relaxation processes but also to follow, with high time resolution, the course of more complex photochemical reactions from the initial excitation through the intermediate states or transient species to radical formation and identification and, if need be, to recombination or generation of new chemical species. In addition, the methods used promise to provide insight into the mechanisms of radical and ionic polymerization and, through the ability to identify transient states and their decay channels and lifetimes, to lead toward the generation of chemical species with novel properties.

References and Notes

1. A. Friedman and R. Bersohn, *J. Am. Chem. Soc.* **100**, 4116 (1978).
2. R. L. Pineault, C. G. Morgante, W. S. Struve, *J. Photochem.* **17**, 435 (1981).
3. Y. B. Band and K. F. Freed, *J. Chem. Phys.* **64**, 4324 (1976).
4. M. Dzwonic, S. Yang, R. Bersohn, *ibid.* **61**, 4408 (1974).
5. P. M. Rentzepis, *Science* **202**, 174 (1978).
6. C. G. Morgante and W. S. Struve, *Chem. Phys. Lett.* **68**, 272 (1982).
7. G. D. Gillispie and E. C. Lim, *J. Chem. Phys.* **65**, 2023 (1976).
8. C. Crentz, M. Chou, T. L. Netzel, *J. Am. Chem. Soc.* **103**, 1309 (1980).
9. D. Huppert, S. D. Rand, A. H. Reynolds, P. M. Rentzepis, *J. Chem. Phys.* **77**, 1214 (1982).
10. P. F. Barbara, L. E. Brus, P. M. Rentzepis, *Chem. Phys. Lett.* **69**, 447 (1980).
11. D. Huppert, J. Jortner, P. M. Rentzepis, *Isr. J. Chem.* **76**, 182 (1978).
12. P. M. Rentzepis and D. C. Douglass, *Nature (London)* **293**, 165 (1980); D. F. Kelley and P. M. Rentzepis, *Chem. Phys. Lett.* **85** (No. 1) (1982).
13. C. J. Calvert and J. Pitts, *Photochemistry* (Wiley, New York, 1966).
14. A. Friedman, S. C. Yang, M. Kuwasaki, R. Bersohn, *J. Chem. Phys.* **72**, 2115 (1980).
15. S. C. Yams, A. Friedman, M. Kuwasaki, R. Bersohn, *ibid.*, p. 4058.
16. C. G. Morgante and W. S. Struve, *Chem. Phys. Lett.* **68**, 277 (1979).
17. D. F. Kelley and P. M. Rentzepis, *J. Am. Chem. Soc.*, in press.
18. D. F. Kelley, M. R. Mazur, J. A. Berson, P. M. Rentzepis, *ibid.* **104**, 3764 (1982).

19. Discussions and collaborations with D. C. Douglass have been invaluable assets in this work. Most of the research work presented in this article was performed with P. F. Barbara (University of Minnesota), D. Huppert (University of Tel Aviv), A. H. Reynolds, and S. D. Rand.

Japanese Supercomputer Technology

B. L. Buzbee, R. H. Ewald, W. J. Worlton

In February 1982, computer scientists from the Los Alamos National Laboratory and Lawrence Livermore National Laboratory (*1*) visited several Japanese computer manufacturers (*2*). The purpose of these visits was to assess the state of the art of Japanese supercomputer technology and to advise Japanese computer vendors of the needs of the U.S. Department of Energy (DOE) for more powerful supercomputers.

The Japanese foresee a domestic need for large-scale computing capabilities for nuclear fusion, image analysis for the Earth Resources Satellite, meteorological forecast, electrical power system analysis (power flow, stability, optimization), structural and thermal analysis of satellites, and very large scale integrated circuit design and simulation. To meet this need, Japan has launched an ambitious program to advance supercomputer technology.

Japanese National Projects

In discussions with H. Kashiwagi of the Electro-Technical Laboratory (a government-funded organization, something like a U.S. national laboratory) we learned that the Japanese are using the concept of national projects to advance the development of supercomputers. Eight national projects in different areas have already been completed (*3*), and nine were still in progress at the end of 1981 (see Table 1). National projects relevant to computers include the National Superspeed Computer Project, the Fifth-Generation Computer Project, and the Functional Device Project. The criteria used by the Japanese for selecting national projects for research and development are as follows.

- The technology is urgently required for upgrading national industrial standards, promoting efficient utilization of natural resources, and preventing industrial pollution.
- The technology is expected to make a great impact on the progress of mining and manufacturing industries.
- The technology cannot be undertaken by private firms because of high risk, huge investment requirements, long-term programming, or absence of profit motives.
- The technology has clearly specified targets and well-examined attainment prospects.
- The project will be carried out in cooperation with universities and industry.

In this article we focus most of our discussion on the National Superspeed Computer Project. We also comment on the Fifth-Generation Computer Project, and describe some of the implications of these projects for the United States.

National Superspeed Computer Project

The six major Japanese computer vendors (Fujitsu, Hitachi, Nippon Electric Company, Mitsubishi, Oki, and Toshiba), in cooperation with the Electro-Technical Laboratory, have joined in the National Superspeed Computer Project to develop a computer more powerful than any now available. The joint effort is organized as the Scientific Computer Research Association.

Funding and duration. The superspeed computer project is funded by the Ministry of International Technology and Industry (MITI), with additional support from each of the six vendors. MITI funding for fiscal year 1982 will be 800 million yen (about $3.8 million). Fifteen percent of the funding for this project will go to the Electro-Technical Laboratory, and the other 85 percent will go to the other participants. Since the salaries of the researchers at the Electro-Technical Laboratory are already paid by the government, the funding for the superspeed computer project is larger than it may appear. Also, this funding may provide up to twice as much manpower in Japan as in the United States because salaries are lower there. Total funding for this project is expected to be about $200 million.

The National Superspeed Computer

R. H. Ewald is division leader and B. L. Buzbee and W. J. Worlton are assistant division leaders of the Computing Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545.

0036-8075/82/1217-1189$01.00/0

Table 1. Ongoing national research and development projects in Japan. [From H. Kashiwagi]

Project name	Period (fiscal year)	Total expenses (millions of yen)
Olefin production with heavy oil being used as a raw material	1975–1981	~ 13,800
Jet engines for aircraft (second phase)	1976–1981	~ 13,800
Resource recovery technology (second phase)	1976–1982	~ 11,000
Flexible manufacturing system.	1977–1983	~ 13,000
Optical measurement and control system	1979–1986	~ 18,000
Monocarbon (C_1) chemical technology	1980–1986	~ 15,000
Manganese nodule exploitation system	1981–1987	
High-speed computer system for scientific and technological uses	1981–1988	
Subsea oil production system	1978–1984	~ 15,000

Summary. Under the auspices of the Ministry for International Trade and Industry the Japanese have launched a National Superspeed Computer Project intended to produce high-performance computers for scientific computation and a Fifth-Generation Computer Project intended to incorporate and exploit concepts of artificial intelligence. If these projects are successful, which appears likely, advanced economic and military research in the United States may become dependent on access to supercomputers of foreign manufacture.

Project was started in January 1982 and is scheduled for completion by 1989. After completion, any Japanese firm that is a member of the project will be able to build supercomputers using the device technology, architecture, and software developed in the project.

Specifications for the computer. The specifications for the National Superspeed Computer include the following.

1) An execution rate of about 10 billion floating-point operations per second (BFLOPS).

2) One billion bytes of memory.

3) A memory bandwidth of 1.5 billion bytes per second.

4) Distributed parallel-processing architecture.

To meet these specifications, fundamental advances will have to be made in computer components, architecture, and software. There was general agreement between us and the Japanese that the maximum performance of a single processor will be about 1 BFLOPS, at least for the remainder of this century. Thus, some form of parallel processing will be necessary to achieve 10 BFLOPS (Fig. 1).

The next generation of American supercomputers will have a maximum execution rate of about 1 BFLOPS, approximately 0.25 billion bytes of primary memory, up to four parallel processors, and a memory bandwidth in excess of 1 billion bytes per second. Initial shipments of such supercomputers are expected by 1984.

Components. The first 3 years of the National Superspeed Computer Project are scheduled to produce the device technology for high-speed logic and memory; about 90 percent of the funding in this period will be used for this purpose. The Japanese are evaluating Josephson junction devices and high-electron-mobility transistors (HEMT's) as well as gallium arsenide and high-speed silicon devices. Goals for each are given in Table 2.

Every participant in the National Superspeed Computer Project is doing research in at least one of the areas of device technology. Oki Electric is doing research on gallium arsenide and emitter-coupled logic devices. Fujitsu is working on HEMT's, and the goal of this company is to decrease the minor-cycle time of a single processor to 1 nanosecond, that is, an execution rate of 1 billion instructions per second. Nippon Electric Company is doing research on Josephson junction technology and gallium arsenide. With gallium arsenide, Nippon members believe they may be able to achieve a 35-picosecond switch time at room temperature. Mitsubishi investigators are conducting research on high-speed silicon emitter-coupled logic devices and gallium arsenide. Their target for gallium arsenide is a 50-psec switch time at room temperature. Hitachi is doing research on d-c powered Josephson junction devices. Toshiba is working on gallium arsenide.

Japanese computer vendors appear to be making a much greater effort to develop gallium arsenide and HEMT technology than the U.S. vendors. The Japanese seem optimistic that the HEMT technology will succeed. What makes the HEMT attractive is that its speed is comparable to that achieved with Josephson junctions, but it requires less power per gate than either silicon or gallium arsenide (see Fig. 2). The HEMT is, in fact, aluminum-doped gallium arsenide. It will operate at room temperature, but reaches its maximum speed at the temperature of liquid nitrogen (77 K). Fujitsu has contributed significantly to the development of HEMT technology. By means of HEMT's, a supercomputer may be built that will operate "slowly" at room temperature to facilitate checking and debugging, and can then be cooled for maximum performance.

We gained the impression that there is a good chance that the HEMT technology will succeed in the next 2 to 3 years. If this is so, it may well preempt work in Josephson junction technology because these two technologies have comparable delay times. Further, by using HEMT's one can take advantage of much of the traditional silicon device technology, whereas use of the Josephson junction requires the development of new methods of fabrication, packaging, testing, and maintenance. Although it is not clear that HEMT's will replace silicon, at the very least they will probably find a role in high-performance circuits in supercomputers, and U.S. manufacturers would be ill-advised to ignore this possibility.

Because of the success of the Japanese in manufacturing the 64k memory chip, and because of their leadership in developing the 256k chip and the quality of their research in device technology (especially HEMT technology), we believe they have a good chance of meeting their goals for components.

Architecture. Work on architecture is just getting started, so most of our discussions were hypothetical. We were informed, however, that Japanese research in parallel processing will focus on parallel algorithms, system architecture, and software. The control scheme for the processing elements has not yet been selected, although our impression is that the Japanese will use multi-instruction, multi-data stream architecture. Japanese scientists are considering the usual interconnection schemes, such as crossbar, nearest neighbor, and shuffle-exchange. It appears that more studies on data-flow architecture are being conducted in Japan than in the United

States, and we visited several sites where such research projects were in progress.

The number of processing elements to be used has not been determined. We suggested that a few fast processing elements would be preferable to many slow ones. The distributed parallel processors shown in Fig. 1 are for pre- and postprocessing. The high-speed parallel processors are intended to run in batch mode; interactions with users will be through a front-end computer. We recommended that an interactive system should be provided.

We were surprised at the number of existing multiprocessor systems in Japan. Such systems include: (i) the Fujitsu M382 is a two-processor system; (ii) the Hitachi M280H can be configured as a four-processor system; (iii) the ACOS System 1000 of Nippon Electric Company can be configured with four processors; (iv) Nippon Telephone and Telegraph researchers have an experimental 16-processor data-flow device in operation; (v) Toshiba has a 16-microprocessor system in operation. It has been successfully used to solve partial differential equations. Its software includes a parallel operating system, parallel processing language, and a program to detect parallelism; (vi) Nippon Electric Company has an operational data-flow processor for image processing; (vii) several manufacturers have multipipe vector devices, both for special-purpose and general-purpose computation.

Thus the Japanese have considerable experience in this area and, perhaps most important, have a large amount of hardware with which to experiment. Their ability in parallel architecture appears to be equal to or greater than that in the United States.

Software. Software is always the toughest part of any computer project.

Table 2. Research and development goals for components.

Device	Goals
Logic	3k gates, 10-psec delay (Josephson junction devices, HEMT's)
	3k gates, 30-psec delay (gallium arsenide)
Memory	16k bits, 10-nsec access

Operating-system software could be a high-risk area for the National Superspeed Computer Project because it will have to provide the capability for managing parallel computation. The languages used for programming may not be a large problem because several participants already have vectorizing Fortran compilers and it may be possible to extend these concepts to parallel architecture. Software studies will include language considerations, for example, whether to use Fortran plus extensions or a new language and implementation techniques (Fortran will be provided); operating systems, for example, communication between system elements, and job control; and development of a software simulator for parallel-software simulation and compiler verification.

Many U.S. computer scientists are skeptical that the Japanese will be able to complete large software projects. We have open minds on this question.

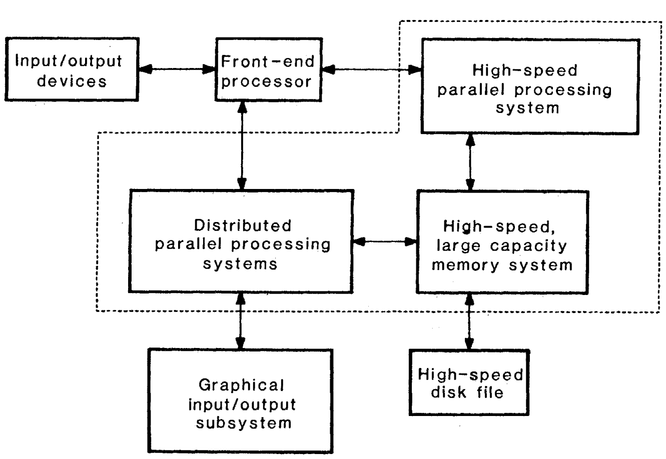
Related vendor activities. In addition to the national project, each of the vendors has one or more internal projects that will affect future supercomputer architecture, software, algorithms, and device technology. Fujitsu has developed the FACOM-APU vector processor, a register-to-register device that shares memory with its host. The FACOM-APU is considered by Fujitsu to be competitive with the Cray-1 of Cray Research Incorporated and with Control Data Corporation's Cyber 205 in some areas. However, comparable benchmark results are not yet available.

The Fujitsu M380 general-purpose computer should be comparable to the Cray-1 on scalar work because each of its processors can execute an instruction every 15 nsec. It is available in a two-processor version called the M382. It uses a 5.5-nsec, 4k chip in the cache; a 16-nsec, 16k chip in the storage control unit; and a 64k chip in the main memory. The logic chips are emitter-coupled logic devices with 400 and 1600 gates per chip. Switch time is 350 psec. The machine features unique packaging and is air cooled.

The M380 technology will also be used in the Fujitsu Vector Processor, the successor to the FACOM-APU. Its highest level of performance should exceed that of the FACOM-APU by an order of magnitude.

Hitachi currently markets a large-scale system called M280H with a minor-cycle time of 15 nsec. The M280H can have up to 32 megabytes of main memory. Emitter-coupled logic chips are used with either 550 gates per chip (450-psec gate delay) or 1500 gates per chip (800-psec gate delay). A 4k bipolar chip (7-nsec access time) is used in the buffer and storage control. Vector processing is available through the addition of an integrated array processor. This processor is a memory-to-memory device that performs only vector operations. Hitachi personnel indicate that its performance is about 30 million FLOPS. It can also be integrated into their M180H and M200H computers. Hitachi is planning a successor. Its performance is expected to exceed that of the integrated array processor by several hundred percent (*4*).

The largest computer offered by the Nippon Electric Company is the ACOS System 1000. It can have up to 64 mega-



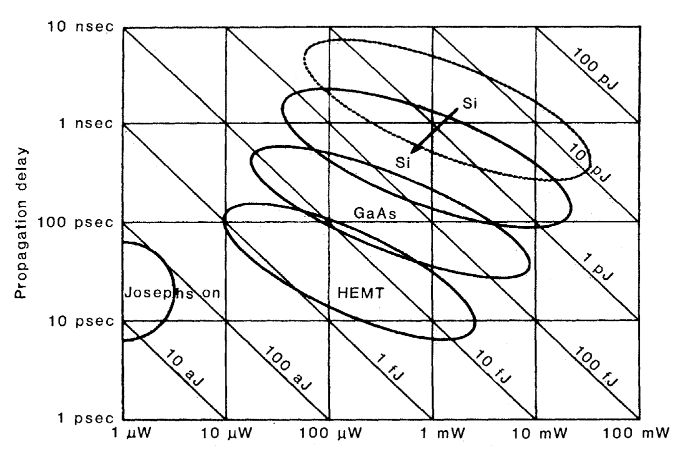


Fig. 1 (left). A preliminary scheme of the Japanese ultrahigh-speed computing facility. Fig. 2 (right). High-speed logic devices.

bytes of main memory. Vector processing is available through an integrated array processor similar to Hitachi's. Systems can be configured with up to four processors. Current mode logic chips are used with either 200 gates per chip (500-psec delay) or 1200 gates per chip (900-psec delay). A 64k chip is used in the main memory.

Fifth-Generation Computer Project

The Fifth-Generation Computer Project started in April 1982 and will run for at least 10 years. MITI and vendors will provide some $500 million for this project. This project, which was described by T. Moto-oka, Professor of Electrical Engineering at the University of Tokyo, represents Japan's first attempt at something really innovative—perhaps even revolutionary—in developing computers. Our understanding is that the Japanese intend to allow participation by foreign firms in the early phases of the project, but the final product will be licensed only to Japanese firms.

The Japanese recognize that highly developed countries are becoming information-oriented societies wherein computers are an indispensible tool for the processing and utilization of information. The objective of the Fifth-Generation Computer Project is to produce systems that offer new capabilities in problem-solving, man-machine interfaces, and cognitive processes. The goals of the project are as follows.

1) To increase productivity in low-productivity areas, for example, agriculture and fishing.

2) To meet international competition and contribute toward international cooperation, for example, "to cultivate information itself as a new resource" (5).

3) To assist in saving energy and resources.

4) To cope with an aging society.

To meet these goals, the project will seek new technology that (i) makes computers easier to use, for example, with the use of audio input and output in everyday language, graphics, knowledge bases, machine learning, and machine inference; (ii) lessens the burden of software generation, for example, by means of improved programming environments and ultrahigh-level languages (easy to use) with a high degree of verifiability; and (iii) improves reliability and cost performance of hardware and software. Very large scale integrated circuits and distributed networks will play important roles in the realization of these capabilities.

Implications of These Projects for the United States

The large-scale computing systems currently offered by Japanese manufacturers are approaching the best available. For example, the Hitachi M200H IAP appears to be competitive with Control Data Corporation's Cyber 205. Its successor is expected to provide a significant increase in performance. Fujitsu believes that its FACOM-APU approaches the Cray-1 in performance. Its successor is likewise expected to provide a significant increase in performance. We conclude that the National Superspeed Computer Project will produce a supercomputer, and the chances are good that it will achieve a significant increase in performance over existing computers in Japan and the United States.

We believe that the Japanese assessment of the role of information in society is correct and thus the development of technology to enhance that role is important. The Fifth-Generation Computer Project has already captured the imagination of computer scientists throughout the world and appears likely to achieve at least partial success. It is therefore important to consider some of the problems these developments may pose for the U.S. computer industry, and to assess the opportunities that such supercomputers may offer to U.S. supercomputer users.

The nation that leads the world in supercomputer technology—and that includes not just hardware but software and algorithms—has the possibility of leading the world in the application of supercomputers. These applications can include not only major national objectives, such as defense and energy, but also research in the fields of design and simulation of very large scale integrated circuits, geophysics, aerodynamics, petroleum engineering, electric power distribution, oceanography, and automotive design and manufacture. In science, the acquisition of knowledge is the single most important benefit obtained from computers, because computers enable us to treat complexity in models that is not otherwise practical. The existence of both the fifth-generation project and the superspeed computer project suggest that these issues are understood at the highest levels of government and industry in Japan.

The United States has been the world leader in developing and marketing supercomputers for the past 20 years. However, this has been leadership by default, because no other country competed for this rather limited market. Even in the United States this is a high-risk market that many vendors have been in at one time or another. Most have found it difficult to compete successfully and today there are only two supercomputer manufacturers in the United States. In June 1982, 50 U.S. supercomputers were in operation worldwide—38 in the United States, ten in Europe, and two in Japan. Of those in the United States, 25 were in government laboratories. Thus, other than the purchase of supercomputers by national laboratories and a few private organizations, the United States has no national support for supercomputer development.

Should another country assume leadership in supercomputing, U.S. defense and technology may depend on access to computers of foreign manufacture. This presents the following risks.

1) *Technology lag.* If countries other than the United States consume the first 2 years of supercomputer production, U.S. scientists will be denied use of these machines and U.S. technology could eventually lag the competition by 2 years. One Japanese manufacturer, in announcing its latest supercomputer, indicated that the computer would be marketed only in Japan for the next 4 years (*4*).

2) *Denial of access.* In this worst case, U.S. technology could be handicapped until domestic sources are developed.

3) *Loss of technology spinoff.* Development of supercomputers has always contributed to development of other computer systems. If another country assumes leadership, we may lose these benefits.

The private sector in the United States is unlikely to carry out the research and development necessary for continued U.S. leadership in supercomputer technology. The problem is that conventional supercomputer architecture is approaching fundamental limits in speed imposed by signal propagation and heat dissipation. In the 1960's the speed of supercomputers increased by a factor of about 100, and in the 1970's, by a factor of about 10; in the 1980's the speed may increase by a factor of less than 10. Thus the rate of increase in supercomputer speed is diminishing. Continued progress requires revolutionary developments in computer architecture that will affect all aspects of computer technology. Historically, the cost of developing a supercomputer has been about $100 million (hardware and software). This cost, combined with the relatively small market and the availability of more attractive avenues of investment, keeps capital- and resource-rich U.S. companies out of supercomputer development.

American universities cannot offer immediate help because supercomputers are almost nonexistent in academia, and academicians have little access to supercomputers at other locations. For example, an advanced supercomputer of the early 1970's, the CDC 7600, was not installed on a single American campus. Thus academic research in supercomputer technology, academic applications of such technology, and the training of people in both are not available in the quantity needed. In contrast, several European universities have American supercomputers and Japanese universities are richly endowed with the latest Japanese equipment.

To maintain U.S. leadership, private and government-sponsored research is required to identify areas for development that are likely to yield technical and market success, thereby lowering the investment risk to a point where the private sector will take over. Collaboration among manufacturers, academia, and government laboratories will be necessary. The requirements for research in such areas as very large scale integration, fifth-generation capability, and algorithms may offer timely opportunities to private research organizations, such as the Microelectric and Computer Corporation (*6*) and the Semiconductor Research Corporation (*7*).

References and Notes

1. The Los Alamos representatives, all from the Computing Division, were Robert Ewald, Division Leader; Bill Buzbee, Assistant Division Leader; and Jack Worlton, Assistant Division Leader. The Livermore representatives, all from the Computation Department, were John Ranelletti, Department Head; George Michael, Group Leader, Computer Research; and Harry Nelson, Senior Program Analyst.
2. Key Japanese personnel and organizations visited included S. Fukuoka, Executive Vice President, Nippon Kogaku (Nikon); H. Kashiwagi, Director-General, Electronic Computer Division, Electro-Technical Laboratory; S. Ninomiya, Director and General Manager, Computer Group, Fujitsu; H. Horitoshi, Deputy Manager, 8th Department, Central Research Laboratory, Hitachi; H. Hatta, Engineering Manager, Systems Engineering Department, Computer Engineering Division, Nippon Electric Corporation; C. Tanaka, Manager, Computer Architecture Group, Mitsubishi; Y. Anraku, Corporate Director and General Manager, Systems Laboratory, Oki; S. Takayanagi, Deputy Director, Toshiba Research and Development Center, Toshiba; N. Kuroyanagi, Director of Research, Nippon Telephone and Telegraph; and T. Motooka, Professor of Electrical Engineering, University of Tokyo.
3. The nine completed national projects are: the superhigh performance electronic computer, a desulfurization process, a new method of producing olefin, a seawater desalination process that includes by-product recovery, a remotely controlled undersea oil drilling rig, an electric car, a comprehensive automobile control technology, a pattern information processing system, and a direct steel-making process that operates at a high temperature with a reducing gas.
4. *Management Information Systems Week* **3** (No. 36), 10 (8 September 1982).
5. Japan Information Processing Development Center, Preliminary Report on Study and Research on Fifth-Generation Computers 1979–1980 (Fall 1981).
6. D. Stamps, *Management Information Systems Week* **3** (No. 35), 4 (1 September 1982).
7. P. J. Klass, *Aviat. Week Space Technol.* **116** (No. 20), 181 (17 May 1982).

Max Born's Statistical Interpretation of Quantum Mechanics

A. Pais

Summary. In the summer of 1926, a statistical element was introduced for the first time in the fundamental laws of physics in two papers by Born. After a brief account of Born's earlier involvements with quantum physics, including his bringing the new mechanics to the United States, the motivation for and contents of Born's two papers are discussed. The reaction of his colleagues is described.

The introduction of probability in the sense of quantum mechanics—that is, probability as an inherent feature of fundamental physical law—may well be the most drastic scientific change yet effected in the 20th century. At the same time, this advent marks the end rather than the beginning of a scientific revolution, a term often used but rarely defined.

In the political sphere, revolution is a rather clear concept. One system is swept away, to be replaced by another with a distinct new design. It is otherwise in science, where revolution, like love, means different things to different people. Newspapermen and physicists have perceptions of scientific revolution which need not coincide. Nor would individual members of these or other professions necessarily agree on what a scientific revolution consists of. For example, the London *Times* of 7 November 1919 headed its first article on the recently discovered bending of light by: "Revolution in science . . . Newtonian ideas overthrown." Einstein, on the other hand, in a lecture given in 1921, deprecated the idea that relativity is revolutionary and stressed that his theory was the natural completion of the work of Faraday, Maxwell, and Lorentz. I happen to share Einstein's judgment, while other physicists will quite reasonably object that the abandonment of absolute simultaneity and of absolute space are revolutionary steps.

However, all of us would agree, I would think, that the *Times* statement "Newtonian ideas overthrown," being unqualified, tends to create the incorrect impression of a past being entirely swept away. That is not how science progresses. The scientist knows that it is in his enlightened self-interest to protect the past as much as is feasible, whether he be a Lavoisier breaking with phlogiston, an Einstein breaking with the aether, or a Max Born breaking with classical causality.

These tensions between the progressive and the conservative are never more in evidence than during a revolutionary period in science, by which I mean a period during which (i) it becomes clear that some parts of past science have to go and (ii) it is not yet clear which parts of the older edifice are to be reintegrated in a wider new frame. Such periods are initiated either by experimental observations that do not fit into accepted pictures or by theoretical contributions that make successful contact with the real world at the price of one or more as-

The author is the Detlev W. Bronk Professor at Rockefeller University, New York 10021. This article is based on an address to the Optical Society of America on 21 October 1982 on the occasion of the centenary of Born's birth.

0036-8075/82/1217-1193$01.00/0