8: "The Explosives Industry"; No. 9: "The Use of Ferrous Materials in Construction". From the course A281, *Technology and Change, 1750-1914:* No. 4: "The Alkali Industry"; No. 6: "Making Steel: An Industry Transformed". (This course also offers updated versions of Nos. 2, 3 and 9 from AST 281)

8. These plans are now in the Science Museum, London.

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THE RISE AND DECLINE OF THE BRITISH DYESTUFFS INDUSTRY:

An Object Lesson for American Industry

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The aphorism that those who do not remember the past are condemned to live it again is an often quoted warning from the writings of George Santayana. This paper will attempt to illustrate this adage with two examples, one having historical and the other having contemporary significance. We will examine the rise and very rapid decline of the British synthetic dyestuffs industry as the historical example and the current dilemma of the American semiconductor industry as the contemporary example. Both industries were pioneers in the application of chemistry (organic in the former and solid state in the latter) to the development of entirely new technologies. Although our analogy may not be perfect, it is hoped that our study will elicit an awareness by the reader of the fact that history may indeed repeat itself.

The birth of the synthetic dye industry represents a classic example of serendipity in chemistry. During the 1856 Easter holidays William Henry Perkin (1838-1907), a student at the Royal College of Chemistry in London, working with its director August Wilhelm Hofmann (1818-1892), produced the first synthetic dyestuff - mauve or mauveine (19). Attempting to produce the drug quinine in his home laboratory by the oxidation of allyl toluidine with potassium dichromate, Perkin obtained a dirty reddish brown precipitate instead of the desired product. Persisting in his belief that quinine could be synthesized from aromatic amines, Perkin next oxidized commercial aniline, which was a mixture of aniline and toluidine. This resulted in a purple solution. It is a testimony to the keenness of Perkin's mind that he was able see the potential of this reaction mixture as a dyestuff - a potential which was

William Henry Perkin at age 28

confirmed when he sent some samples of silk that he had dyed with the mixture to Pullar & Sons, of Perth, Scotland, a silk and calico dyer. Thus, quite by chance, the synthetic dyestuffs industry was born and along with it the aromatic chemical industry.

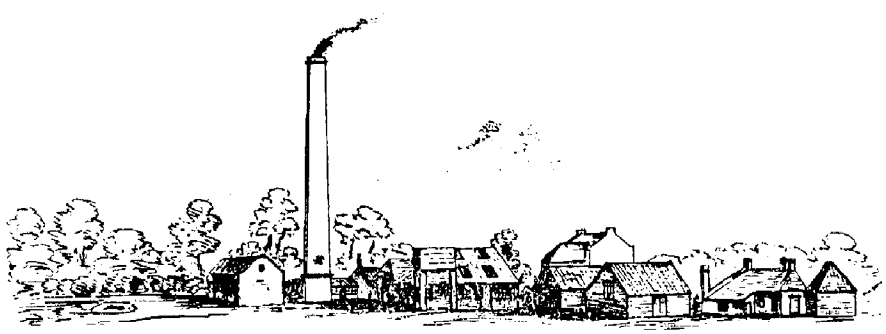
In retrospect the dye industry is the first example of a science-based industry. As Raphael Meldola stated in 1886 (1):

> The successive steps in this development ... [furnish] ... us with one of the most striking illustrations of the utilization of scientific discovery for industrial purposes, and the reaction of industry upon pure science.

What were some of the factors that were operative in Victorian Britain that led to the development of the dyestuffs industry? This era in British history was one of technological breakthroughs in many industries, such as machinery for the production of textiles and for mining. The acquisition of wealth by investing in the exploitation of natural resources was a route that was taken by many entrepreneurs of the day. The dyestuffs industry exploited a product known as coal tar which was produced in great abundance by the gas industry but which had little if any value. A large textile industry based upon imported cotton and wool was already in place which could readily absorb the products produced by the synthetic dye industry. Prior to Perkin's discovery, this industry used dyes which were almost exclusively obtained from natural materials, most of which had to be imported at great expense. In 1856 the figure of two million pounds sterling in real value has been given for these imports. Finally, educational institutions at this time were geared to the development of technologically based industries. As Travis has written (2):

> ... the environment (of practical men) provided problems to solve as well as the raw materials to be studied (by scientific men), and the educational institutions could only attract students if they offered adequate opportunities to acquire work-related skills, especially those required in the nearby area.

Perkin received a patent on 26 August 1856 for his new dye and with his father and brother established the firm of Perkin & Sons for the commercial production of the purple aniline dye. To convert a laboratory discovery into a commercial product was a major problem that had to be solved. The difficulties involved were many, such as securing sources of benzene from coal tar, developing a commercial-scale nitration procedure, as well as adapting to an industrial scale the reduction of nitrobenzene by iron filings first discovered by Béchamp in 1854 (3).



The Greenford Green Works in 1858

These problems were all solved and production of the dye which Perkin called Tyrian purple began at a plant built at Greenford Green west of London. In December of 1857 the first delivery of the new dye was made to the silk dyer Keith located in the Bethnal Green section of London. The dye was an instant success, especially in the fashionable circles of Parisian *haute couture* where it acquired the name mauve. In a period of less than 18 months, a laboratory discovery had been converted into a commercial product!

As shown in Table 1, in the next decade chemists in both Britain and France, by using various analogs of aniline and oxidation procedures, were able to produce a whole range of colors. Commercially the most significant of these was magenta. The reasons for this rapid advance were outlined by Perkin in 1868 (4):

> ... to introduce a new coal-tar colour after the Mauve was a comparatively simple matter. The difficulty in the manufacture of all the raw materials had been overcome, as well as the obstacles in the way of practical application of an aniline colour to the arts.

These discoveries also spawned a whole host of competitors for Perkin & Sons, among which the best known were Simpson, Maule & Nicholson in Britain and Renard Frères in France.

Table 1. Early evolution of aniline dyestuffs

Magenta	1859
Violet Imperial	1860
Bleu de Lyon	1861
Chrysaniline Yellow	1862
Aniline Black	1863
Methyl Violet	1866

The development of a commercial synthesis of the natural dye alizarin in 1869 marked the zenith of the British dye industry. Independently, Perkin in England and Heinrich Caro (1834-1910) in Germany devised a procedure to produce this natural dyestuff. Alazirin is an anthraquinone, the structure of which had been elucidated in 1868 by two students of Adolf Baeyer, Carl Graebe (1841-1927) and Carl Liebermann (1842-1914). Graebe and Liebermann took out a patent and assigned it to BASF, where Caro was able to make it into a viable commercial process. Caro had worked in the British dye industry from 1859-1866 during the heyday of the rapid development of aniline dyes and had returned to Germany to become technical director at BASF. At the same time, Perkin developed a four-step process for the synthesis of the dye starting from anthracene which involved chlorination, sulfonation, oxidation, and alkali fusion.

In 1874, as alizarin production was reaching its peak of 435 tons, Perkin & Sons was sold to the firm of Brooke, Simpson & Spiller, the largest dye manufacturer in Britain at that time. However, in this same year at BASF and Hoechst in Germany, alizarin production was already 1000 tons a year. Perkin realized that to compete with the newly-emerging German industry he would have to greatly expand his plant at Greenford Green. This was physically impossible so, instead, he and his brother sold out and Perkin withdrew from further active involvement in the dye industry, though not from chemistry. It has been argued by Travis that by 1870 Perkin was out of touch with what was happening in aromatic chemistry, and that he flourished in an environment which adapted technology to aromatic chemistry rather than the reverse, as exemplified in the approach of Caro (5). This may have also contributed to his removal from the business.

As Perkin was ending his active involvement in the dye industry, a new class of dyes known as the azo dyes was coming on stream. This class of dyes represents yet another example of where the original discoveries and production occurred in Britain but the advantage was soon lost to the emerging German industry. The diazotization reaction was discovered by the German chemist, Peter Griess (1829-1888), who spent the better part of his life working in England. Griess had been one of Hofmann's assistants (1858-1861) at the same Royal College of Chemistry where Perkin had received his training. In 1861 he took up employment as a brewery chemist and pursued his research in organic chemistry as a hobby. It was during this early period of Griess's work at the Allsop brewery in Burton-on-Trent that he discovered the diazotization process.

The first azo dye, called aniline yellow (*p*-aminoazobenzene), was formed by the coupling of the diazonium salt with aniline and its subsequent rearrangement. It was marketed in 1863 but did not prove very satisfactory in its application. Karl A. Martius (1838-1920), another German chemist working in Britain at Roberts, Dale & Co. in Manchester, produced the first successful commercial azo dye, Bismarck Brown, in 1866 as the product of the diazotization reaction of *m*-phenylenediamine instead of aniline. Another decade would pass before further azo dyes would appear. Caro in Germany and Otto Witt (1853-1915), another German working in Britain, produced simultaneously an orange azo dye called chrysodine. Chrysodine is the coupling product of *m*-phenylenediamine and benzenediazonium chloride. Thus we have seen that three of the most important classes of dyes were initially discovered and put into production in Britain in a period of about two decades. Yet by 1881 the distinguished British educator and chemist, Henry Enfield Roscoe (1833-1915) of the University of Manchester, would lament that (6):

> To Englishmen it is a somewhat mortifying reflection that whilst the raw materials from which all these coal-tar colours are made are produced in our country, the finished and valuable colours are nearly all manufactured in Germany.

By that year 50% of all dyestuffs were being made in Germany and by 1900 the figure would be 90%.

What were the factors that led to the decline of the British industry and to the development of such a dominant position by the German industry? They can be roughly classified as "external" - over which the British dye industry and chemical community had little control - and as "internal" - over which some degree of control existed.

The first of these, the external factors, were due largely to the lack of any kind of unified British industrial policy that would have fostered the dye industry and to a patent law that actually worked against it. The laissez-faire economic policy that pervaded Victorian Britain did little to protect domestic industry and all that was important was that the textile industry continue to obtain its dye requirements. The role of the state was not to help domestic industry compete with imports. In 1902, Ivan Levinstein (1845-1916), one of the most vocal of the dye manufacturers, complained that it was "difficult to get the House [of Commons] to consider any question of commercial importance" (7). Indeed, if the Germans could supply all that was required at a price less than domestic manufacturers, then all the better. This of course led to a rapid decline in the number of dye manufacturers after the 1880s and to a virtual end to technological development in the industry in Britain.

The dimensions of this decline can be seen in the number of British patents taken out between 1884 and 1900 by the six largest British and German firms. The number is 86 for British firms versus 948 for the Germans. By 1900 the six largest German firms employed 500 chemists whereas the British had a meager 35. Only with the advent of the First World War, when dyestuffs from Germany were no longer available, would the magnitude of the decline of the British dyestuffs industry clearly be seen. Then only reluctantly did the government intercede to try to rescue an industry that had basically collapsed under foreign competition.

The patent laws also played a role in the decline. There were no effective patent laws in Germany in the 1860s when the aniline dyes and alizarin were the major products. German firms were free to manufacture these dyes using information from the British patents. Even the new class of azo dyes were pirated; chrysodine for example, was copied by Martius at Agfa. Heinrich Caro best summarized this early period in the German industry, when he wrote (8):

> It was a joyless and profitless industry in those early years. It imitated the most valuable English and French inventions as described in the patent specifications ...

With the development of industrial research laboratories in Germany, the need for an effective patent law became evident. A patent law to protect the investment which various firms made in research was enacted for the whole German Empire and put into effect on 1 June 1877. This law was enacted only after input from a committee of the German Chemical Society as well as from the leading industrialists of the day. The law was rigorous, requiring that claims made for the product be valid, and thus, when a patent was granted, it became a valuable commodity. As R. D. Welham observed (9):

> ... there can be little doubt that the lack of a patent law, followed by the large profits to be made from the manufacture of magenta and alizarin, created the conditions for the rapid expansion of the German industry after its retarded start.

The patent laws in Britain were less strict and thus made it very easy for the Germans to patent large numbers of dyes. In addition, nothing required the patent holder to manufacture the product or, for that matter, to license its production in Britain to firms willing to meet the expenses of start-up and marketing. With the advent of the German industrial research laboratory and various types of new dyes, the patent laws led to a virtual monopoly by the Germans in the British market. Reform of the patent laws occurred in 1883 but was totally ineffective in terms of its working clause. The law was proposed without any input from the chemical industry and the clause requiring a patent holder to manufacture the product or license it was easily evaded. Even if a strict working clause had been included, it would have forced the Germans to set up plants in Britain where the raw materials were readily available. This would have done nothing for the domestic industry as a whole. A good analogy are the inroads made by Japanese manufacturers of automobiles, consumer electronics and machine tools in the United States. Although this is not the result of any patent law, it is still analogous in the sense that these foreign-owned firms manufacture in the U.S. to avoid loss of their market due to quotas and are now competing directly with domestic firms.

An effective patent law was finally passed in 1907 but it was essentially of little value to a dye industry which was already in terminal decline. The point can be made that even if compulsory licensing had occurred, it would have made little difference. German firms could have offered their products at prices much lower than the British licensee since the German industry was so much more modern and efficient by this time.

The most significant internal factor for the decline was the British educational system. Although there was probably no shortage of trained chemists in Britain throughout the period between 1856-1914, it was the type of training that was at the center of the problem. Institutions of higher education moved further and further away from a concern with practical research and became more and more involved in doing work which advanced the science of chemistry rather than the industry. Training of chemists tended to focus on the ability to perform research rather than on vocational training. The attitude taken by the dye industry toward this training was a major factor in its decline. British manufacturers were terribly short-sighted in terms of the value they placed on long-term research versus short-term profitability. In the early days of the industry, when Britain was in an almost monopolistic position, the profits that accrued were quite large. There was then a great reluctance to see that growing competition was going to end these easily-made profits and that profits must be plowed back in the form of research and development. The Germans, on the other hand, were quite willing to do this, just as the Japanese are today.

British manufacturers agitated not for better research training but for better technical education. They wished newly employed chemists to have a working knowledge of the dye industry so they would not have to pay salaries for what they considered an excessive period of time before these persons would become productive. A Royal Commission set up to study technical education reported in 1884 that (10):

> The Englishman is accustomed to seek for an immediate return and has yet to learn that an extended and systematic education up to and including original research is now a necessary preliminary to the fullest development of industry.

Another major fault of the English educational system was the way in which it trained its managers. A general classical education which completely neglected any training in the sciences was the norm. Many people who became involved in the more technical aspects of the business were woefully inadequate for the job. The Germans had a superb system of education, particularly on the secondary level, that included science and mathematics. This produced the type of person who could run the technical service departments and take charge of the routine control of processes to produce a consistently high-quality product. In general the Germans were better suited to realize the problems of the industry and were more responsive to the concerns of manufacturers than were the British.

In Britain the early retirement of Perkin at age 38 and Edward C. Nicholson (1827-1890) at age 41 deprived the industry of two manufacturers who had started their careers as chemists. Nicholson was also a student of Hofmann at the Royal College of Chemistry and had discovered magenta. Both realized the necessity for the reinvestment of profits in continuing research with the chance that it might ultimately pay off. With the loss of persons of this type the industry was run by those who were primarily businessmen. It was far different in the German industry, as many of the early dye pioneers, several of whom, like Caro, Martius, and Witt, had worked in Britain, eventually came to hold managerial positions with the large German companies set up in the 1860s and thereafter.

In retrospect, perhaps the ultimate reason for the decline of the British industry and the success of the German industry is to be found in the contrasting attitudes of the two societies toward science, education and their roles in the industrial well-being of the nation. Ivan Levinstein, that perceptive observer of the industrial decay that infected Britain in the latter part of the 19th century, best expressed this thesis in an address given in 1886 (12):

> The development of industrial enterprise in this country has for the last 30 years been practically confined to cotton, wool, iron and coal, to the lamentable neglect of other industries of apparently minor importance, while the chemical industries have been left in the hands of a few who - often more by good luck than through intelligent and economical management or scientific attainments, but aided by the natural wealth of the country - have carried on the business more or

less successfully, whilst outside of these few the general public was in profound ignorance of industrial chemistry. Hence the total want of enterprise in this direction on the part of the nation, owing to an insufficient appreciation of the importance of the chemical industries; the consequent apathy and the absence of any intimate connection or intercourse between our scientific men and our manufacturers; and, finally, the very great facility with which fortunes had been made in years gone by in what were then considered staple industries.

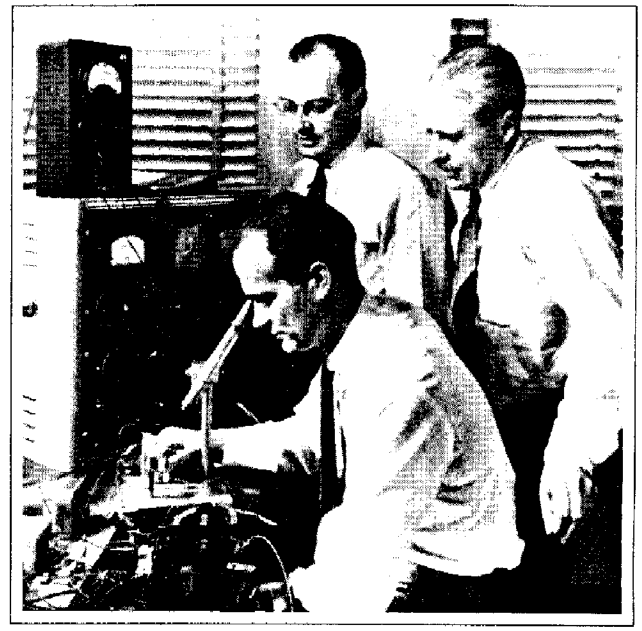
Certainly just the opposite characterized the newly emergent united German nation (13).

Turning to our contemporary analogy, we will now review the American semiconductor industry.

The initial discoveries and commercialization in semiconductors were a purely American achievement. In 1947 William Shockley (b. 1910), John Bardeen, (1908-1991) and Walter Brattain (b. 1902) at Bell Laboratories produced the first transistor which gave birth to the industry. The transistor allowed for the magnification of electronic messages using less current and producing less heat than the conventional vacuum tube. The longer life, smaller size, and greater reliability of this device led to its rapid commercialization after the initial problems in manufacturing were overcome. By 1956 there were already 20 companies making transistors, all of them located near Palo Alto, California in what was to become known as "Silicon Valley". This concentration was the result of William Shockley starting his own company after leaving Bell. Shockley had been raised in Palo Alto and had attended Stanford University. The university had started a research park on its property, and also Arnold Beckman was willing to invest in Shockley's company (14). Shockley hired eight very promising young men from the east coast who went on to found such companies as Intel, Fairchild Semiconductors, National Semiconductors, and Advanced Microsystems.

During the early years of development, 1947-1958, the American semiconductor industry was the world leader in both innovations and production. The industry was dominated by large vertically integrated producers, like IBM and AT&T, but merchant firms, like Texas Instruments and Fairchild also entered the market during the 1950s. Merchant firms sell their entire production on the open market. It is important to note that these two merchant producers were among the most important contributors to the industry's early growth and technological advance. For example, Texas Instruments came up with the silicon junction transistor (1954), the diffused transistor (1956), introduced the integrated circuit (1958), and Fairchild invented the planar process (1959).

The Department of Defense provided large amounts of money for the early development of transistors, and both the military and NASA stimulated the industry's growth through procurement and contributions to research and development. This provided firms the needed capital to take on high-risk and costly ventures, and created an important market for domestic semiconductors. The result was a greater incentive for firms to innovate and introduce new techniques. Direct U.S. government support for R&D and production refinement between 1955 and 1961 amounted to $66.1 million.



William Shockley (seated), John Bardeen (left) and Walter Brattain (right)

During this same period, the Japanese semiconductor industry consisted almost exclusively of vertically-integrated producers, such as Nippon Electric, Hitachi, Toshiba, Matsushita, Mitsubishi, Sony, and Fujitsu. While the Japanese were generally slow to innovate, Sony in 1955 did introduce transistor radios. From the beginning, the consumer market for electronic goods was the principal market for semiconductors. Japanese exports to the United States of transistor radios and black and white television receivers grew rapidly in the 1950s and early 1960s. By 1958, the Japanese had already become the second largest producer of semiconductors in the world, but the U.S. maintained an enormous lead over all other countries. Both the U.S. and Japanese semiconductor industries were in a constant trade surplus during this period.

While the Japanese government did not provide direct aid to the industry, it did enact policies aimed at supporting the industry's growth. The government regulated foreign investment; it protected the infant industry from entry by foreign firms; it encouraged cross-licensing agreements with U.S. companies; and it ensured that Japanese firms had to hold over 50% of the capital in joint ventures. Thus, Japanese firms had sole access to the domestic market and could take advantage of the low cost of labor.

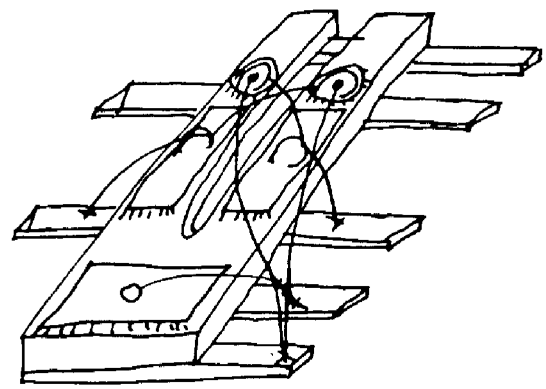
In 1958, a new period in the semiconductor industry began with the introduction of the integrated circuit by Texas Instruments. An entire circuit could now be placed on a silicon wafer. The demand for digital integrated circuits grew rapidly due to their use in computers and telecommunications. The planar process (1959) allowed integrated circuits to be produced by means of large-scale production techniques, thereby lowering production costs and improving reliability. Because the process could only be applied to integrated circuits made of silicon material, silicon replaced germanium as the primary material used for semiconductor devices.

If we consider the period from 1958-1971 (1971 being the year the microprocessor was produced), the U.S. remained the largest producer and consumer of semiconductors in the world. For instance, in 1969, 55% of the world's semiconductors were supplied by the United States (15). The U.S. also remained the world's leading innovator, with merchant producers like Texas Instruments and Fairchild, along with Motorola, holding the largest shares of the U.S. semiconductor market (17%, 13%, and 12% respectively, in 1966).

Military and space procurement was largely responsible for the expanding market in integrated circuits during the 1960s. Of course, the rapid growth in computer demand for both public and private (business and consumer) applications was also a major factor in the growth of the semiconductor industry. Some firms, like IBM, became captive producers, developing semiconductor components for in-house use only. But many new producers entered the computer market, and this resulted in a growing demand for integrated circuits.

The Japanese had devoted considerable amounts to R&D on integrated circuit technology, beginning as far back as 1960. But mass production of integrated circuits lagged behind the U.S. industry because the Japanese remained committed to the use of transistors for their consumer electronics market. Indeed, large imports of integrated circuits into Japan created a trade deficit in semiconductors after 1967; however, this was short-lived. During the 1960s the computer market in Japan was small in comparison to the consumer market, so there was no great demand for integrated circuits for use in computers. This was to change in the 1970s. The government during the 1960s protected the Japanese semiconductor market with high tariffs and by limiting American investments. Only Texas Instruments was allowed to open a plant in 1968. But even then, it had to enter a joint venture with Sony, where Texas Instruments could only hold a 50% share. Further, licenses to produce integrated circuits had to be given to NEC, Hitachi, Mitsubishi, and Toshiba, besides Sony. Also, Texas Instruments could not hold larger than a 10% share of the Japanese market. By protecting its two infant industries - computers and semiconductors - the Japanese laid the groundwork for successful competition with the U.S. in the 1970s and 1980s.

In 1971, Intel introduced the microprocessor, and the period of large-scale integration began. A microprocessor is a single integrated circuit chip which is capable of performing all the central processing unit functions of a computer. When



Jack Kilby's original 1958 drawing of the first integrated circuit

combined with memory and input-output circuits it becomes a microcomputer. World demand for semiconductors grew at an 11.8% annual rate between 1973 and 1982, with the demand for integrated circuits growing at a 15.7% rate. Integrated circuits encompass a wide range of product types, including logic devices, memories, and microprocessors, which has allowed the United States and Japan to compete in a number of different areas.

While most innovations in the semiconductor industry still occurred in the United States, by the early 1980s the American industry was faced with a highly competitive Japanese industry. The Japanese had made progress in both product and process technologies and were challenging the U.S. industry in specific product memory chips. By 1978, the U.S. had a trade deficit in semiconductors, while the Japanese found themselves with a growing surplus. Due to the increasing role of semiconductor technology in the electronic and computer industries, as well as the importance to national security, the following discussion will center on how the Japanese came to challenge U.S. dominance in semiconductors.

The Japanese have always been quick to copy or adapt new technology and products, and to foresee the marketing possibilities of semiconductors. For example, during the 1970s, while the American industry first developed metal-oxide semiconductor technology and produced watches and calculators with these circuits, it was the Japanese who saw the potential and moved rapidly to take advantage of these burgeoning markets. Furthermore, the Japanese industry has introduced new products, such as high electron mobility transistors, optical fibers, and long-wavelength semiconductor lasers.

Japanese semiconductors are produced not by relatively small merchant producers, but mostly by large electronics firms manufacturing consumer products, computers, etc. These vertically integrated producers can raise capital more easily and at lower cost than can a smaller, specialized firm, and some of their semiconductor products are then allocated for end-product use.

The growth of the computer industry in the 1970s stimulated demand for digital integrated circuits and particularly for memory devices. Computer firms, like Hitachi and NEC, integrated vertically into the production of memory devices. The data in Table 2 compare the position of the Japanese versus the American semiconductor industries through the early 1980s in terms of memory chips (16). In the early 1980s, four of the ten major semiconductor firms in the world were Japanese, with NEC and Hitachi ranked 3rd and 4th in 1982 in terms of world market share. In 1989, six of the top ten were Japanese (NEC, Tashibu, Hitachi, Fujitsu, Mitsubishi, and Matsushita) and only three were American (Motorola, Texas Instruments, and Intel). In the same year, the U.S. had a 35% share of world semiconductor sales, while Japan had a 52% share; also the Japanese semiconductor market had overtaken the U.S. market and was now the largest in the world. Even in the area of microprocessors, peripherals and microcontrollers, seven Japanese firms rank among the world's top ten suppliers (1987) (17).

What are some of the factors responsible for the growth of the Japanese semiconductor industry? Perhaps the foremost factor is that by the early 1970s the Japanese had a consistent, well-coordinated industrial policy. The Japanese Ministry of International Trade and Industry (MITI) was responsible for creating and implementing this cohesive industrial policy. The semiconductor industry was designated a strategic industry deserving of support. There has never been such a policy in the United States or, as we have seen, in Britain in the 19th century.

By providing money for R&D, restricting foreign imports, and emphasizing the development of the computer and telecommunication industries, domestic semiconductor production became highly successful. MITI provided interest-free loans to help develop "very large system integration" technology, and helped coordinate joint R&D ventures among Japanese firms. Research projects are ranked according to priority; only those projects deemed feasible and essential to Japan's technological development are undertaken. The policy is formulated in close consultation between industry and government, and its goals are dependent upon both technological and commercial requirements. Since the 1970s some $1 billion has been allocated to various research projects. Besides direct subsidies, the Japanese have benefited from tax credits for research, tax incentives for investment, loans to high-priority industries at lower than market interest rates, import duties, quotas, and controls on foreign investment and technology acquisitions.

Table 2. Japanese share of world computer memory chip market

Chip Type	Date	Percentage
1K RAM	early 1970s	0
4K RAM	mid 1970s	12
16K RAM	1979	40
64K RAM	1981	70
64K RAM	1984	54
256K RAM	1984	90

It should be noted that tariffs and other restrictions on foreign investment were all but eliminated by 1987, due in large part to U.S. pressure for the Japanese to open their domestic market. Also, government financing has declined in recent years, as private banks and institutions became eager to loan needed funds to semiconductor firms. Therefore, today's industrial policy in Japan is directed primarily at improving the competitive position of the industry, and seeing to it that the semiconductor industry can respond to a changing economic and technological environment.

In terms of technology, while virtually all of the breakthroughs in the semiconductor area were as a result of U.S. firms engaged in research and development, the Japanese have made important strides in process technology as did the Germans in the dye industry in the 19th century. For example, the Japanese firms moved towards greater automation well before American firms, the results being lower costs and greater quality and reliability of semiconductors. Due to Japan's employment practices, which ensure lifetime employment, workers more easily accept automation as a way of increasing productivity, unlike U.S. workers who see automation as a threat. Thus, Japan has been able to achieve a quality edge over the U.S. in production, assembly, and testing. Given the long-term relationship of the Japanese worker to the firm and his commitment to the firm's success, this has led to better communication between labor and management, managerial efficiency, teamwork, and higher productivity.

For a number of years, American firms have accused Japanese producers of predatory pricing, that is, "dumping" semiconductors, especially memory chips, in the United States at prices below per unit average costs. The result has been to drive American firms from specific product markets, and in some cases out of business. However, this is difficult to prove, as the low prices may be justified due to the so-called learning curve. Many British manufacturers were also driven out of business due to cheap German imports. In 1986 American firms did accuse the Japanese of pricing below cost, and the Japanese agreed to raise semiconductor prices. However, in 1987 the Japanese were accused of going back on the agreement.

We need to make one final point on technology. A great deal of Japanese success can be attributed to licensing agreements and second sourcing with U.S. companies. This is where Japanese manufacturers are licensed to produce and sell U.S. designed devices (memory chips, microcontrollers, etc.) so as to guarantee customers adequate supplies at fair prices, and to better market a device. The consequence, however, has been to allow the Japanese to produce products of higher quality and at lower cost than that of the U.S. and thus improve their own competitive position.

The savings rate in Japan has remained consistently higher than the U.S., well over 20% of GNP in the postwar years. Coupled with a cost of capital almost three times higher in the U.S. than in Japan, American companies are at a disadvantage. The prices of U.S. products are higher and the return on investment lower than in Japan. Historically, the U.S. firms have depended on equity financing (stock issues), while the Japanese have chosen debt financing (bank loans and corporate bonds), as a means to raise capital. From 1967 to 1983, the average debt-market value ratio was 26% in the U.S. and 63% for the Japanese. American companies (including all industries) invest about 1.8% of GNP; the Japanese invest 2.8% of their GNP. In 1987-1988, U.S. spending on R&D was 3%. For Japan it was 11%. In fact, five countries spent more of their GNP on R&D than the United States. For example, from 1972-1980, U.S. semiconductor companies spent between 6 and 12% of their revenues on R&D. Japanese semiconductor firms, from 1973-1978, spent 16.9% of their integrated circuits revenue on R&D. U.S. dependence on equity financing causes companies to put greater emphasis on short-term earnings and risk-avoidance. Japanese companies, on the other hand, are willing to take risks on new investment in physical capital, and can sustain short-term losses in order to attain a larger market share. As was seen earlier, a similar difference in German versus British attitudes towards long-term investment contributed to the decline of the British dye industry.

How has the U.S. responded to Japan's challenge? American semiconductor companies are working towards achieving improved technological and cost efficiencies, capital improvements, and greater spending on R&D in hopes of developing a new generation of semiconductor products. Areas of research include gallium arsenide semiconductors, superconductivity, and important developments in microprocessors. American firms have restricted second source production by Japanese firms, particularly in microprocessors, in order to increase profits.

Can the U.S. compete successfully in the future? Will history repeat itself? It may, unless industry and government form a coordinated approach in which the semiconductor industry can set long-term goals and where the government provides subsidies and tax incentives for R&D and capital formation. An investment tax credit and reduction in capital gains taxes could stimulate industry growth. Trade sanctions can also be a useful tool, if used sparingly in order to avoid a trade war with Japan. Above all, U.S. firms must expand their technological base and protect new technologies from infringement by Japanese companies. Only by maintaining a technological edge can American semiconductor firms achieve success, for "... the Japanese have begun an initiative to build a superior technological base, which, if it comes even close to the success of their manufacturing programs, could make them an unbeatable competitor" (17).

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THE FIRST HALF CENTURY OF CHEMISTRY AT CLARK UNIVERSITY

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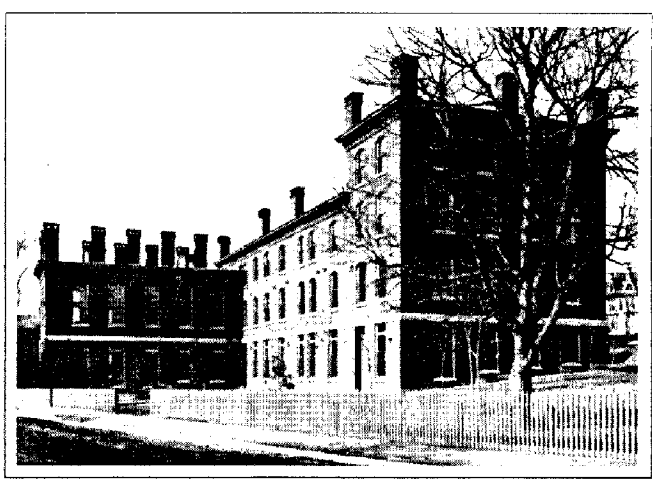
In 1987 Clark University observed the centennial of its founding, which was instigated by Jonas Clark (1815-1900), a successful businessman in Worcester, Massachusetts, where the institution was to be located. It was created strictly as a graduate school, with programs first set up in physics, chemistry, mathematics, biology, and psychology. G. Stanley Hall (1846-1924), holding a Ph.D. in psychology from Harvard, was appointed the first President (1).

Clark University sprang into being just as the 19th century was coming to an end. This coincided with the peak of activity in the traditional sciences, including chemistry, in Germany,



The chemical laboratory at Clark, circa 1890

John Ulric Nef

whereas these fields were still in the early stages of development in the United States and Canada. Thus it is understandable that the graduate programs at Clark were tailored after the German model. President Hall himself had spent time in Germany before beginning his Ph.D. His first action, on being chosen to head up the new university, was to sail for Europe, where he spent six months establishing contacts with German professors and evaluating young Americans who were studying there. Both Hall's personal experiences in Germany and his hiring of German-trained faculty in all of the disciplines contributed to the molding of the character of the early Clark graduate program. It was similar to the program in chemistry established by Ira Remsen at Johns Hopkins, where Hall had held the position of Professor of Psychology and Pedagogy before his selection as the first president of Clark.

Although the university had its beginning in 1887, the chemistry department came into existence slightly later. By 1890 the chemistry laboratory was completed and the first faculty member to head up chemistry, Arthur Michael (1853-1942), was appointed in 1889. He had spent time in several German university laboratories, though he never earned an advanced degree. However, his tenure at Clark was fleeting, lasting only a few months in the fall of 1889, not even long enough to make the listing in the university catalog. The reason for his abrupt departure was the refusal of Jonas Clark to allow laboratory privileges for Michael's wife, also a student of chemistry. This placed President Hall in an awkward position, for he had included this promise as one of the conditions of Michael's appointment. Michael simultaneously held a teach-