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ABSTRACT

This monograph is one in a series of analytical reports presenting findings from the National Science Foundation's 1989-90 National Survey of Academic Research Instruments and Instrumentation Needs. It describes recent national trends in academic research equipment and equipment needs in the physical sciences. It also documents equipment trends in central academic computing facilities. The data were obtained from a sample of 55 universities statistically selected to represent all institutions with annual science/engineering research and development expenditures of $3 million or more. The analysis compares data obtained in 1989 to similar data collected from the same institutions in 1986 and 1983. Information about current needs and priorities refers to the year the survey was conducted; information about equipment amounts and expenditures refers to the year prior to the survey (i.e. 1988, 1985, 1982). The study is limited to research equipment originally costing $10,000 c· more per system. Sections are: (1) equipment investments and expenditures; (2) sources of funds; (3) perceived equipment trends; (4) types of existing and needed equipment; and (5) institution profiles. A list of sampled institutions and a list of university-administered federally funded research and development centers are appended. (KR)

ACADEMIC RESEARCH EQUIPMENT AND EQUIPMENT NEEDS IN THE PHYSICAL SCIENCES: 1989

Kenneth Burgdorf, Westat, Inc.

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At NSF, the survey was developed and guided by Judith F. Coakley, Senior Science Resources Analyst, Division of Science Resources Studies, Science and Engineering Activities Program (SEAP). Guidance and review were provided by William W. Ellis, Acting Director, Division of Science Resources Studies.

Paul Seder, NIH Office of Science Policy and Analysis, directed the National Institutes of Health components of the study.

The study also benefited from the advice of an expert advisory panel. As well as providing many useful recommendations for the design and conduct of the study, several members of the current advisory panel made significant contributions to the development of the equipment classification taxonomy that is used in the data analysis. The members of this panel are named on the inside back cover of this report.

The burden of the study's extensive data collection activities was borne largely by the institution-appointed survey coordinators at the 55 sampled institutions, to whom we owe a special debt of gratitude. The institutions that participated in the survey are listed in Appendix A.

SUGGESTED CITATION

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HIGHLIGHTS

This monograph is one in a series of analytical reports presenting findings from the National Science Foundation's 1989-90 *National Survey of Academic Research Instruments and Instrumentation Needs*. It describes recent national trends in academic research equipment and equipment needs in the physical sciences. The data were obtained from a sample of 55 universities statistically selected to represent all institutions with science/engineering R&D expenditures of $3 million or more. The analysis compares data obtained in 1989 to similar data collected from the same institutions in 1986 and 1983. Information about current needs and priorities refers to the year the survey was conducted; information about equipment amounts and expenditures refers to the year prior to the survey (i.e., 1988, 1985, and 1982). The study is limited to research equipment originally costing $10,000 or more per system.

Existing Research Equipment

- Even with the exclusion of 18 large university-administered Federally funded R&D centers, instrument systems costing $1 million or more account for 35 percent of the current total investment in physics/astronomy research equipment ($551 million). Instrument systems in this cost range are essentially nonexistent in chemistry, accounting for less than 1 percent of current investment ($537 million).

- Most research equipment in chemistry is located in traditional academic departments (92 percent of current investment). Much of the research equipment in physics/astronomy is located in specialized research centers outside traditional departments (44 percent of investment).

- For research instrumentation in the $10,000 to $1 million range:

  - Chemistry has a larger current inventory ($532 million) than physics/astronomy ($357 million).

  - In the three-year period from 1985 to 1988, chemistry had a greater net increase in its national inventory than did physics/astronomy (59 percent versus 42 percent, controlling for inflation).

  - The chemistry inventory is dominated by spectrometers (61 percent of current investment) and computers (9 percent). In physics/astronomy, computing equipment accounts for 31 percent of current investment, spectroscopy equipment represents an additional 17 percent, and other types of equipment account for the remaining 52 percent.

Funding Sources

- In chemistry, funding for instrumentation in the current inventory was evenly divided between Federal and non-Federal sources (50 percent each); in physics/astronomy, Federal sources accounted for 64 percent of the total investment, and non-Federal sources accounted for the remaining 36 percent.

- In both chemistry and physics/astronomy, aggregate instrumentation investments increased from 1982 to 1988 for all major funding sources. In relative terms, the largest increases were found for institution-funded equipment (which grew in physics/astronomy from 14 percent to 27 percent of the total); NSF showed the largest relative decrease (in physics/astronomy, the NSF share decreased from 29 percent in 1982 to 24 percent in 1988).

Annual Expenditures

- In both fields, controlling for inflation, expenditures for purchases of research equipment were essentially the same in 1988 as they had been three years earlier: $102 million in physics/astronomy and $84 million in chemistry. This contrasts with the previous three-year period (1982-85), which saw substantial spending increases in both fields. Examination of other data (e.g., trends in total R&D expenditures) suggests that 1985 was a year of unusually high equipment spending, rather than 1988 being a year of unusual retrenchment.

Equipment Needs

- In both fields, a growing need for big ticket research equipment was evident. For example, in chemistry, the percent of department heads saying increased Federal support is most needed for equipment in the $50,000 and over range increased from 54 percent in 1983 to 81 percent in 1989. In both fields, over 90 percent of the aggregate cost of all reported top-priority equipment needs was for systems costing $100,000 and above.

- In chemistry, 95 percent of the aggregate cost of the reported top priority equipment needs is in NMRs or mass spectrometers (57 percent), other spectroscopy equipment (22 percent), and computing equipment (16 percent). Physics/astronomy departments had much more diverse needs, with spectroscopy and computing equipment each accounting for 16 percent, and the remaining 68 percent being distributed among many other types of equipment.

Perceived Trends

- Most chemistry department heads seem pleased with the equipment trends they have experienced in the last three years: 84 percent reported net increases in the aggregate dollar amount of their equipment, and 71 percent reported qualitative improvements in the overall adequacy of their equipment; 70 percent characterized the general adequacy of their current equipment as adequate or better. The largest chemistry R&D programs produced the most positive perceptions, but the differences between the largest and the smaller institutions were not very great.

- In physics/astronomy, the general level of satisfaction with current instrumentation and with recent trends was consistently lower than in chemistry (e.g., only 54 percent of department/center heads described their current equipment as adequate or better, and only 41 percent said the adequacy had improved in the last three years), and the differences between the 20 largest physics/astronomy research programs and the smaller programs was more pronounced (e.g., 80 percent of physics/astronomy department heads at the largest research institutions reported adequate or better current equipment, versus only 48 percent of those at smaller institutions).

BACKGROUND

This report describes recent trends in academic research equipment and equipment needs in the physical sciences (chemistry and physics/astronomy).[1] The data come from the 1989, 1986, and 1983 cycles of the National Survey of Academic Research Instruments and Instrumentation Needs. This triennial survey program is conducted by the National Science Foundation (NSF), with major support from the National Institutes of Health (NIH). It is designed to monitor emerging instrumentation needs and trends in the amounts, costs, and characteristics of existing academic research equipment in selected science/engineering (S/E) fields. The survey program was undertaken in response to a Congressional directive to the Foundation to: "...develop indices, correlates or other suitable measures or indicators of the status of scientific instrumentation in the United States and of the current and projected need for scientific and technological instrumentation."[2]

The most recent data were collected in 1989 from physical science departments and research centers at a sample of 55 universities and colleges statistically selected to represent the 174 largest R&D-performing institutions in the nation.[3] The heads of these departments and centers were asked to complete a department questionnaire concerning their expenditures, priorities, and needs for research equipment. In addition, samples of existing research equipment were selected in each department and research center, and the responsible principal investigator was asked to complete a brief data form concerning the instrument's cost, age, condition, etc. The equipment sample was selected to represent all instrument systems originally costing $10,000 or more that were used for S/E research at any time in 1988. The resulting data were statistically weighted to represent all such equipment at all institutions represented in the survey.[4]

The survey excludes equipment assigned to any of 18 university-administered Federally funded research and development centers (FFRDCs).[5] The instrumentation in these large national labs (Lawrence Livermore, Brookhaven, Oak Ridge, etc.) is well known to the sponsoring agencies and is outside the scope of this study. However, academic institutions also contain a number of other specialized, custom-built research facilities in high energy physics and in astronomy that consist of large, integrated instrument systems costing over $1 million (research reactors, electron storage rings, observatories, etc.). Such "supersystems" were excluded in previous cycles of this survey but are included in the current (1989) cycle. Findings for these supersystems are not included in trend analyses.

All 55 sampled institutions participated in the 1989 survey, and data were obtained for all of the 31 supersystems at these institutions. Usable questionnaire responses were obtained from 144 of the 158 surveyed departments and research centers (91 percent) and from 2,215 of the 2,412 sampled research instruments in these departments/centers (92 percent).

Findings from the current (1989) survey are compared to those from similar surveys conducted in 1986 and 1983 to examine trends over the three-year intervals between surveys.[6] In all three surveys, information about current equipment needs and priorities was obtained with reference to the year the

[1] A companion report discusses instrumentation trends in engineering and computer science. Additional analytical reports concerning other fields and topics are planned for issuance in mid-1991.

[2] An Act To Authorize Appropriations for Activities for the National Science Foundation for Fiscal Year 1980, and for Other Purposes. Public Law 96-44, Section 7.

[3] The sampled institutions are listed in Appendix A. The universe this sample represents consists of the 174 universities and colleges with reported nonmedical S/E R&D expenditures of $3 million or more in Fiscal Year 1984. These 174 institutions collectively accounted for 98 percent of all FY 1984 nonmedical academic S/E R&D expenditures, of which 57 percent was encompassed by the study sample of 55 institutions. (National Science Foundation, Academic Science/Engineering: R&D Funds, Fiscal Year 1984, Detailed Statistical Tables, 1985).

[4] All of the data shown in this report are in the form of national estimates developed from these samples. As estimates, they are subject to variability due to sampling error. Estimates of the sampling errors associated with the survey statistics, and additional information about details of the study's sample design and data collection instruments and procedures, are available upon request from NSF. Detailed statistical tables, from which the information presented in this report was distilled, are also available upon request (contact Dr. Eileen Collins at NSF/SRS, 202-634-4655.)

[5] The 18 excluded FFRDCs are listed in Appendix B.

[6] For a detailed presentation of findings from these earlier studies, see: National Science Foundation, Academic Research Equipment in Selected Science/Engineering Fields: 1982-83 to 1985-86, SRS 88-D1, (June) 1988.

survey was conducted; information about equipment amounts and expenditures refers to the year prior to the survey (i.e., 1988, 1985, and 1982, respectively).

This report first describes current status and recent trends in existing and needed research equipment. It then presents statistical profiles contrasting the 20 largest (and, presumably, best-equipped) R&D-performing institutions in a field (chemistry or physics/astronomy) to institutions with smaller research programs in that field on various indices of the average current amount, composition, and adequacy of their research equipment. These profiles are intended to (a) describe the kinds and amounts of equipment that are to be found at the best-equipped academic research programs in the nation, and (b) assess how the equipment situations of the institutions with smaller research programs compare to those of the best-equipped institutions.

Throughout this report, there are many references to percent change in equipment dollar amounts from 1985 to 1988. All such "percent change" figures are adjusted for inflation, based on U.S. Bureau of Labor Statistics Producer Price Indices for equipment-related products.

EQUIPMENT INVESTMENTS AND EXPENDITURES

Current Amount and Distribution of Research Equipment

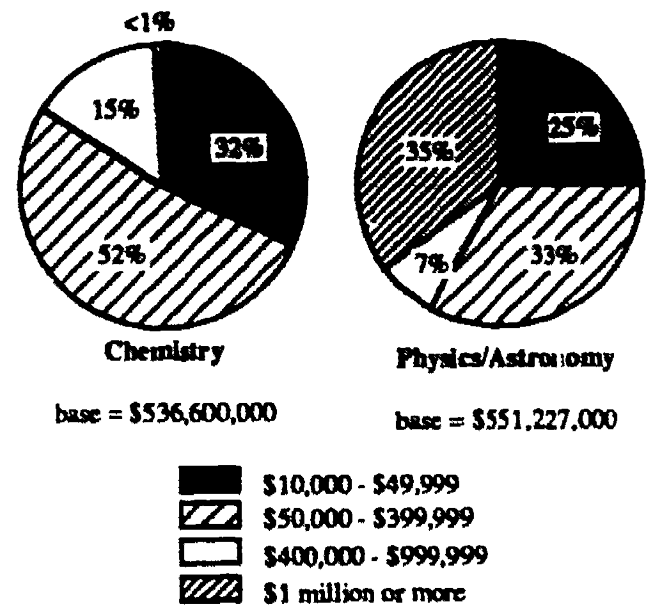
At the end of 1988, the aggregate purchase price of all in-use chemistry research equipment costing $10,000 or more per system was an estimated $537 million (Table 1). This is equivalent to $156,000 of research equipment per faculty researcher in chemistry. The analogous figures for physics/astronomy are $551 million in total research equipment, $127,000 per faculty researcher. These differences between chemistry and physics/astronomy would have been considerably larger if equipment in the 18 Federally funded R&D centers (FFRDCs) had been included, since most of the FFRDCs are large astronomical observatories or facilities for research in high energy physics. Even with the exclusion of FFRDCs, however, a substantial portion (35 percent) of the aggregate price of all remaining $10,000+ academic research equipment in physics/astronomy is for instrument systems in the $1 million and over range (Figure 1). By contrast, less than 1 percent of the current (1988) equipment investment in chemistry is for systems costing $1 million or more. Most of the investment in chemistry equipment (84 percent) is for systems costing $10,000 to $399,999.

Table 1. Aggregate purchase price of academic research equipment costing $10,000 or more per system, in chemistry and physics/astronomy, by cost range and location: 1988

System cost range and location	Chemistry	Physics/ Astronomy
	(dollars in millions)	
Total	536.7	551.2
Systems in $10,000-$999,999 range	532.3	356.7
In academic departments	487.5	277.1
In research centers	44.8	79.6
Systems $1 million or more	4.4	194.5
Supersystems	0	121.6
Observatories	0	53.7
Nuclear science facilities	0	67.9
Other	4.4	72.9

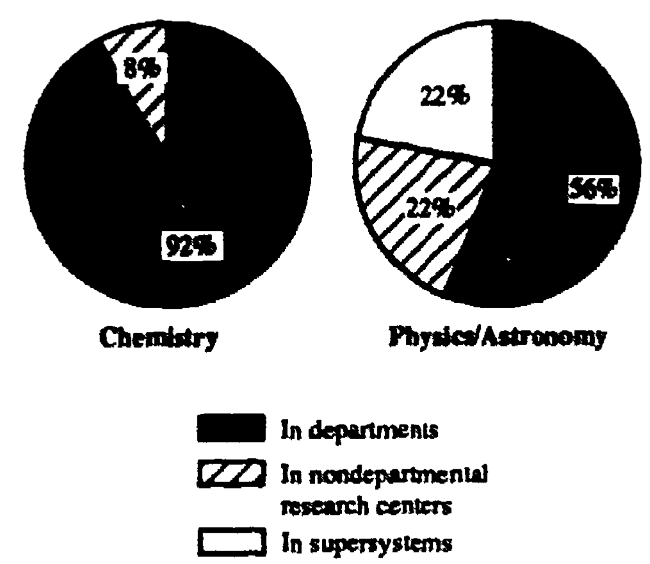
Source: National Science Foundation, SRS

Figure 1. Percentage of aggregate price of all $10,000+ moveable research equipment in chemistry and physics/astronomy by cost range: 1988



Source: National Science Foundation, SRS

Figure 2. Percentage of aggregate price of all $10,000+ moveable research equipment in chemistry and physics/astronomy by administrative location of equipment: 1988



Source: National Science Foundation, SRS

Chemistry and physics/astronomy also have very different profiles regarding the location of their research equipment. In chemistry, most research equipment (92 percent of current investment) is located in traditional academic departments, and the remainder (8 percent) is in specialized research

Table 2. Trends in research equipment amounts and expenditures in chemistry and physics/astronomy: 1982-88

Statistic	Chemistry			Physics/astronomy		
	1982	1985	1988	1982	1985	1988
TOTAL AMOUNT			(dollars in millions)			
Aggregate purchase price of existing research equipment in $10,000-$999,999 range	211	327	532	180	245	357
Annual purchases of nonexpendable research equipment:						
(a) Costing $500 or more*	39	81	84	52	91	102
(b) Costing $,000-$999,999**	35	72	75	29	50	56
RELATIONAL INDICES			(percent)			
Annual purchases (b) as a percent of aggregate equipment amount ($10K-$1M)	17	22	14	16	20	16
Annual equipment purchases (a) as a percent of total R&D expenditures***	13	19	15	10	13	11

*Estimates do not include supersystems.

**Projection assumes that 35% of physics/astronomy purchases are for systems $1 million or more, and that, in both disciplines, 10 percent are under $10,000.

***Denominators are from Academic Sciences/Engineering: R&D Funds: Fiscal Year 1988, Detailed Statistical Tables, National Science Foundation, NSF 89-326, 1990.

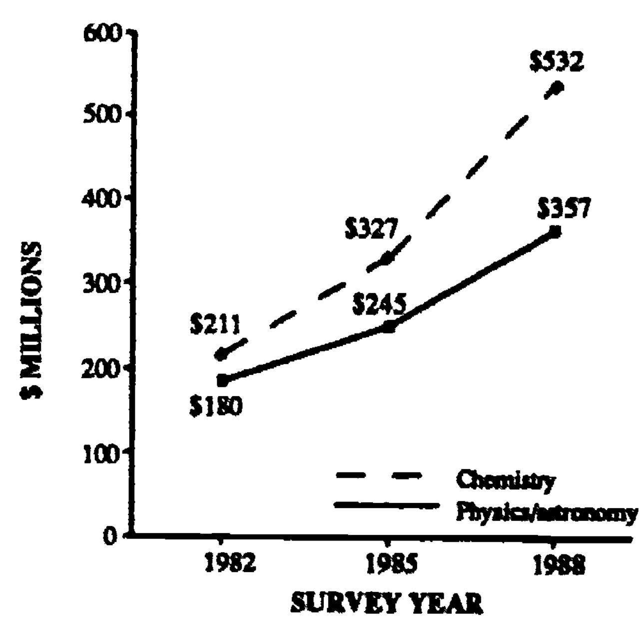
Source: National Science Foundation, SRS

centers (Figure 2). In physics/astronomy, however, only about half (56 percent) of the equipment investment is in department-based labs. The rest is in nondepartmental research centers (22 percent) or in supersystems (22 percent). These physics/astronomy "supersystems," which are defined as specialized research facilities organized around single very large -- and often nonmovable -- instrument systems, comprise 33 observatories with an estimated $54 million in movable research equipment, and 17 nuclear science facilities (research reactors, etc.), containing an estimated $68 million in movable research equipment (Table 1).[7]

Trends in Equipment Amounts

Earlier cycles of the equipment survey were limited to research instrumentation in the $10,000 to $999,999 range, so analyses of time trends must be limited to equipment in this range. In chemistry, the aggregate amount of research equipment in this cost range has increased steadily and substantially, from $211 million in 1982 to $532 million in 1988 (Figure 3). Controlling for inflation, the net increase over the period 1985 to 1988 was 59 percent. For equipment in this cost range, physics/astronomy has also shown steady growth, though from a somewhat smaller base and at a somewhat slower pace. Thus, the amount of equipment in physics/ astronomy increased from $180 million in 1982 to $357 million in 1988, with a 1985-88 growth rate of 42 percent.

Figure 3. Aggregate purchase price of academic research equipment costing $10,000 - $999,999 in chemistry and physics/astronomy: 1982-88



Source: National Science Foundation, SRS

[7]These estimates do not include the cost of fixed equipment (e.g., the central telescope of an observatory). The estimated total costs of these supersystems, including both fixed and movable equipment, are $254 million for observatories and $666 million for nuclear science facilities.

In addition to collecting information about net changes in aggregate equipment amounts, the survey obtained information about trends in levels of annual equipment purchases. In chemistry, annual expenditures for the acquisition of additional research equipment in the $500 and over range more than doubled from 1982 ($39 million) to 1985 ($81 million; Table 2). In 1988, however, the level of equipment purchases was essentially the same as in 1985: $84 million, which represents an absolute increase of $4 million but a constant-dollar decrease of 4 percent.

Physics/astronomy exhibited a similar trend in annual equipment purchases, which increased substantially from 1982 ($52 million) to 1985 ($91 million) but then increased very little from 1985 to 1988 ($102 million, an inflation-adjusted increase of only 3 percent). When the figures are adjusted to reflect estimates for equipment in the $10,000 to $1 million range, rather than all purchases $500 and above, the dollar amounts are reduced (especially for physics/astronomy), but the time trends remain the same (Table 2).

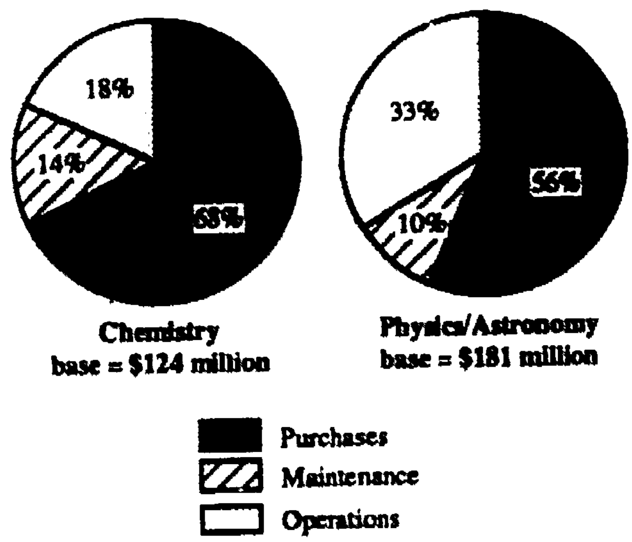
In both chemistry and physics/astronomy, in both 1982 and 1988, estimated annual purchases of research equipment in the $10,000 to $1 million range were equivalent to 14 to 17 percent of the aggregate purchase price of all in-use research equipment in this cost range. Against this standard, the level of equipment purchases in 1985 (20-22 percent) was unusually high in both fields.

Another (and perhaps the best) way of expressing relative annual levels of equipment purchases is as a percentage of total academic R&D expenditures for the year in question. On this index, 1988 research instrumentation expenditures in chemistry (15 percent of all chemistry R&D expenditures) were about the same as they had been in 1982 (13 percent; Table 2). Similarly, instrumentation expenditures in physics/astronomy were about the same in 1988 (11 percent of total R&D) as they had been in 1982 (10 percent of total R&D). This suggests that, while research equipment amounts and annual expenditures increased considerably in the physical sciences over the 1982-88 period, the increase was proportionate to the overall growth in academic research in the physical sciences over this period, and equipment has become neither more nor less prominent as a contributer to total research costs.

Other Equipment-related Expenditures

In addition to the expenditures required to replenish and upgrade equipment stocks, research institutions must expend funds for the maintenance/repair and operation of existing equipment. In physics/astronomy departments and facilities, almost as much was spent for maintenance/repair and operation of existing equipment in 1988 as for the purchase of additional equipment (Figure 4). Equipment operating costs (mainly technician salaries) were especially prominent in physics/astronomy, accounting for one-third of all equipment-related expenditures. In chemistry, where there are fewer large, technician-operated instrument systems, operating expenses were lower (18 percent of the total) and equipment purchases were correspondingly more prominent (68 percent, versus 56 percent in physics/astronomy).

Figure 4. Composition of expenditures for purchases, maintenance, and operations of academic research equipment in chemistry and physics/astronomy: 1988



Source: National Science Foundation, SRS

Trends in research equipment operating costs cannot be assessed, since information about operating expenses was obtained for the first time in the current (1989) study.

Table 3. Trends in equipment-related annual expenditures in chemistry and physics/astronomy: 1982-88*

Statistic	Chemistry			Physics/astronomy		
	1982	1985	1988	1982	1985	1988
TOTAL AMOUNT			(dollars in millions)			
Research equipment purchases $500+ per item	39	81	84	52	91	102
Maintenance/repair (M/R) of research equipment	12	17	17	16	21	19
Operation of research equipment (technician salaries, supplies, etc.)	–	–	23	–	–	60
RELATIONAL INDICES			(percent)			
Annual equipment M/R as a percent of annual equipment purchases	31	21	20	31	23	19
Annual equipment M/R as a percent of aggregate purchase price of existing equipment**	6	5	3	7	7	4

*Estimates do not include supersystems.

**Denominators are from Table 2, adjusted to include systems over $1 million.

– Not ascertained.

Source: National Science Foundation, SRS

Information about trends in maintenance/repair expenditures is available, however. These expenditures increased from 1982 to 1988, but not at the same pace as equipment expenditures or accumulated equipment stocks (Table 3). When expressed as a percentage of the aggregate cost of existing research equipment in the $10,000 to $1 million range, maintenance/repair expenditures in chemistry appear to have declined markedly, from 6 percent in 1982 (which was already well below the 10 percent figure often cited by equipment manufacturers as the rule-of-thumb norm for equipment maintenance) to 3 percent in 1988. A similar trend occurred in physics/astronomy, where 1982 and 1985 maintenance/repair expenditures were equivalent to 7 percent of aggregate equipment purchase cost, which dropped to 4 percent in 1988.

This finding may signal growing difficulty in the physical sciences in obtaining adequate funding for equipment maintenance. It is also possible, however, that the apparent downward trend in maintenance/repair expenditures may not be real. Conceivably, with the opportunity to report both maintenance/repair and operating expenditures in the 1989 survey, some expenditures that had previously been reported as maintenance/repair may have been shifted into the operating costs category in 1989. All that can be said at this point (i.e., until the next survey is done in 1992) is that the survey has raised a question about possible emerging problems in the area of equipment maintenance/repair.

SOURCES OF FUNDS

In both chemistry and physics/astronomy, the overall increases in research equipment stocks over the period encompassed in this research reflect growing cumulative funding contributions from all major sources (Figure 5). These contributions and increases have not been of uniform size, however. The aggregate amounts of equipment funded from NSF and from internal institution funds has been larger, and has increased faster (particularly from 1985 to 1988), in chemistry than in physics/astronomy. The 1985-88 net increase in the amount of institution-funded chemistry equipment (from $100 million in 1985 to $200 million in 1988) was especially pronounced. These trends favoring chemistry have been somewhat offset by the fact that Federal agencies other than NSF have provided greater instrumentation funding support in physics/astronomy than in chemistry, though the difference was less pronounced in 1988 than in previous survey years.

In addition to NSF, the major Federal instrumentation funding sources in physics/astronomy are the Department of Energy (DOE, currently 16 percent of the total support) and the Department of Defense (DOD, currently 13 percent; Table 4). In chemistry, the National Institutes of Health (NIH, 13 percent of total funding) follows NSF (26 percent) as the principal Federal funding source.

As well as looking at overall trends in funding amounts and funding shares from various sources, it is of interest to examine how widely the macro-trends have been distributed across departments. In chemistry, many more departments reported 1986-89 increases in Federal instrumentation support and perceived trends in support from all sources (48 percent) than reported decreases in Federal support (16 percent; Table 5). The opposite was true for physics/astronomy, where only 24 percent of departments and research centers reported increased Federal instrumentation support and 33 percent experienced decreases. For all other funding sources as well, the percentage of chemistry departments reporting increased instrumentation funding was greater than the comparable percentage of physics/astronomy departments.

Physics/astronomy supersystems seem to have fared somewhat better than regular physics/astronomy departments and facilities over the 1986-89 period. Thus, over half of the observatories reported increased equipment funding from institution sources (58 percent), and nearly half reported increased Federal funding (48 percent). Many nuclear science facilities received increased funding from industrial sources (58 percent), and 22 percent had increased Federal funding; none had reduced funding from either of these sources.

Table 4. Sources of funds for acquisition of research equipment in chemistry and physics/astronomy: 1982-88*

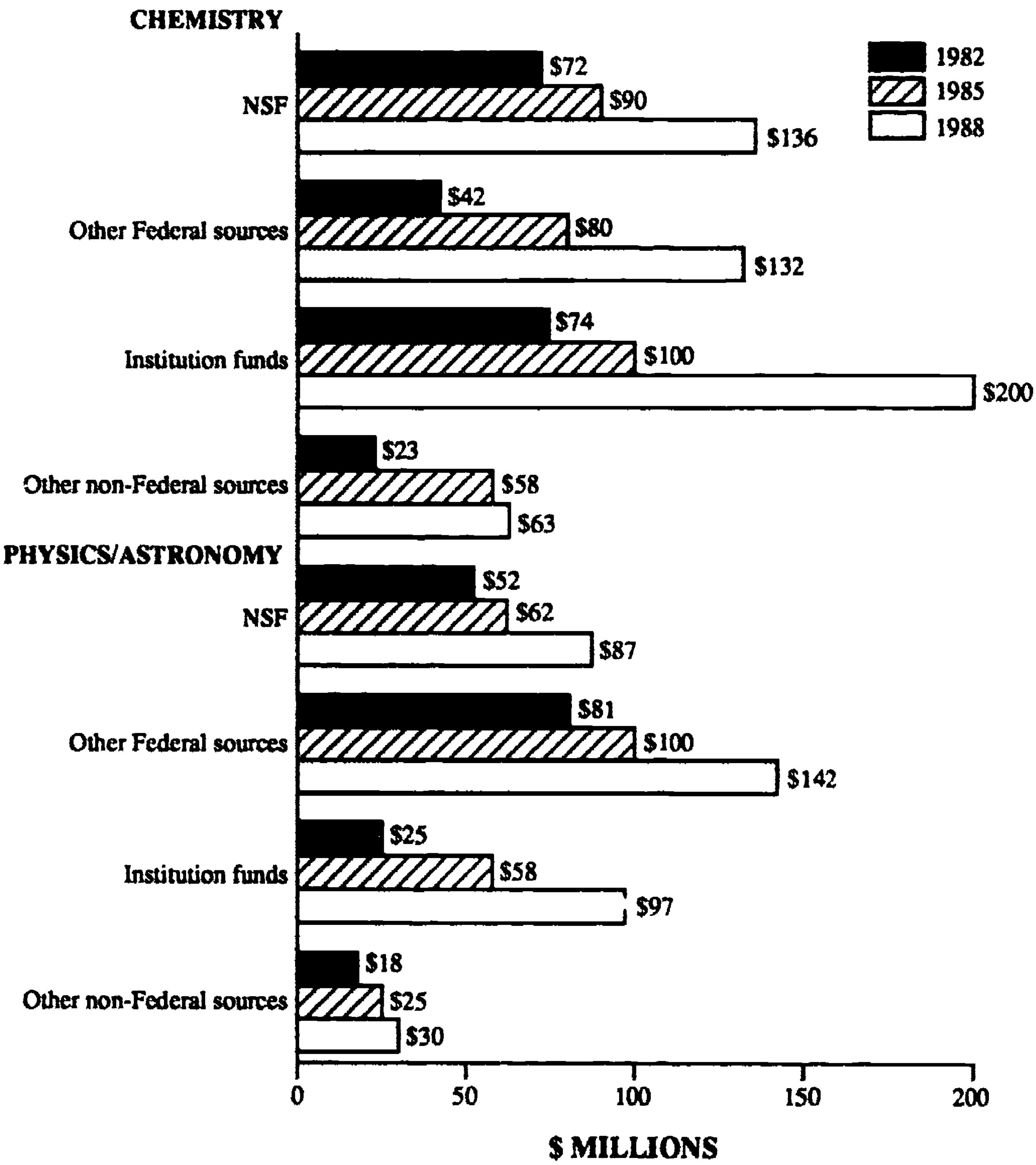
Sources of funds	Chemistry			Physics/astronomy		
	1982	1985	1988	1982	1985	1988
Total (aggregate purchase price, in millions of dollars)	$211	$327	$532	$180	$245	$357
			(percent of total)			
Federal, total	54	52	50	76	66	64
NSF	34	27	26	29	25	24
NIH	9	11	13	1	1	<1
DOD	5	5	6	13	12	13
DOE	3	6	4	16	14	16
Other (NASA, etc.)	4	3	1	17	13	10
Non-Federal, total	46	48	50	24	34	36
Institution funds	35	31	38	14	24	27
State government	3	5	6	<1	2	4
Private/industry	7	9	5	7	6	4
Other/unknown	1	4	1	2	2	1

*Estimates are for research equipment costing $10,000-$999,999 per unit.

Note: Details may not sum to 100 because of rounding.

Source: National Science Foundation, SRS

Figure 5. Contributions to aggregate amount of research equipment in chemistry and physics/astronomy by source of funds: 1982-88



Source: National Science Foundation, SRS

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Table 5. Perceived trends in instrumentation funding support for departments, research centers, and supersystems in chemistry and physics/astronomy: 1986 to 1989

Funding source and perceived trends in support	Departments/centers		Supersystems	
	Chemistry	Physics/astronomy	Observatories	Nuclear science facilities
Number of departments/centers/supersystems	194	228	33	17
	(Percent)			
Federal government:	100	100	100	100
Increased	48	24	48	22
Remained the same/NA	37	43	25	78
Decreased	16	33	28	0
State equipment appropriations and equipment funded in state capital projects:	100	100	100	100
Increased	23	18	15	0
Remained the same/NA	53	71	85	90
Decreased	24	11	0	10
Internal institution funds:	100	100	100	100
Increased	38	29	54	16
Remained the same/NA	47	51	46	58
Decreased	16	19	0	26
Private nonprofit foundations/organizations:	100	100	100	100
Increased	7	5	11	10
Remained the same/NA	79	90	89	90
Decreased	14	5	0	0
Industry:	100	100	100	100
Increased	24	9	0	58
Remained the same/NA	60	84	100	42
Decreased	15	7	0	0

Note: Details may not sum to 100 because of rounding.

Source: National Science Foundation, SRS

PERCEIVED EQUIPMENT TRENDS

Most heads of departments, research centers, and supersystems reported that their research instrumentation needs had increased over the three-year period 1986-89, in both chemistry (96 percent) and physics/astronomy (87 percent; Table 6). The percentage of department/center heads who reported that their actual amount of research equipment had also increased over this period was quite high in chemistry (84 percent reported increases of more than 10 percent in aggregate dollar amount) but was lower in physics/astronomy (56 percent reported increases, most of only moderate size).

Most heads of chemistry departments reported overall qualitative improvements in the adequacy of their research equipment (71 percent), but less than half of the heads of physics/astronomy departments and research centers reported such improvements (41 percent). At the other end of the scale, 29 percent of physics/astronomy department/center heads reported net declines in the overall adequacy of their research equipment from 1986 to 1989, versus only 7 percent of the heads of chemistry departments/centers.

Another way of examining trends in perceptions is by comparing qualitative assessment findings across surveys (Figure 6). Such inquiries indicate the following comparisons:

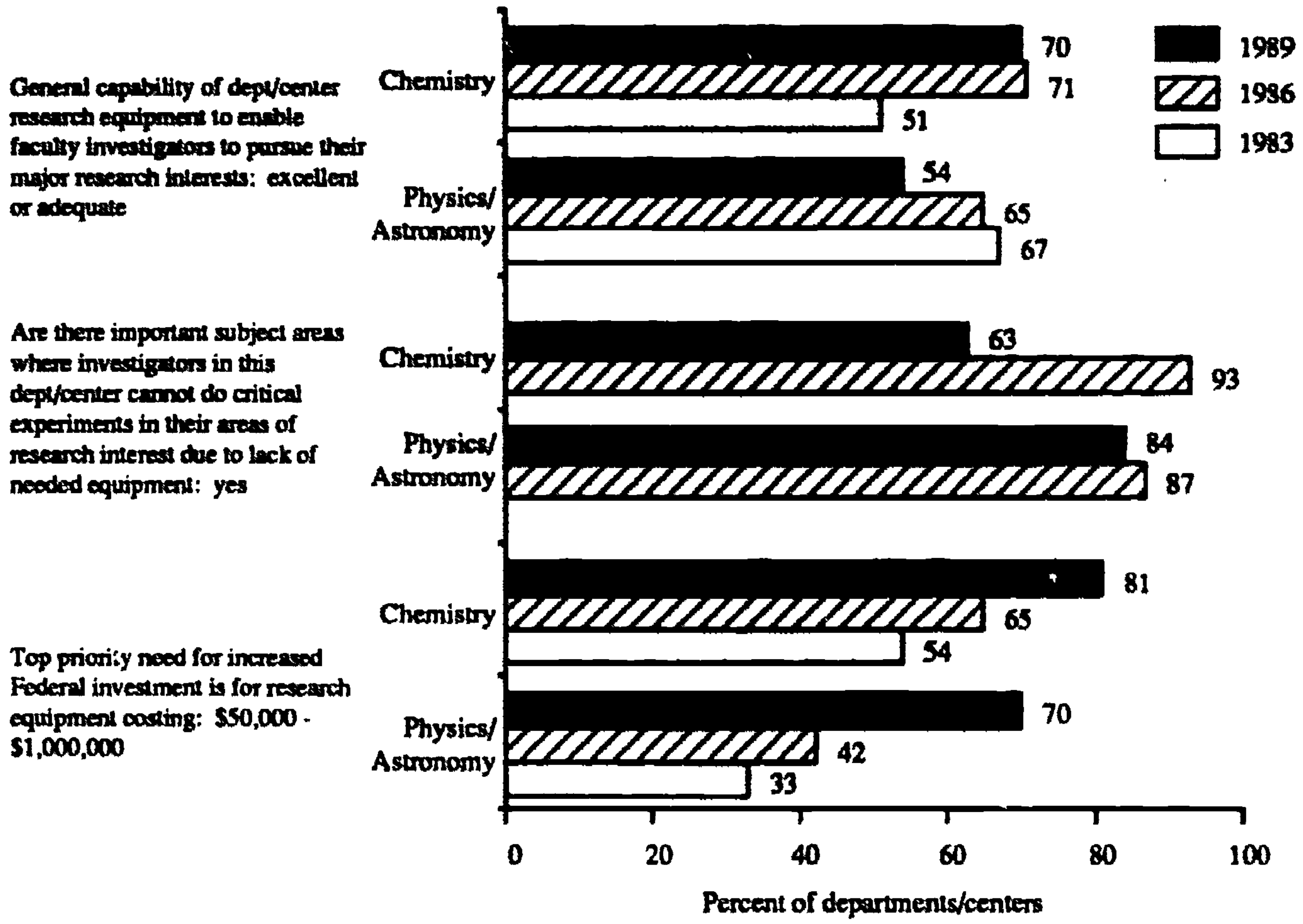
- There has been a gradual decline in the percentage of physics/astronomy department/facility heads reporting that their unit's research equipment affords faculty researchers adequate or better capabilities to pursue their research interests, from 1983

Table 6. Perceived equipment trends in chemistry and physics/astronomy: 1986 to 1989

Statistic	Departments/centers		Supersystems	
	Chemistry	Physics/ astronomy	Observatories	Nuclear science facilities
Number of departments/centers/supersystems	194	226	33	17
		(Percent)		
THE RESEARCH INSTRUMENTATION NEEDS OF THIS UNIT HAVE:				
Increased (e.g., because of expanding staff or program or other factors)	96	87	79	94
Remained the same	4	8	21	6
Declined	0	5	0	0
THE AMOUNT OF USABLE RESEARCH EQUIPMENT IN THIS UNIT HAS:				
Increased substantially (50% or more in aggregate cost/value)	30	7	57	12
Increased (by 11-49%)	54	49	24	58
Remained the same (+/- 10%)	15	38	19	30
Decreased (by 11-49%)	0	6	0	0
Decreased substantially (by 50+%)	0	0	0	0
THE ADEQUACY OF THE RESEARCH EQUIPMENT IN THIS UNIT HAS:				
Improved	71	41	80	70
Remained the same	23	30	14	24
Declined	7	29	6	6

Note: Details may not sum to 100 because of rounding.
Source: National Science Foundation, SRS

Figure 6. Trends in department/center heads' assessments of research equipment adequacy and need in chemistry and physics/astronomy: 1983-89



Source: National Science Foundation, SRS

(67 percent) to 1989 (54 percent). The opposite trend occurred in chemistry, where the percentage reporting adequate or better equipment increased from 51 percent in 1983 to 70 percent in 1989.

- In physics/astronomy, the percentage of department/center heads reporting problems resulting from a lack of needed research equipment remained stable at a high level from 1983 (87 percent) to 1989 (84 percent). In chemistry, reporting of such problems declined, from 93 percent of department/center heads in 1983 to 63 percent in 1989.

- In physics/astronomy, there has been a pronounced upward shift in the equipment cost range for which increased Federal funding support is thought to be most needed. In 1983, only 33 percent of physics/astronomy department/center heads said increased support was most needed for equipment in the $50,000 to $1 million range (the other 67 percent favored increased support for equipment below this range); by 1989, this percentage had more than doubled, to 70 percent. A similar upward shift occurred in chemistry.

Another indication of the growing need for relatively big ticket instrument systems is that, when department/center heads were asked to identify their three top-priority research equipment needs, the median price of the most-needed systems in chemistry in 1989 was $150,000; it was even higher in physics/astronomy at $165,000 (Table 7). In chemistry, almost half (48 percent) of the aggregate price of all most-needed instruments was for systems costing $400,000 or more, and the percentage was even higher in physics/astronomy (67 percent). In cost terms, about two-thirds of the aggregate price of these most-needed instruments, in both chemistry and physics/astronomy, was for systems that would create new capabilities, enabling researchers to perform experiments they cannot now do. Systems that would merely replace, or provide more copies of, existing instruments accounted for only about one-third of the reported needs.

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Table 7. Top-priority research equipment needs of departments/centers in chemistry and physics/astronomy--prices and reasons needed: 1989*

Statistic	Chemistry	Physics/ Astronomy
Aggregate price of needs list (dollars in millions)	$127	$208
Median price per item (dollars in thousands)	$150	$185
	(Percent of aggregate price)	
System price range	100	100
$10,000-$99,999	5	4
$100,000-$399,999	47	28
$400,000 or more	48	67
Reason needed	100	100
Replace an existing instrument	17	12
Expand capacity (more copies of existing equipment)	21	16
Upgrade capabilities (to perform experiments you cannot do now)	62	69

*From 1989 lists of three items per department/center of top-priority research instruments in $10,000-$1 million range. Needs lists include some items over $1 million and some that call for multiple copies (e.g., 10 workstations--$250,000).

Note: Details many not sum to 100 because of rounding.

SOURCE: National Science Foundation, SRS

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TYPES OF EXISTING AND NEEDED EQUIPMENT

The national inventory of chemistry research equipment is dominated by spectrometers and related instruments and accessories (Figure 7).[8] The category "spectroscopy and light measurement equipment" accounts for over half of the total investment in existing chemistry research equipment in both 1985 (60 percent) and 1988 (61 percent), and it encompasses about four-fifths of the aggregate cost of all most-needed instrument systems identified by chemistry department/center heads in 1989 (79 percent). Nuclear magnetic resonance (NMR) and mass spectrometers were especially prominent, together accounting for about one-third of the total existing investment (32 percent in both 1985 and 1988) and for over half of the most-needed equipment (57 percent of aggregate price).

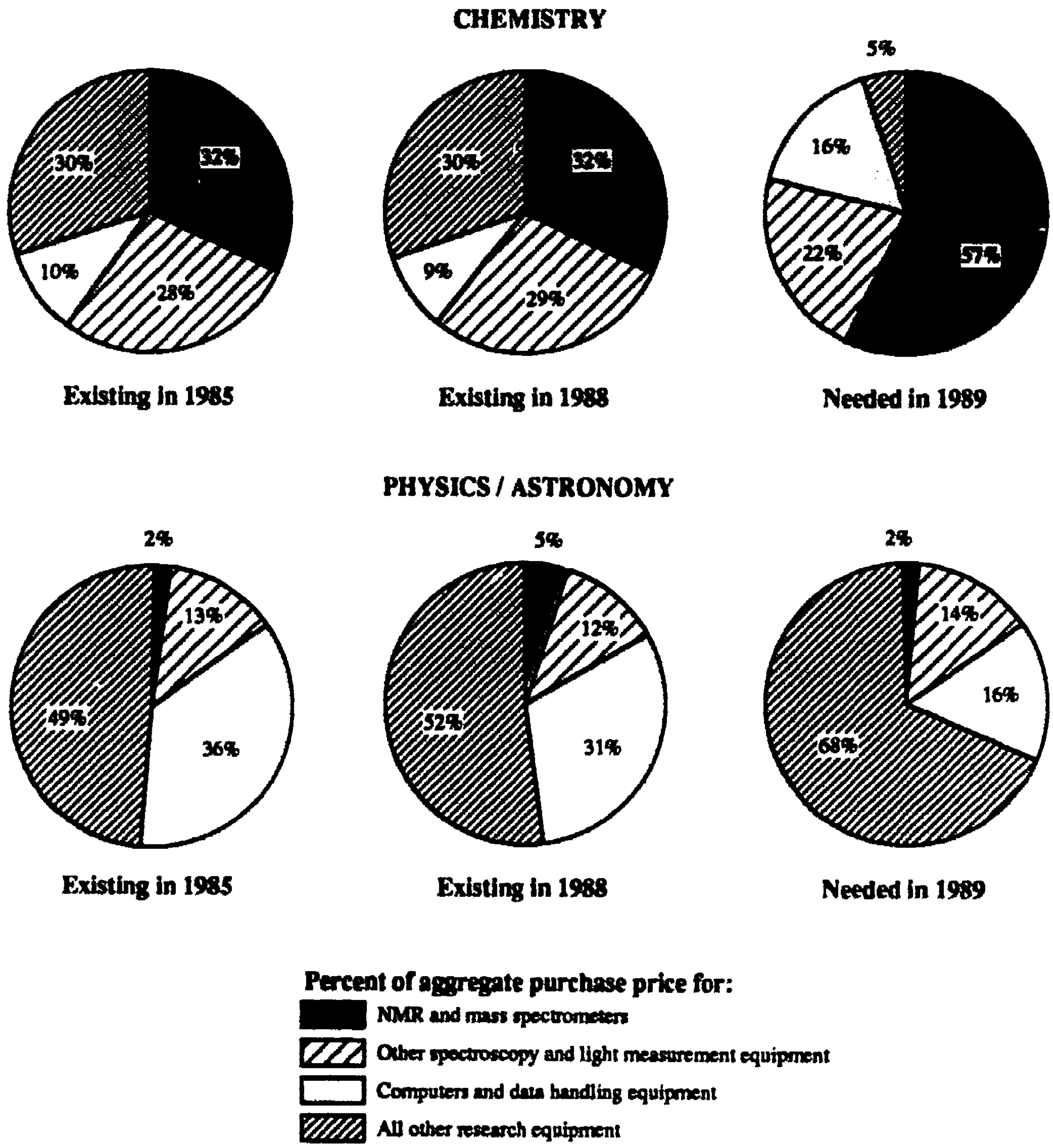
Computer systems and related equipment (PCs, peripherals, graphics and imaging equipment, etc.) accounted for an additional 9-10 percent of the existing research equipment inventory in chemistry, and they constituted a somewhat more prominent share of the equipment identified as most needed (16 percent). All other types of equipment combined (in essence, everything that is neither a spectrometer nor a computer) collectively accounted for only 30 percent of the aggregate investment in existing chemistry research equipment and for a remarkably low 5 percent share of the equipment identified by chemistry department/center heads as being their current top-priority needs.

As one might expect, the types of research equipment that are found (and that are needed) in physics/astronomy are quite different from those in chemistry. NMR and mass spectrometers are much less prominent, and while other types of spectroscopy equipment are found in quantity in physics/astronomy (such as optical spectrometers and monochromators), they are not as prominent there as in chemistry (12 percent of the 1988 inventory, versus 29 percent). Computing equipment constitutes a substantial but perhaps declining share of the physics/astronomy inventory: such equipment made up 36 percent of the aggregate investment in 1985, 31 percent in 1988, and only 16 percent of the most-needed equipment identified in 1989. The majority of the research equipment in physics/astronomy is in categories other than spectroscopy or computing; this is true both for existing equipment (52 percent) and for needed equipment (68 percent).

More detailed breakdowns of existing and needed research equipment in chemistry and in physics/astronomy are given in Table 8.

[8] The classification taxonomy used in this analysis was developed during the current survey and was then applied in the classification of equipment and equipment needs in both the 1989 and 1986 survey data. The taxonomy was generally modelled after the one used in *Science* magazine's annual "Guide to Scientific Instruments" (see *Science*, vol. 243, Part II, February 24, 1989), but contains many modifications suggested by members of the project Advisory Group to adapt it to the variety and cost range of equipment represented in this survey.

Figure 7. Trends in types of existing and needed research equipment in chemistry and physics/astronomy: 1985-89 *



* All estimates are for research equipment costing $10,000 - $999,999 per system. Needs data are from department/center reports of 3 top priority equipment needs.

Source: National Science Foundation, SRS

Table 8. Types of existing and needed* research equipment in chemistry and physics/astronomy: 1985-89

Equipment type	Chemistry			Physics/astronomy		
	Existing		Needed	Existing		Needed
	1985	1988	1989	1985	1988	1989
Total (dollars in millions)	$326	$532	$127	$245	$367	$208
			(percent of total)			
Spectroscopy/light measurement equipment	60	61	79	15	17	16
NMRs	22	21	35	2	4	2
Mass/GC-MS	10	11	22	<1	1	<1
Electron/auger/ion scattering/surface analysis	7	8	4	2	4	2
Infrared/FTIR/GC-FTIR/Laser Raman	6	8	5	1	3	<1
X-ray (diffractometers, etc.)	5	6	10	1	1	3
Other and unspecified	11	6	3	8	3	8
Computers and data handling equipment	10	9	16	36	31	16
Computer systems $200,000+	2	2	11	8	7	8
Minicomputers ($50-$199K) and peripherals	3	4	3	17	14	4
Single-user workstations ($10-$49K) and networks	2	2	-	8	6	2
Other	3	2	3	4	4	3
Other	30	30	5	49	52	68
Lasers and optical equipment	12	12	1	11	14	4
Cameras, recorders, and electronics	3	3	<1	8	8	9
Environmental/temperature control chambers	3	3	1	7	7	6
Electron/ion/molecular beam equipment (MBE, etc.)	1	1	-	1	4	9
Nuclear instruments	1	1	-	5	5	7
Microscopes and accessories	1	1	-	1	1	4
Telescopes and components	-	-	-	3	3	7
Robots, manufacturing machines	<1	-	-	<1	1	8
Laser-doppler velocimeters, anemometers	<1	-	-	<1	<1	8
Organic/bioscience equipment+	5	6	2	1	1	<1
All other	4	2	1	11	8	11

*From 1989 lists of three items per department/center of top-priority research instruments in $10,000-$1 million range. Needs lists include some items over $1 million and some that call for multiple copies (e.g., 10 workstations--$250,000).

+Includes cell sorters, centrifuges, chromatographs, protein synthesizers/sequencers, etc.

Note: Details may not add to totals because of rounding.

SOURCE: National Science Foundation, SRS

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INSTITUTION PROFILES

Separately for chemistry and physics/astronomy, this section contrasts the 20 largest research institutions in the field (those with the largest reported total annual R&D expenditures) to the approximately 150 next-largest institutions on measures of average program characteristics. As well as providing normative, quantitative information about current instrumentation at what may be presumed to be the best-equipped research universities in the field (the 20 largest), these data provide a basis for examining ways in which the relative amount, distribution, and usage of research equipment may be different at the smaller institutions than at the largest ones.

As background, the 20 institutions with the largest 1988 chemistry R&D expenditures reported average (mean) R&D expenditures of $9.3 million per institution in that field. Collectively, they reported $185 million in R&D expenditures that year, one-third (33 percent) of the total for all academic institutions in the nation.[9] The 20 largest institutions in physics/astronomy R&D accounted for an even larger share of the national research effort in that field; they reported average expenditures of $27.6 million per institution in 1988, collectively accounting for $553 million, 57 percent of the national total.[10]

Annual Equipment-related Expenditures

As would be expected, average annual expenditures for the purchase, operation, and maintenance of research equipment are far higher at the 20 largest R&D institutions than at institutions with smaller research programs, in both chemistry and physics/astronomy (Table 9). In physics/astronomy, for example, the 20 largest institutions spent an average of $4.2 million per institution for purchases

Table 9. Institution profiles in chemistry and physics/astronomy–average annual expenditures per institution for purchase, operation and maintenance/repair of research equipment: 1988*

Statistic	Chemistry		Physics/astronomy	
	20 largest in field	Other	20 largest in field	Other
MEAN FY 1988 EXPENDITURES PER INSTITUTION (dollars in thousands)				
Purchase of nonexpendable research equipment				
(a) All costing $500 or more per unit	$1,605	$325	$4,226	$349
(b) Equipment in $10,000-$999,999 range**	1,427	291	2,100	236
Operation of research equipment (technician salaries, etc.)	516	80	3,087	208
Maintenance and repair (M/R) of research equipment, total	261	77	$760	85
Service contracts and field service	132	18	247	24
Other	129	58	513	61
OTHER INDICES:				
Mean number full-time faculty researchers	38.9	17.0	66.9	19.8
Mean number Ph.D.s awarded last year	34.5	8.7	25.2	4.5
Equipment purchases per faculty researcher	$41,260	$19,120	$63,170	$17,630
Equipment purchases per Ph.D. awarded last year	$46,520	$37,360	$167,700	$77,560
Service contracts & field service as a percentage of total maintenance/repair (M/R) expenditures	51%	23%	32%	28%
M/R per $1 in equipment purchases	$0.16	$0.24	$0.18	$0.24
Operation costs per $1 in equipment purchases	$0.32	$0.25	$0.73	$0.60
M/R + operation costs per $1 in equipment purchases	$0.48	$0.48	$0.91	$0.84

*In each field, the 20 largest research performers (in FY 1988 R&D expenditures) are compared to institutions with smaller research programs in the field. Supersystems are included.

**Projection assumes the percent of (a) for equipment costing over $1 million is the same as it is for all existing equipment (see Table 10) and that 10 percent of the remainder is for equipment in the $500-$9,999 range.

Source: National Science Foundation, SRS

[9] National Science Foundation, Academic Science/Engineering: R&D Funds, Fiscal Year 1988, Detailed Statistical Tables. NSF 89-326, 1988, p. 111.

[10] These statistics do not include expenditures at the 18 large Federally funded R&D centers, most of which are located at (or administered by) institutions that are among the 20 largest physics/astronomy R&D performers.

of research equipment in 1988, as compared to an average of $349,000 per institution for the 154 next-largest institutions.[11]

Of course, the large research institutions have more faculty researchers and graduate students than institutions with smaller research programs. Even on a per person basis, however, the 20 largest R&D institutions have considerably higher annual levels of equipment purchases than are found at the smaller institutions, in both physical science fields (e.g., in chemistry, $41,260 per faculty researcher at the 20 largest institutions, versus $19,120 at the smaller institutions).

Regarding equipment maintenance, one might expect that the large R&D institutions would be able to achieve economies of scale that would permit them to rely heavily on their own personnel for much of their maintenance and repair work. In chemistry, though, external maintenance/repair (service contracts and field service, rather than service from institution-employed personnel) is actually more prominent at the largest institutions than at the smaller ones: the 20 largest research performers spend half of their annual maintenance/repair budgets externally (51 percent), as compared to 23 percent at the smaller institutions. In physics/astronomy, there is less difference between large and small institutions: 32 percent external versus 28 percent (Table 9).

Other aspects of the data suggest that the larger institutions do achieve some overall economies of scale in equipment maintenance: in chemistry, the 20 largest research performers spend an average of 16 cents on maintenance/repair of existing equipment for every dollar they spend on acquisition of new equipment, as compared to 24 cents to the dollar at the smaller programs. The figures are essentially the same for physics/astronomy. However, these differences are offset by the fact that expenditures for equipment operation (per doller of equipment purchases) are somewhat higher at the large research institutions. In chemistry, the result is that combined expenditures for maintenance/repair and operation of existing research equipment (per dollar of equipment purchases) are the same at the smaller institutions as at the largest 20: 48 cents to the dollar.

Similar relationships are seen in physics/astronomy, although equipment operation costs are higher in physics/astronomy than in chemistry (especially at the largest institutions). Consequently, the combined costs of equipment maintenance/repair and operation are also higher: 91 cents per dollar of equipment purchases at the 20 largest institutions.

Amounts and Characteristics of Existing Equipment

In physics/astronomy, the most conspicuous difference between the 20 largest research institutions and smaller research programs is in the area of big ticket equipment and facilities (observatories, nuclear reactors, etc.), which are heavily clustered at the large institutions and account for a substantial fraction of their total equipment investment (Table 10). The 20 largest physics/astronomy institutions contain a per institution average of 2.2 systems, with $6.9 million in movable equipment, in systems costing $1 million and over; this is almost as much as their average of $8.5 million for equipment costing under $1 million per system. Outside the top 20, there are an average of only 0.2 systems per institution in the $1 million and over range, about one for every five such institutions. Partly because of the influence of these big ticket items, the 20 largest physics/astronomy institutions also have larger average dollar amounts of equipment per faculty researcher, or per doctorate degree awarded, than are found at smaller institutions.

In chemistry, big ticket items in the $1 million and over range are not a factor, even in the largest research institutions. For equipment in the $10,000 to $999,999 range, the average amount (measured in terms of aggregate purchase price) at the 20 largest institutions is certainly greater than the average for the next 154 institutions ($7.7 million versus $2.4 million), but the difference is not nearly as great as it is in physics/astronomy ($8.5 million versus $1.2 million).

In both fields, for equipment in the $10,000 to $999,999 range:

- There is remarkably little difference between the largest research institutions and the smaller ones in either the cost distribution or the age distribution of their research equipment.

[11] These figures include expenditures at specialized physics/astronomy "supersystems," but not those at the 18 FFRDCs that are outside the scope of this study. Inclusion of FFRDCs would have no effect for chemistry but would make the differences between the 20 largest physics/astronomy institutions and all other institutions even greater.

Table 10. Institution profiles in chemistry and physics/astronomy–average amounts and characteristics of existing research equipment: 1988*

Statistic	Chemistry: 20 largest in field	Chemistry: Other	Physics/astronomy: 20 largest in field	Physics/astronomy: Other
SYSTEMS COSTING $1 MILLION +				
Mean number/university	<1	<1	2.2	0.2
Mean amount/university (dollars in millions)	<$1	<$1	$8.9	$0.4
SYSTEMS COSTING $10,000-$999,999				
Mean number/university	149	48	143	24
Mean amount/university (dollars in millions)	$7.7	$2.4	$8.5	$1.2
Mean amount/faculty researcher (dollars in thousands)	$198	$141	$127	$83
Mean amount/Ph.D. degree awarded last year (dollars in thousands)	$223	$278	$337	$279
Price range (percent of aggregate price)	100%	100%	100%	100%
$10,000-$99,999	47	48	54	57
$100,000-$399,999	41	36	33	35
$400,000-$999,999	13	16	14	8
Year of purchase (percent of aggregate price)	100%	100%	100%	100%
1986-88	42	43	40	49
1983-85	29	30	32	26
1982 or before	29	27	28	25
Use in 1988 (percent of aggregate price)	100%	100%	100%	100%
Research only	72	67	74	72
Research and instruction	28	33	26	28
Mean number research users/system in 1988	24.8	13.6	22.6	11.0

*In each field, the 20 largest research performers (in FY 1988 R&D expenditures) are compared to institutions with smaller research programs in the field.

Note: Details may not add to 100 because of rounding.

SOURCE: National Science Foundation, SRS

- There is also remarkably little difference between the largest institutions and the smaller ones in the proportion of equipment that is dedicated solely for research use, as opposed to being used for both research and instruction: in both institution categories and in both fields, 67-74 percent of the total investment is for equipment dedicated only for research use.

- The average annual number of research users per system is about twice as high at the 20 largest institutions as at smaller programs.

Perceived Current Status and Trends

In chemistry, department/facility heads at the 20 largest (and presumably best-equipped) institutions seem generally quite satisfied with the overall adequacy of their current research equipment: 61 percent rated their overall instrumentation situation as excellent in 1989, and the remaining 39 percent described their existing equipment as generally adequate; none characterized their instrumentation as inadequate (Table 11). Chemistry department heads at smaller institutions were less contented: 34 percent characterized their research equipment as inadequate, and only 17 percent reported having excellent equipment.

In both institution categories, physics/astronomy department/facility heads gave generally less positive assessments of their current research equipment than did their counterparts in chemistry. Thus, even in the 20 largest physics/astronomy institutions (which contain such a high proportion of the nation's total instrumentation inventory in that field), 20 percent of the department/facility heads complained that their current equipment is generally inadequate to enable faculty investigators to pursue their major research interests, and only 9 percent described their instrumentation situation as excellent. At institutions outside the top 20, over half of all physics/astronomy department heads (52 percent) characterized their current instrumentation as inadequate.

Table 11. Institution profiles in chemistry and physics/astronomy--department/center assessments of current adequacy and recent trends in their research equipment: 1989*

Statistic	Chemistry		Physics/astronomy	
	20 largest in field	Other	20 largest in field	Other
	(percent of departments/facilities)			
Adequacy of current research equipment	100	100	100	100
Excellent	61	17	9	4
Adequate	39	49	71	44
Insufficient	0	34	20	52
PERCEIVED TRENDS IN LAST 3 YEARS:				
Amount of research equipment	100	100	100	100
Increased	95	83	79	49
Remained the same (±10%)	5	17	16	44
Decreased	0	0	5	7
Adequacy of department's research equipment	100	100	100	100
Improved	75	70	52	39
Remained the same	17	23	36	28
Declined	8	7	12	33
Federal equipment support	100	100	100	100
Increased	26	50	49	18
Remained the same	66	33	36	44
Decreased	8	17	13	38
Not applicable	0	0	2	1

*In each field, the 20 largest research performers (in FY 1988 R&D expenditures) are compared to institutions with smaller research programs in the field.

SOURCE: National Science Foundation, SRS

To some extent, these relatively negative assessments by physics/astronomy department heads may reflect the importance of large, specialized regional and national labs for many areas of research in physics and astronomy. For example, in the case of astronomers who have ready access to off-campus national observatories that meet their needs, it might be descriptively accurate but programmatically irrelevant to say the equipment available on-campus is inadequate.

Turning to other indicators, 95 percent of chemistry department/center heads at the 20 largest programs reported net increases in their amount of research equipment over the last three years, and 75 percent reported that the overall adequacy of their equipment (relative to their needs) had improved over this period. The findings were almost as positive for chemistry programs outside the top 20: 83 percent reported increased equipment amounts, and 70 percent reported improved overall adequacy of equipment.

In physics/astronomy, 79 percent of department/center heads at the 20 largest R&D institutions reported that their amount of research equipment had increased in the last three years, and 52 percent reported net qualitative improvements in equipment adequacy. Both figures are lower than those obtained in chemistry. For physics/astronomy departments outside the top 20 institutions, the picture is still less positive: only 49 percent reported any net increase in equipment amounts, and only 39 percent reported any qualitative improvement; almost as many (33 percent) reported a qualitative decline in equipment adequacy (Table 11).

For chemistry (both the 20 largest institutions and the smaller ones) and for the 20 largest physics/astronomy programs, most department/center heads (over 80 percent) reported that their Federal instrumentation support had remained the same or had increased over the last three years. For physics/astronomy programs outside the top 20 institutions, however, only 18 percent reported an increase in Federal instrumentation support, and 38 percent reported decreased support.

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These latter findings suggest that, particularly for institutions outside the top 20 research performers, physics/astronomy department heads' complaints of the inadequacy of their existing equipment are not simply a trivial indication that much of the equipment they need is located in large, off-campus regional and national labs. Rather, they seem to be saying that their sources of instrumentation funding support have begun to dry up in recent years (or, at best, have remained static) and that the adequacy of their equipment stocks is begining to decline. In chemistry, on the other hand, reports of recent increases in both quantity and quality of research instrumentation were widespread, for the smaller research programs as well as for the largest ones.

APPENDIX A
LIST OF SAMPLED INSTITUTIONS

INSTITUTION SAMPLE

Brown University
California Institute of Technology
Colorado State University
Cornell University
Duke University
Georgia Institute of Technology
Harvard University
Johns Hopkins University
Louisiana State University
Massachusetts Institute of Technology
Michigan State University
Mississippi State University
New Mexico Institute of Mining & Technology
North Carolina State University
Northeastern University
Northwestern University
Ohio State University
Oklahoma State University
Oregon State University
Pennsylvania State University
Princeton University
Purdue University
Rockefeller University
Stanford University
Stevens Institute of Technology
Temple University
Texas A&M University
Texas Tech University
University of Arizona
University of California at Berkeley
University of California at Davis
University of California at Los Angeles
University of California at San Diego
University of Central Florida
University of Colorado (Boulder & Denver)
University of Connecticut
University of Dayton
University of Denver
University of Illinois
University of Iowa
University of Kansas
University of Maryland
University of Michigan
University of Minnesota
University of Nebraska
University of North Dakota
University of Oklahoma
University of Pennsylvania
University of South Alabama
University of Texas
University of Washington
University of Wisconsin
Virginia Polytechnic Institute
Washington State University
Yale University

APPENDIX B
LIST OF UNIVERSITY-ADMINISTERED FEDERALLY FUNDED R&D CENTERS

(which are excluded from this survey)

UNIVERSITY-ADMINISTERED FEDERALLY FUNDED R&D CENTERS

Department of Defense

Lincoln Laboratory (Massachusetts Institute of Technology)
Software Engineering Institute (Carnegie Mellon University)

Department of Energy

Ames Laboratory (Iowa State University of Science and Technology)
Argonne National Laboratory (University of Chicago and Argonne Universities Association)
Brookhaven National Laboratory (Associated Universities, Inc.)
Continuous Electron Beam Accelerator Facility (Southeastern Universities Research Association)
E. O. Lawrence Berkeley Laboratory (University of California)
E. O. Lawrence Livermore Laboratory (University of California)
Los Alamos Scientific Laboratory (University of California)
Fermi National Accelerator Laboratory (Universities Research Association)
Oak Ridge Institute of Nuclear Studies (Oak Ridge Associated Universities)
Plasma Physics Laboratory (Princeton University)
Stanford Linear Accelerator Center (Stanford University)

National Aeronautics and Space Administration

Jet Propulsion Laboratory (California Institute of Technology)

National Science Foundation

National Astronomy and Ionosphere Center (Cornell University)
National Center for Atmospheric Research (University Corporation for Atmospheric Research)
National Optical Astronomy Observatory (Association of Universities for Research in Astronomy, Inc.)
National Radio Astronomy Observatory (Associated Universities, Inc.)

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