Italy	253	2.3	630	3.0	377	149
Netherlands	133	1.2	339	1.6	206	155
Poland	18	0.2	113	0.5	95	528
Spain	120	1.1	790	3.7	670	558
Sweden	119	1.1	293	1.4	174	146
Switzerland	111	1.0	251	1.2	140	126
U.K.	229	2.1	915	4.3	686	300
ASIA						
China	45	0.4	454	2.2	409	909
India	111	1.0	307	1.5	196	177
Japan	821	7.6	2,062	9.8	1,241	151
Taiwan	40 <sup>b</sup>	0.4	327	1.6	287	718
South Korea	22	0.2	346	0.5	324	1,472
LATIN AMERICA						
Brazil	16 <sup>b</sup>	0.2	96	0.5	80	500

a West Germany only. b Data for 1989. SOURCE: ACS Journals Publishing Group

ing to CAS, of from 13,700 papers in 1988 to 59,300 in 2001. This 45,600 gain was larger than the 32,600 gain for the U.S. over the same time period. It boosted China from seventh to third on the world ranking.

Japan overtook the former Soviet republics to claim the second ranking by 2001 with 79,200 papers, up from 44,600 in 1988. And South Korea had the highest percentage growth of more than 500%—from 2,175 in 1988 and 12,575 in 2001.

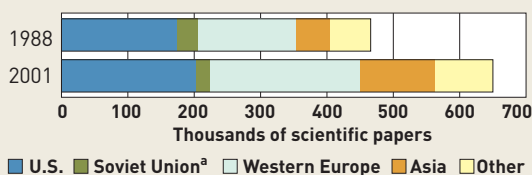
All of these trends primarily reflect what is happening in academic science. According to NSF, 73.6% of papers worldwide were from academia in 2001. The range was from 92.8% for mathematics to 65.5% for engineering/technology, with chemistry at 75.8%.

**CHEMISTRY.** The NSF count for classic chemistry indicates an increase in papers worldwide of from 57,400 in 1988 to 77,300 in 2001. Only 1,100 of this 19,900 gain was accounted for the U.S., which went from 13,200 to 14,300 over the period, with a peak of 15,100 in 1991.

U.S. physics did even worse. Worldwide, the number of papers rose from 62,000 in 1988 to 87,100 in 2001, while the U.S.

## GLOBALIZATION OF SCIENCE

Asia and Europe account for 80% of growth in scientific papers



NOTE: Data include papers in the social and behavioral sciences. <sup>a</sup>Total for republics of the former Soviet Union. SOURCE: National Science Foundation, *Science and Engineering Indicators 2004*

## TRENDS IN NSF ARTICLE COUNT

U.S. total has been stagnant since 1992

THOUSANDS OF PAPERS BY NSF COUNT	WORLD	U.S.	NON-U.S.	% NON-U.S.
1988	466.4	177.9	288.6	61.9%
1989	497.1	187.2	309.9	62.3
1990	508.8	191.6	317.2	62.4
1991	515.5	194.0	321.5	62.4
1992	547.6	198.9	348.8	63.7
1993	540.5	197.4	343.1	63.5
1994	567.2	199.8	367.4	64.8
1995	580.8	202.9	377.9	65.1
1996	593.6	201.8	391.8	66.0
1997	594.5	197.5	396.9	66.8
1998	617.8	197.9	419.9	68.0
1999	632.1	198.5	433.5	68.6
2000	632.8	196.2	436.6	69.0
2001	649.8	200.9	448.9	69.1

NOTE: These data include papers in the social and behavioral sciences. SOURCE: National Science Foundation, *Science and Engineering Indicators 2004*

contribution dipped from 18,000, or 29%, to 17,400, or 20%.

ACS journals have enjoyed a healthy increase in the total number of articles they publish: from 10,900 in 1988 to 21,100 in 2001 and 24,200 in 2003. This more than doubling reflects both the expansion of the number of ACS journals as well the worldwide growth in chemical papers, as indicated by the NSF data.

The ACS journal data, however, show the same trends in geographic distribution as NSF's data do. Contributions to ACS journals from the major European countries increased from 16% in 1988 to 26% in 2001 and from Asia from 10% to 16%.

In 1988, chemistry papers were 12.3% of the scientific papers published worldwide, according to NSF. By 2001, this was down to 11.9%. Of the U.S. papers, chemistry claimed a substantially lower 7.4% in 1988 and 7.1% in 2001.

In Asia, chemistry held on to a larger

share, 18.2% of papers in both 1988 and 2001. Western Europe fell between: 13.1% of its 1988 papers and 11.5% of its 2001 papers were in chemistry.

Among the major paper producers in 2001, the highest percentages of chemistry papers were 26.7% for Poland, 26.3% for China, 25.5% for India, and 18.5% for Spain. On the lower end of the scale, along with the U.S., were the U.K., Sweden, the Netherlands, Australia, and Canada, all in the 7–8% range.

**BY DISCIPLINE.** Of the science disciplines that were identified by NSF, earth/space science showed the largest percentage gain in the number of papers published worldwide between 1988 and 2001, 83%. Physics came in second at 40%, and chemistry and clinical medicine tied for third at 35%. Biology had the smallest increase, 26%. The overall gain for all disciplines was 41%.

Gains for the U.S. were far smaller, with

## PAPERS BY DISCIPLINE

Decline in U.S. share is across the board

THOUSANDS OF PAPERS BY NSF COUNT	1998	2001	GROWTH	% GROWTH
<b>All disciplines except social sciences</b>				
World	422.2	593.3	171.1	41%
U.S.	150.4	170.8	20.4	14
% U.S.	36%	29%		
<b>Clinical medicine</b>				
World	136.7	184.5	47.8	35
U.S.	55.0	63.7	8.7	16
% U.S.	41%	35%		
<b>Biomedical research</b>				
World	70.9	92.3	21.4	30
U.S.	27.5	34.0	6.5	24
% U.S.	39%	37%		
<b>Biology</b>				
World	35.0	44.2	9.2	26
U.S.	12.9	12.5	-0.4	-3
% U.S.	37%	28%		
<b>Chemistry</b>				
World	57.4	77.3	19.9	35
U.S.	13.2	14.3	1.1	8
% U.S.	23%	19%		
<b>Physics</b>				
World	62.0	87.1	25.1	40
U.S.	18.0	17.4	-0.6	-3
% U.S.	29%	20%		
<b>Earth/space science</b>				
World	19.1	35.1	16.0	83
U.S.	8.1	11.3	3.2	40
% U.S.	42%	32%		
<b>Engineering/technology</b>				
World	31.3	58.5	27.2	87
U.S.	11.8	13.9	2.1	18
% U.S.	38%	24%		
<b>Mathematics</b>				
World	9.8	14.3	4.5	46
U.S.	3.9	3.7	-0.2	-5

SOURCE: National Science Foundation, *Science and Engineering Indicators 2004*

an overall 14% increase. Chemistry came in at 8%, and both biology and physics had decreases of 3%.

**ANALYSIS.** The output of scientific papers is just one quantitative parameter that yields an indirect measure of scientific activity and of trends in its national origin and subject matter. The issuance of patents and the commitment of funding, resources, and people power are among others.

All such indicators should be handled with an appreciation that any discontinuities in the way they are measured or outside factors that transcend them can render them less than precise and definitive measures of what is really happening in science.

Be that as it may, the data on scientific publication unambiguously suggest a leveling of science activity in the U.S.—if at a still relatively very high level—while activity in the rest of the world, except the former Soviet republics, continues to grow apace. ■