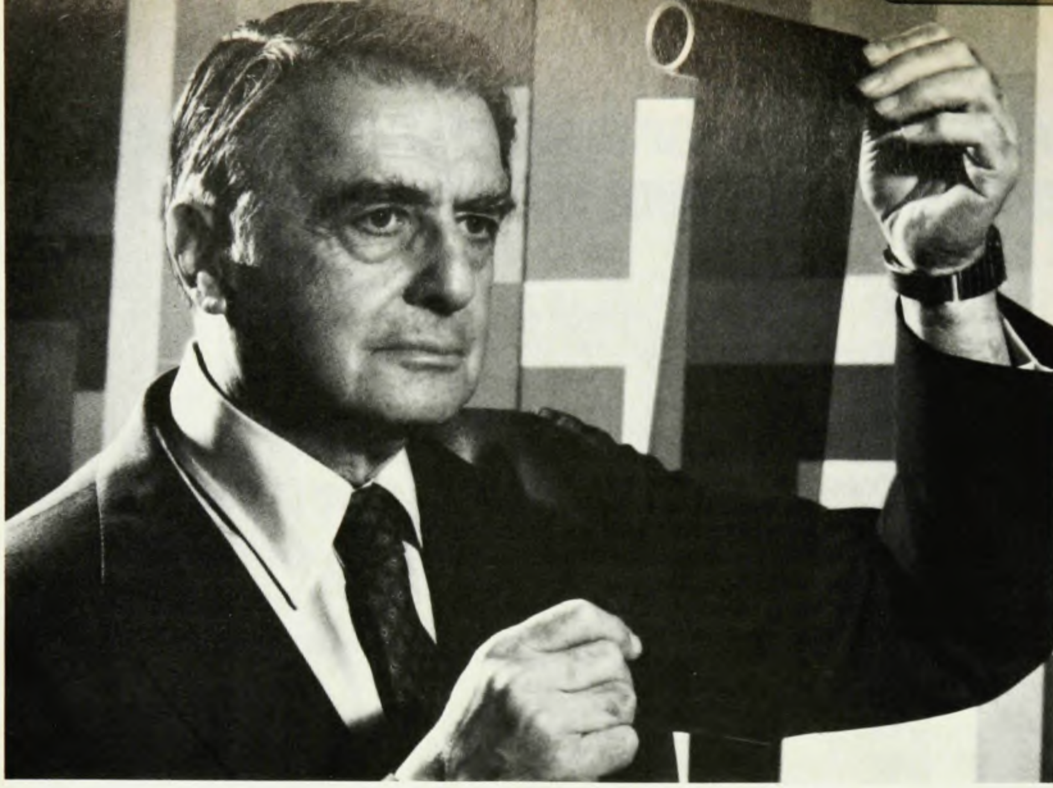
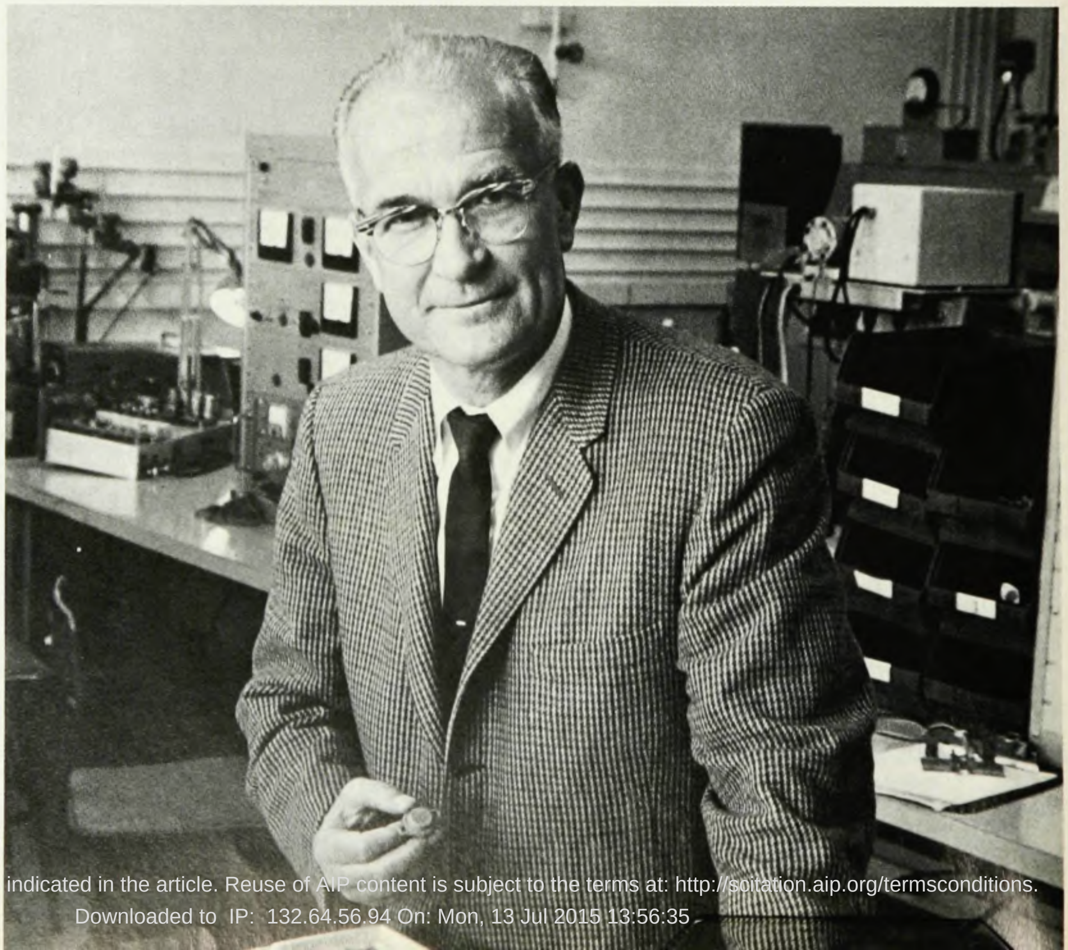


Edwin Land started the Polaroid corporation in 1937. It was one of the first "science centered" companies, placing as much emphasis on research as on profits.

The physicist as entrepreneur

"I believe quite simply that the small company of the future will be as much a research organization as it is a manufacturing company, and that this new kind of company is the frontier for the next generation."—Edwin Land (1946)



William Shockley, one of the inventors of the transistor, and one of the founding fathers of the independent electronics companies in "Silicon Valley" in California. (Photo by Robert W. Kelley, Life Magazine © Time Inc.)

Michael Jacobs

The phenomenal growth of physics as a science over the past half century has been paralled, breakthrough for breakthrough, by the explosion of physics as a marketable commodity. Technology has followed close on the heels of research, and has sometimes even taken the lead and acted as a stimulus for research.

As often as not, those responsible for bringing the latest technologies to the marketplace have been the physicists themselves, too devoted to the technologies to trust their development to others, unable to interest any existing industries in the unproven innovation, or just too shrewd to let the valuable technologies slip through their fingers. If anything unites this group of physicist-businessmen, it is their unerring dedication to their technologies, and the dream of establishing them as items of utility and profit.

Instant pictures, gradual success

Land is perhaps the most philosophical of all the physicists who have decided to trade their grade books for balance sheets. He started Polaroid in 1937 with a dream that he was determined to see become a reality. The dream was of a "science-centered" company, as he called it, that would place as much emphasis on research as it did on profits. His goal was to see the growth of small, technology-oriented companies that would commit at least 5% of their net earnings to research activities. He set up Polaroid as a model of such a company and it has proved to be just that, demonstrating both gratifying success and disappointing failure in the course of its history.

The innovativeness of the company that Land built spread to both its style of research and management, and to the products of that research: cameras, film and other products that won the public over by their very ingenuity. After modest growth with a line of polarizing products and black-and-white instant cameras, the company took off in 1965 with the introduction of color film and lower-priced cameras. By 1970 Polaroid was up to a half billion dollars in sales, and in 1977 it broke the billion-dollar mark. This year sales are expected to exceed $1.5 billion.

Unfortunately, not everything Land touched turned to gold. For example, the company was unable to persuade Detroit to make polarizers on automobile headlights and windshields standard equipment, although all of the technical problems had been solved. More recently, the company lost money on the Polavision instant movie system. But these were failures only in a financial sense (and Polavision may yet redeem itself, says Land).

Much of Polavision's past failure has been blamed on poor marketing techniques. "I don't think we found the right way to tell the world about it," says Land. In any case, he points out, the real value of some innovations does not manifest itself for decades after the initial discovery. For example, polarizing light valves were developed in the 1930s, but did not come into general use until 50 years later, when digital watches exploited this technology.

Another reason for the limited success of Polavision was that there simply wasn't enough of a market for an instant home movie camera when it was introduced two years ago, no matter how ingenious. Competition from the growing videotape industry was, and still is, fierce.

Instead of coming to grips with Polavision's inherent marketing disadvantages, Polaroid chose to ignore them. Its strategy was simply to distribute this new product as broadly as it had the SX-70 camera five years earlier. Interestingly, this marketing strategy is identical to that spelled out by Land in 1946. "I believe it is pretty well established now that neither the intuition of the sales manager, nor even the first reaction of the public is a reliable measure of the value of a product to the consumer," he told the Chemical Institute in Toronto. "Very often the best way to find out whether something is worth making is to make it, distribute it, and then to see, after the product has been around for a few years, whether it was worth the trouble."

Will it play in Peoria?

The problem of establishing the existence of a market for a product is one that confronts every innovator. It is especially severe for entrepreneurial physicists, because, more often than not, companies started by physicists are set up to exploit a certain technology, rather than to serve an existing market. Physicists often start with what is termed "a solution in search of a problem."

The search for a problem can be more arduous than the entrepreneur might have anticipated. More than one company has failed, not because it was unable to perfect a technology, but because it misjudged the market for that technology. Franklin Johnson, a West-coast venture capitalist who has seen the rise and fall of enough high-technology empires to be a pretty good judge of success potential, says that physicists most often fail in the business world because of market ignorance.

On the other hand, market analyses, Land rightly pointed out, go only so far, and are especially deficient when it comes to predicting the market for truly innovative products that will be newcomers to the marketplace. "One had to be very far-seeing," Johnson says, "to have extrapolated from the first solid-state work to the modern computer. The pioneers in that field were making products for markets that they were creating as they went along. The same was true for the laser industry." According to Robert Noyce, president of Intel Co., one of the most successful semiconductor industries in the country, "If one had tested the market for semiconductors early on, the only application you would have found would have been in hearing aids." The extreme underrating of the market for office copiers is another classic tale of faulty market analysis.

One other case in point is LeCroy Research Systems of Spring Valley, New York. The company was founded in 1964 by physicist Walter LeCroy to produce electronic instrumentation for high-energy physics research. LeCroy was not the only company manufacturing such equipment in the 60s, but one of the things that gave the company as advantage over the competition, says LeCroy, "was our willingness to take risks with products. We would design and build things more on a hope than on the definite knowledge that they could be useful."

"The problem with traditional methods of market research," according to Noyce, "is that they tend not to predict the secondary effects of market feedback." For example, the semiconductor and computer industries "grew up" together (even physically close to each other), providing mutual support for one another throughout their early years.

The golden chips of Silicon Valley

Perhaps the most interesting phenomenon in the history of high-tech industry in America has been the development of the so-called "Silicon Valley" in northern California as a haven for the enterprising scientist. Though there are similar areas elsewhere in the country, no other region can match the Valley's tremendous intellectual and technological concentration, which constantly stimulates the creation of new products and companies.

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Credit for the area's phenomenal industrial growth stems partly from the proximity of the Stanford and Berkeley campuses, partly from the pleasant climate, and partly from the efforts of certain farsighted individuals, most notably Fred Terman, now a retired professor of electrical engineering and provost emeritus of Stanford. The late 1930s saw a surge of inventiveness at Stanford. Terman encouraged his students, who included David Packard, William Hewlett and Russel and Sigurd Varian, to establish businesses locally, based on the new high technology of electronics.

Ironically, the company that was more than any other responsible for the growth of the electronics industry in Silicon Valley was not itself financially successful. But Shockley Transistor Co., founded by Nobel-prizewinning physicist William Shockley, was the grand-daddy of nearly every semiconductor corporation in the area today.

Shockley left Bell Laboratories in 1954 and started his company with backing from Beckman Instruments in Palo Alto in 1955. Despite an uncanny genius for spotting and recruiting talent, he was less adroit at managing that talent. Within two years, a number of Shockley's top associates departed, largely over Shockley's decision to concentrate on four-layer diodes rather than transistors. The company never really recovered from the blow and went through several owners before being closed in 1968.

Shockley's associates began a trend that today is well established in high-technology industry: spinoffs. Very often, a physicist working for one company has an idea that his employer is not prepared to implement, so the physicist uses the idea as the nucleus for his own company.

For example, when Robert Noyce and Gordon Moore left Shockley Transistor in 1957 they founded Fairchild Semiconductor. Then in 1968, the two left Fairchild to start Intel (a contraction of integrated electronics). Noyce and Moore have demonstrated what can be accomplished with the right combination of good science and business acumen. In its 13-year history, Intel has introduced over 20 significant innovations in integrated circuitry, including the microprocessor, and has grown from 42 employees to 16 000.

"Intel was kind of the next logical extension beyond what Fairchild had been doing in this technology," says Noyce. "When we left Fairchild, they were making integrated circuits with hundreds of components. Intel was started with the idea of going to thousands of components, and we are now into the hundreds of thousands."

Why did it take a new company to make the jump to higher levels of integration? "I think that any existing company tends to emphasize the products they are already producing and to ignore the next generation," Noyce answers. "One way to give birth to the next generation of technology is to start over with a new company."

In the last decade, Intel has grown from an under-$10-million company to one whose sales last year were over $850 million. Its stated goal is to achieve at least $150 million annually in net income by 1983.

What has made Intel so phenomenally successful? One key is the company's emphasis on research and development. Research and development takes about 10% of Intel's revenue—an exceptionally high fraction, even for the electronics industry. Almost all this research is concentrated on innovative technology, rather than "me-too" products. It is risky research, but not too risky: "What we have is far from a campus environment," Noyce said. "I have striven for a close coupling between the R&D we do and what the market calls for."

Being first at a new technology carries with it distinct advantages. The company's technological leadership—in both products and processes—lasts at most two years. But in those two years Intel has significant market advantages over the competition. An example was the product called erasable programmable read-only memories (EPROMs), which allow one to rewrite microprocessor programs by using ultraviolet light to change the contents of the program memory. This feature was quite expensive when Intel first brought it out in 1971, but nonetheless found a ready market.

Another advantage of being first is that, by the time competitors have their products ready, the company is already way down the learning curve and producing the component cheaply enough to earn high profit margins, even without a technological monopoly. It may also have come up with an improved version of the product. By the time everyone else has gotten down the learning curve, Intel is ready to pull out of a product that is now a low-margin, standard item, replacing it with a more cost-effective design.

Intel has also gained a reputation for tight financial control. The company aims for a major market share in each product it enters, and is prepared to chop unpromising lines early. Its growth since 1971 has been almost entirely self-financed.

To be sure, Intel has had its problems, too. It lost money in the digital watch business in 1975 and sold it off.

But, as one market analyst has said, "This company anticipates. Other companies react." And Forbes magazine has said of Intel: "In its brief history, Intel has called the turn again and again. Each decision has been vindicated by remarkable growth and profitability."

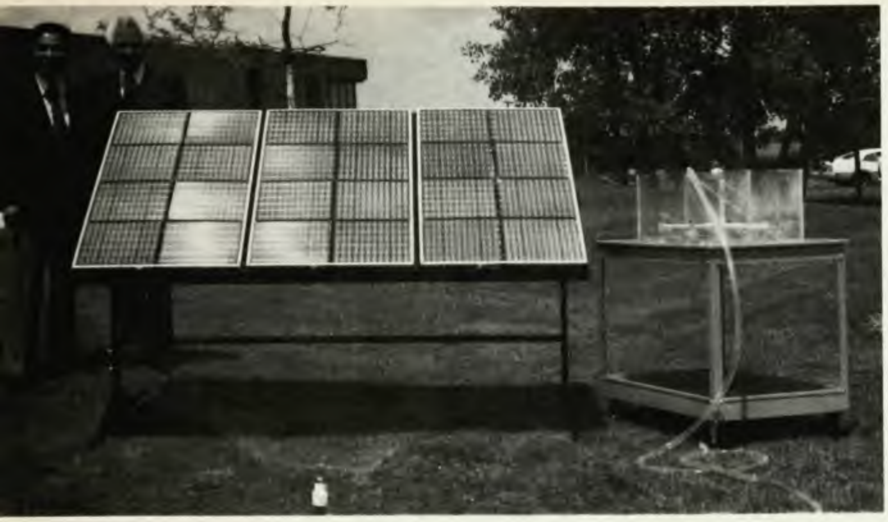
Another highly successful spin-off company, though it is rarely thought of as such today, is TRW. "We are a combination of hardware manufacturing and science and technology," says vice chairman Simon Ramo (the R in the company's name). TRW acquired its dual character when Thompson Products, a large Cleveland automobile- and airplane-parts manufacturer, decided that the company needed more technical sophistication. The company made an unsuccessful bid to buy Hughes Aircraft, where Ramo had built-up an almost unprecedented concentration of technical talent. Soon after, Hughes' top two scientist-executives, Simon Ramo and Dean Wooldridge, called Thompson Products saying that they were leaving Hughes to form their own company. Thompson Products agreed to help the two physicist-engineers, and after a period in which Thompson Products acted as a close financial backer, the two operations were merged in 1958 as Thompson-Ramo-Woolridge, later shortened to TRW.

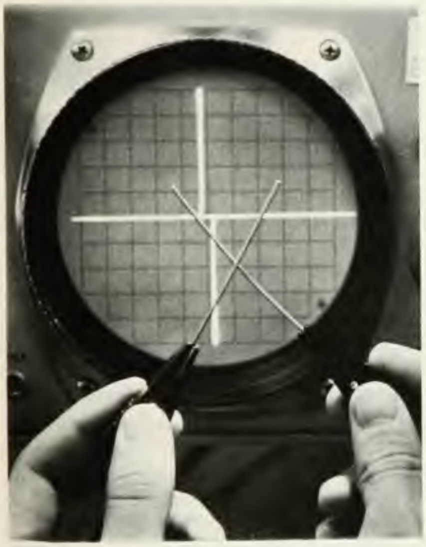
The company soon became, and still is, chief engineer and technical director for the US intercontinental ballistic missile program, and, among other things, has been one of the leading manufacturers of unmanned spacecraft.

The company's unique combination of manufacturing skills and high technology also permitted TRW to invade the data communications field. It now runs three established data businesses, including the first and largest national computerized credit service. TRW is also the largest independent manufacturer of electrical components.

Spinning off for fun and profit

The problem of developing technologies that they are unable to successfully exploit has been plaguing many large companies for several years. Sometimes the problem is that the technologies simply have no apparent commercial applications. But in other cases the problem is that the markets for the technologies are relatively small, greatly out of proportion to the size and method of operation of a large corporation. The huge overhead of major companies demands high-volume businesses. Unless a new technology shows clear signs of becoming something big, the managers responsible for it are reluctant to nurse it along while it drains money and managerial talent. Further, a large company often has to consider the antitrust implications of entering small markets which it would no doubt tend to dominate.





Stanford Ovshinsky (above, right) and a colleague in front of a demonstration of solar power; amorphous-silicon solar cells deliver power to a pump that drives a lawn sprinkler. The photo at left shows an early (1961) demonstration of switching in amorphous materials.

In the 1970s, General Electric figured out a way around complete loss of such technologies: spin them off into small businesses that would be partly owned by GE. From 1970 to 1976, ten such companies were set up under the direction of physicist David BenDaniel. "In the 1960s GE came up with a great deal of innovative technology in its physics and semiconductor laboratories," BenDaniel said. "GE was interested in businesses that could make $100 million in sales. These businesses were roughly $10-million businesses," BenDaniel says, "which any entrepreneur would be perfectly happy with." In addition, their association with GE was costing the small businesses a fair amount in corporate overhead, BenDaniel said.

A GE manager saddled with a money-losing business, or a scientist convinced that his research project was slated for cancellation, could bring his problems to BenDaniel, who determined whether the technology involved had the makings of a solid venture. In making that judgment, he applied several criteria.

First, the technology had to have what BenDaniel termed a "niche market"—that is, a segment of a market in which the technology had a competitive edge and could be used as an opening wedge for expansion into the entire market. Second, the technology had to be one in which GE was interested in maintaining a tie. He also looked for "committed champions" among GE's scientists and managers—men who believed in the businesses enough to invest their savings and risk their futures in it. With minor adaptations, BenDaniel says, these same criteria can and should be applied to any entrepreneurial venture.

BenDaniel turned down many more new venture proposals than he approved. For example, he rejected a proposal to spin off the integrated circuit business, which had been a poor performer in a highly competitive industry, because it had no particular niche and would have required more money than a small business venture could raise. Instead, GE liquidated this business, at an estimated loss of $300 000—about average for one of its "turned-off" technologies.

When BenDaniel approved a new venture, GE transferred to it the assets of the business, including the patents or a license to use the technology and equipment related to the venture, in exchange for which GE typically took about a one-third interest in the new business. The remaining two-thirds was split between the scientists and managers who helped launch the new company on the one hand, and outside investors on the other.

This three-pronged approach at financing the new ventures was based on BenDaniel's philosophy of entrepreneurial dynamics. Had the new venture been set up as a wholly-owned subsidiary of GE, the managers would still have been bogged down in the hierarchical reporting procedures required by large corporations. Even more important, by giving the new company's manager a direct ownership stake, GE supplied an incentive for performance that couldn't be equalled within a large corporation. The managers had to invest in the ventures themselves—"up to their necks," as BenDaniel put it—so that the penalty for failure was far greater than the mere loss of a job. Finally, BenDaniel saw the raising of outside capital as a sort of test of the manager's entrepreneurial mettle, in addition to the fact that such ventures generally required more financial backing than the entrepreneurs alone could give. And the whole capital-raising procedure subjected the venture to independent scrutiny by outside businessmen who were unlikely to have their judgment swayed by sentimental attachment to the technology.

There have been very few new spinoffs since BenDaniel left GE five years ago. "I think we just used up most of the spinoffable technology," he said.

Not all of the ten companies that BenDaniel helped set up are still in business. Although the reasons were different for each of the failures, BenDaniel did detect an element of commonality among those that survived, which is that the key management, though they may have been future-oriented, were not dreamers. "They were pragmatic about the future," he said. "They weren't fooling themselves. Their business plans were realistic and they didn't make promises they couldn't keep." Once an entrepreneur fails to achieve a self-imposed milestone, even an unrealistic one, BenDaniel says, he starts along a downward spiral that includes loss of self-confidence and loss of credibility with his backers.

One company that has had to pull itself out of such a downward spiral is Energy Conversion Devices, Inc., founded by Stanford and Iris Ovshinsky in 1960. In 1968, Stanford Ovshinsky created a storm in the electronics world when he announced the discovery of semiconducting properties in amorphous solids. Ovshinsky predicted that the new "Ovonic" materials would create hundreds of new electronic devices. The press conference he held in 1968 sent his company's stock

Fairchild Semiconductor, one of the early settlers in "Silicon Valley." The photo above shows Robert Noyce (at left) and Charles Sporck (next to Noyce) showing three visitors around the plant; the photo below shows Noyce (foreground) with the other founders of Fairchild.

zooming, and prompted charges of intentional exaggeration.

The revolution never came to pass, though amorphous semiconductors have been used in computers and imaging devices.

In 1977, Ovshinsky claimed he could have amorphous semiconductor devices producing solar electricity at a price competitive with conventional forms of electricity within three to five years. He is well on the way, with laboratory efficiencies of 7%. His work has sufficiently impressed two major oil companies, Atlantic Richfield and Standard Oil of Ohio, to prompt them to invest in his technology.

"When I look at a new venture," BenDaniel says, "I weigh the technology 10% and the business plan 15%. The remaining 75% is the people who are running it. The technologies can change in time, and business conditions may change and force the entrepreneurs to adopt a new business plan. "The question really is, 'are the people you are looking at sufficiently inventive, sufficiently adaptive, so that they can continuously concoct new improvements in the technology and new business plans that are appropriate to the present, as opposed to the past?' "

Put another way, BenDaniel says, "It doesn't take much to run a car. But if your car breaks down, then it requires a whole higher order of skill to fix it. Basically, a new venture is always breaking down in that sense."

A case in point is EG&G. The company had its beginnings at MIT during the depression, when Harold Edgerton, a professor there, formed a loose partnership with two of his students who were having trouble finding jobs, Herbert Grier and Kenneth Germeshausen. "We worked on insignificant little problems [like developing the stroboscope] and we had a little consulting money here and there," Edgerton says. "It was hardly enough to keep body and soul together." Edgerton recalls that one of the group's first paying jobs was for a soap company that needed a high-speed photograph taken to use as evidence in patent litigation it was involved in.

After World War II, the Atomic Energy Commission asked the triumvirate to continue work they had performedfor the Manhattan Project on detonating nuclear bombs and monitoring and measuring the results.

But in 1958, a moratorium was imposed on atmospheric testing, and many felt this would be the end of EG&G. "In fact," says Edgerton, "I sometimes think that was the best year we had, because that's when we started diversifying." It was their flexibility that kept Edgerton, Germeshausen and Grier in business. Today, EG&G has approximately 160 individual product areas.

David vs Goliath

On first thought, it may seem pure folly for a physicist to set up a company in a field dominated by one or several large corporations, with their greater resources and marketing capacities. How can he hope to compete? In point of fact, small corporations have several things going for them. For one thing, as BenDaniel pointed out, the small company has less overhead (and more control over its overhead) than the same operation would have as part of a large corporate structure. For another thing, high-technology markets, excluding government markets, often involve many customers of limited size, and so are better suited to the flexible, entrepreneurial companies. Also, small companies can often afford to offer products tailored to clients' requirements, thereby negating somewhat the economies of scale sought after by the larger companies.

To compete with the giant corporations, though, a small company has to approach problems on a different level. This is as true today as it was 35 years ago when Land discussed it: "It seems more important for a small company to approach its problems from the point of view of basic research than it does for a large company. The large company can afford to solve a problem in a way that is not the best way and to make up for its errors by investing more capital in machinery and in advertising. It is essential for the small company to pick one of the better and simpler ways of arriving at a new product if it is going to see it through manufacturing and marketing."

The laser field is a good example of how small and large companies can coexist in a given technological arena. Two relatively small companies, Spectra Physics and Coherent, have together conquered an impressive share of the market, even competing with a number of major companies, such as IBM, RCA, Bell Laboratories, Xerox, GTE, Hughes Aircraft, Honeywell and LTV, to name a few. Spectra and Coherent together have roughly one-fourth as much in sales as all of these companies put together. Some of these large corporations are recipients of military contracts and large-scale government research contracts. Others, like IBM, Xerox and Bell, are mostly manufacturing for in-house requirements.

Spectra Physics was started in 1961 by five people from Varian Associates. It is now a $130-million company with eight operating divisions. One of the earliest applications the company found for its products was in the construction industry, as leveling apparatus. Present uses are in medicine, spectroscopy and manufacturing.

Coherent, founded in 1966 by Spectra Physics alumni, introduced the carbon dioxide laser to the market. In 1980 the company chalked up $60 million in sales, ten times its 1970 sales figures.

James L. Hobart (foreground, far right) and his associates at Coherent, Inc., in 1966 with the first commercial CO_2 laser. (Photo courtesy Coherent.)

The best-laid plans

Even the best-laid plans of entrepreneurial physicists can sometimes go awry for reasons beyond the control of the owner, as, for example, in the case of Zoltan Kiss, who left RCA's laboratories in 1969 to start up his own venture in new technology. He had read up on the great successes and failures of similar endeavors and believed that small companies have certain inherent advantages over giants; he reasoned that he could beat out the large corporations by making decisions with dispatch and by using his resources more efficiently. He also felt confident that he could avoid the kinds of mistakes that had undone others—spending too much money, for example, or clinging to technologies that had no practical future. But what Kiss had not anticipated was the strength of the combined forces of domestic and foreign competitors.

Kiss quickly recruited three former RCA associates to help him establish Optel and a friend from Hewlett-Packard's Toronto branch to head marketing. The five started out in a bare building near Princeton—an area smaller than, but similar to, Route 128 near Boston or Silicon Valley, in that it is heavily populated by small electronics companies.

"Technically, we were very successful," Kiss recalls. "We really pioneered the development of the first manufacturable liquid crystal display. Then we actually developed the manufacturing process to produce the LCDs, and in 1972 we were the first to develop a digital watch with a liquid-crystal display." But Optel's first four years brought wrenching production problems, supply shortages, the threat of a potentially crippling lawsuit from its largest customer, a bitter boardroom split over its management and goals and only two profitable months. But by 1975 Optel had grown nicely to about $18 million in sales. Unfortunately, this was the time when most of the American, European and, especially, Far-Eastern companies decided that the digital watch business was such a large market that they wanted to get into it. So 1975 was the year when prices really started to collapse. Optel found that it needed additional capital to survive, but there was only one willing investor—the Japanese firm Mitsubishi. Mitsubishi insisted on bringing in its own management team, so Kiss resigned in 1976.

Kiss finds some poetic justice in noting that all of the American companies that helped bring the price of digital watches below the level at which Optel could compete have since been driven out of business by the Japanese producers, including the last one, Texas Instruments, just in the last year.

Kiss realizes that he is not the first entrepreneur to be driven out of business by largely foreign competition. He sees the same thing happening today in the home video industry. But he has developed what seems to be a successful strategy for survival: Always stay one step ahead of the competition.

After leaving Optel, Kiss started another company, Chronar. He vowed to stick to one basic rule: the operation would always be profitable on a daily, weekly, monthly, and yearly basis, even if growth suffered in the process. "I started Chronar five years ago with a $60 000 capitalization. We haven't grown very rapidly; we are presently doing about $2 million in annual sales. But it has been profitable from day one, and it is only this year that we went out and raised a small amount of money and are going public," Kiss said.

Chronar has two separate product lines. To generate a cash flow for the company, Kiss capitalized on his technical knowhow in the digital-watch and liquid-crystal-display fields; initially Chronar designed, built and marketed specialty watches. Five years ago, for example, it marketed a solar calculator watch. "At that time, nobody else had such a watch," Kiss recalls, "but within a year the Japanese had copied it and we moved on to other items." Since then, the company has moved out of the LCD watch business and into large-area liquid crystal displays, which promise advantages to a small company such as his. As a second product line, Chronar built up a component, equipment and technical-assistance business with foreign companies, setting up production facilities on a turnkey basis. The profits from these operations (on the order of $1 million) were invested into the research and development of thin-film photovoltaics.

By imaginatively using older technologies and simultaneously moving into new areas, the company is able to exist "on an edge-of-technology basis," says Kiss. "We are now at the point where we believe that we can put into production a process to make thin-film photovoltaic cells, and this is the reason we have decided to go public."

Another company that was, in a sense, "beat out" by the competition is Micro-Bit. This company was founded by three physicists from MIT's Lincoln Laboratory, Donald Smith, Kenneth

Advice to an entrepreneur

PHYSICS TODAY asked eight "experts" what advice they would give a physicist just starting a company today. Here is what they said:

Edwin Land: "Work only on problems that are manifestly important and seem to be nearly impossible to solve. That way, you will have a natural market for your product and no competition."

Harold Edgerton: "The first thing I look at when I tour a new corporate facility is the floor. If there are fancy rungs on the floor, I know that the company is not frugal enough and is bound to fail.

"Also, the entrepreneurs I know who have made it are mostly very persistent people, almost fanatics. They get the idea that something will work and you can't discourage them no matter what you show them from physics or chemistry or finance. I also know some who haven't made it who were just as persistent, so there is a lot to be said for knowing when you are wrong and when to get out."

David BenDaniel: "You should write a thorough business plan that shows at least the following: that your product is makeable and marketable, that the amount it costs to buy the necessary equipment and make the product with profit results in a price that is not out of line with what people will be willing to pay for it, and that the product has at least some set of customers who are willing to buy the product soon. The worst thing you can do is assume that because you like something, everyone else does, too."

Zoltan Kiss: "Slow down growth if you have to, but never get yourself behind the eight ball so that you don't have the money to meet next week's payroll."

Robert Noyce: "You have to be careful about developing a paranoia about losing control over your technology. The idea, though it is important, is only 10% of it; the other 90% is the execution of that idea. Some people have become so concerned about proprietary rights and such that they wouldn't even tell their backers what they wanted to do, or they would demand 51% interest in their company in order to retain control. I think this is often a mistake."

Walter LeCroy: "Good associates, some good ideas, and a lot of stubbornness—as far as I can see, that's the formula, if there is one. Business expertise, or access to it, is important, but commitment to the technology, the product and the customer is the central thing, not exotic financial wizardry."

Stanford Ovshinsky: "When you go off on your own in an area that is very new, the only advice I can give is that you better be right. Someone once said that you can recognize a pioneer by the arrows in his back."

Franklin Johnson: "From a venture-capitalist standpoint, I would say that scientists in general are better candidates for venture capital than MBAs, but I think it is a good idea for a physicist-entrepreneur to associate himself with a bright person trained in business. Also, I think successful entrepreneurs have to have certain personal qualities, which include a strong desire to succeed (or an unwillingness to lose) and a high degree of practicality."

Harte and Mitchell Cohen, physicist Dennis Speliotis from the University of Minnesota, and Sterling Newberry, an electron optician from General Electric. The five tried to perfect electron-beam memories for computers. "We did a lot of technical work that was first-class," Smith says, "but in terms of the business world, we have not produced a highly profitable item." In 1978 Micro-Bit was taken over by Control Data Corporation, and last year the work on electron-beam memories was shelved. The company is now working on developing electron-beam lithography techniques for computer memories and logic circuits.

Smith analyzes his company's limited success this way: "The product that we had in mind was not sufficiently modular; we had to develop a 'supermemory' all at once. The thing that really made the semiconductor memories such formidable competition was that they could come in with tiny memories that didn't cost very much." In other words, the semiconductor memories were developed in stages, and each stage was marketable, so that Micro-Bit's competition had a constant flow of income with which to pay for further research. "On the other hand, we had to come in with a technological *tour de force*, or we had nothing," says Smith.

The future of enterprise

The rise of the physicist as an entrepreneur over the last 50 years has changed the whole character of physics and physicists. "Fifty years ago," BenDaniel says, "physicists were considered almost as impractical as poets." A physicist in the business world seemed somehow out of place. But all that has changed. Today, physicists are recognized as being at the heart of the technical-economic framework in which we live.

And this is something of a self-fulfilling prophecy. More and more, students are choosing to go into physics with the intention of someday starting their own businesses. As physics has gained an accepted place in the business world, students who in other decades might have gone into business or engineering, are now going into physics. This has helped bring a different character of individual into physics, reinforcing the new image of physicists as businessmen. □