The Takeover Wave of the 1980s

ANDREI SHLEIFER AND ROBERT W. VISHNY

The takeover wave of the 1980s moved large enterprises toward specialization and away from the diversification of the 1960s. The easy availability of funds made acquisitions affordable, while the hands-off antitrust policy allowed mergers between two firms in the same industry. Hostile takeovers and leveraged buyouts fostered the break up of conglomerates and the sell-off of divisions to buyers in the same industry; they helped speed the economy-wide move toward specialization. The poor performance of conglomerates indicates that this trend toward specialization is likely to make U.S. industry more competitive. Current state antitakeover laws are probably the result of intense lobbying by managers trying to entrench themselves; these laws do not promote competitiveness of U.S. industry. In contrast, the current accommodating federal antitrust stance encourages specialization.

TAKEOVERS DRAMATICALLY ALTERED THE U.S. ECONOMY IN the 1980s. The total value of assets changing hands in this period was $1.3 trillion. Of the 500 largest industrial corporations in the United States in 1980 (Fortune 500), at least 143 or 28% had been acquired by 1989. The majority of takeovers have been friendly, carried out with the consent of the management of the target firm. But in many other so-called "hostile" takeovers, the target firm's management fought the bid. The period also saw the rise of management buyouts, in which managers used borrowed funds to buy the company they run.

Hostile takeovers and management buyouts have sparked enormous public controversy as well as calls for and enactment of antitakeover laws. Takeovers are blamed for layoffs, decimation of communities, cuts in investment and R&D, short horizons of U.S. managers, increased instability resulting from higher debt, as well as the decline of U.S. competitiveness. Many new state laws all but ban hostile takeovers, and Congress periodically considers federal antitakeover legislation. In 1988, a presidential candidate promised that his Justice Department would block mergers between large firms in the same industry to protect consumers from monopoly.

In this article, we summarize what we and others have learned about the 1980s takeover wave. The evidence suggests that takeovers in the 1980s represent a comeback to specialized, focused firms after years of diversification. In the 1980s, most acquirers bought other firms in their own lines of business. In addition, many diversified firms (conglomerates) were taken over, and their various business lines were sold off to different buyers in the same line of business. To a significant extent, takeovers in the 1980s reflect the deconglomeration of American business. Hostile takeovers and leveraged buyouts, which have attracted much public scrutiny, facilitated this process of deconglomeration. We show below that some of the common objections to takeovers, such as reduction of competition, cuts in employment, investment, and R&D, are not supported by the data. Although there is no evidence on the long-run post takeover performance of the 1980s acquisitions, the past failures of conglomerates suggest that performance is likely to improve.

We begin with a historical perspective on the 1980s takeover wave, then address some common concerns about takeovers, and finally discuss public policy.

Takeovers in the 1980s in Historical Perspective

There have been four takeover waves in the 20th century. The largest of them occurred around the turn of the century. The Sherman Antitrust Act of 1890 precluded collusive agreements between firms but allowed the creation of near monopolies with 50 to 90% market shares. In response to this law and with the help of new stock issues during the booming market, many industries merged into near monopolies overnight (*1*). The U.S. Steel Corporation was formed in this period and controlled 65% of steel-making capacity. American Tobacco had a 90% market share. (However, General Motors could not find financing to buy Ford for $3 million!) The wave ended in 1904 when the Northern Securities decision of the Supreme Court greatly expanded the interpretation of the Sherman act. Congress firmed up this case law by prohibiting monopolization through merger in the Clayton Antitrust Act of 1914.

The second merger wave came in the late 1920s, again coincident with a buoyant stock market receptive to new securities issued to finance the takeovers. As in the first wave, most deals were mergers of firms in the same industry. Now the courts did not allow monopoly, but still permitted formation of oligopolies—concentrated industries dominated by a few firms. Allied Chemical and Bethlehem Steel are products of this wave. This merger wave was stopped by the Great Depression and the collapse of the stock market, rather than by regulation.

The third wave is the conglomerate mergers of the late 1960s. Like the previous waves, it came during a stock market boom, which enabled buyers whom the stock market rewarded with high price/earnings ratios to finance their acquisitions with equity at attractive terms. Unlike those in the previous merger waves, a typical 1960s merger brought together two firms from completely different industries, leading to the formation of the so-called conglomerates. ITT and Teledyne are famous products of this era. The most likely reason for diversification was the antitrust policy which turned fiercely against mergers between firms in the same industry when

The authors are professors of finance at the University of Chicago Graduate School of Business, Chicago, IL 60637.

the Celler-Kefauver Act passed in 1950. Unable to acquire businesses related to their own, flush with cash, and facing a favorable market for equity issues, acquirers bought companies outside their industries.

At the time conglomerates were formed, several theories were advanced to explain how they would improve the efficiency of U.S. businesses. One idea was that control of businesses changed from self-taught, unsophisticated entrepreneurs who started their own firms to experienced professional managers of conglomerates. Another idea was that conglomerates were an efficient way to monitor individual businesses by subjecting them to regular quantitative evaluations by the central office. Perhaps the most widely accepted rationale for conglomerates was the view that the central office reallocated investment funds from slowly growing subsidiaries, which generated cash, such as insurance and finance, to fast growing high technology businesses, which required investment funds. In this way, each conglomerate created an internal capital market, which could allocate investment funds more cheaply and efficiently than the banks or the stock and the bond markets.

The alleged superior efficiency of conglomerates is probably not what drove their creation. As in all other waves, it was more likely the case that firms wanted to grow and had access to cheap internal and external funds. But they could not continue to grow in their own lines of business because of aggressive antitrust enforcement. As a second best alternative from the point of view of growth-oriented managers, firms diversified. From the point of view of the shareholders, it might well have been best just to pay out the 1960s profits as dividends.

Recent evidence shows that conglomerate acquisitions typically failed. Although the buyers paid a premium to acquire the businesses, earnings of these businesses did not rise when they were acquired by conglomerates. In fact, some studies find that their earnings performance deteriorated (*2*). Equally telling are the massive divestitures of assets acquired by conglomerates during the 1960s and 1970s. According to one estimate, 60% of the unrelated acquisitions taking place between 1970 and 1982 had been divested by 1989 (*3*).

Why have conglomerates failed, despite all the efficiency arguments advanced in their favor? Perhaps the most important reason is that conglomerate builders ignored Adam Smith's principle that specialization raises productivity. In conglomerates, managers running central offices often knew little about the operations of the subsidiaries and could not allocate funds nearly as well as experts could. Nor could they rely on the managers of the subsidiaries to give them honest and accurate information, since each manager lobbied for his own business, and had little incentive to give up resources for the benefit of the other parts of the conglomerate. As a result, the crucial business decisions were made by nonspecialists with only limited information who had to divide their attention and resources between multiple businesses. Some divisions were neglected; others were probably overfed. For example, the Eveready battery division of Kraft is alleged to have been ignored as cheese took priority, and the cosmetics business of Revlon suffered as the company dedicated its scarce capital to expanding its health care subsidiaries. In addition, conglomerates lost many divisional top managers, who left to run their own shows at smaller specialized firms. The inefficiency of decision-making by nonspecialists offset the potential benefits of conglomerates.

In their attempt to monitor the divisions, conglomerates developed large and expensive central offices. But these central office controls often proved much less effective than the market discipline that stand-alone businesses are subjected to. Such businesses face competition in product markets, competition for capital in capital markets, and managerial competition. To a large extent, divisions of conglomerates are insulated from these forces, because they can afford to lose money and can be subsidized by other divisions, do not have to raise external capital, and face weaker managerial competition. In some respects, conglomerates resembled state ministries in centrally planned economies, where centralized control and transfer pricing replaced market forces. As this happened, many divisions of conglomerates became weaker competitors and often performed very poorly—as measured by low earnings and the high rate of divestitures. Below we argue that the takeover wave of the 1980s was to a large extent a response to the disappointment with conglomerates.

As did all merger waves, the 1980s saw rising stock prices and rising corporate cash reserves stimulating the usual demand for expansion through acquisitions. However, in the 1980s the Reagan Administration consciously eased up on antitrust enforcement in an effort to leave the market alone. As a consequence, intraindustry acquisitions became possible on a large scale for the first time in 30 years. The easy availability of internal and external funds for investment coupled with the negative experience with the diversification of the 1960s and the first laissez-faire antitrust policy in decades shaped the takeover wave of the 1980s.

The return to expansion in core businesses is evident in the prevalence of two types of deals in the 1980s. In the first type, a large firm with most of its assets in a particular industry bought another large firm in the same industry. Some peripheral businesses were divested, but most of the acquired assets were kept. Such deals were common in gas pipelines, food, banking, airlines, and oil. In the second type of deal, a "bustup," the acquired firm was typically a conglomerate. Placing its assets in specialists' hands required a sale of many divisions to separate buyers. Our data indicate that in 62 hostile takeover contests between 1984 and 1986, 30% of the assets were on average sold off within 3 years (*4*). In 17 cases more than half the assets were sold. Roughly 70% of the selloffs were to buyers in the same line of business.

In the face of the hostile pressure to divest, some managers realized that they themselves could profit from bustups, by taking the company private and then selling peripheral business to specialized acquirers. This realization explains a significant number of leveraged buyouts of the 1980s followed by large-scale divestitures. For leveraged buyouts in our 1984 to 1986 sample, selloffs are even higher than for takeovers as a whole, amounting to 44% of total assets.

In the 1980s takeover wave, the so-called "corporate raiders" and many leveraged buyout (LBO) specialists played the critical role of brokers. They acquired conglomerates, busted them up, and sold off most business segments to large corporations in the same businesses. Michael Jensen has argued that takeovers by raiders and by leveraged buyout funds move us toward a new incentive-infused organizational form that will permanently deliver shareholders from the wasteful ways of public corporations (*5*). The evidence does not support his view. First, most takeovers do not involve raiders or LBO funds. Second, many raider and LBO-controlled firms are temporary organizations designed to last only as long as it takes to sell off the pieces of the acquired firm to other public corporations. The remaining pieces are often reoffered to the public, especially when their value has been enhanced by some operating changes.

A takeover that illustrates some of the features of the 1980s wave is the acquisition of cosmetics giant Revlon by the raider Ronald Perelman. This fiercely hostile takeover took place in 1985, at the price of $2.3 billion. Before the takeover, Revlon acquired many businesses outside cosmetics, particularly in health care. The top management of Revlon thought that health care offered better growth opportunities than cosmetics, and so reduced the investment

and advertising budget of cosmetics to support the growth of the health care business. After the takeover, Perelman sold off $2.06 billion of Revlon's health care and other noncosmetics businesses. Perelman had an offer to sell the cosmetics business for $905 million (which, combined with $2.06 billion, shows how profitable this bustup was), but turned it down. About 60% of asset selloffs were to other companies in the health care field, but some were to management buyout groups. After the selloffs, Revlon substantially revamped the cosmetics business and tripled its advertising budget. ("Some of the most beautiful women in the world wear Revlon.") Headquarters staff was also reduced, although there is no evidence of blue-collar layoffs or of investment cuts. Revlon's profits increased substantially.

Table 1 summarizes more systematically the eventual allocation of assets induced by the hostile takeovers of 1984 to 1986. Combining direct acquisition of related assets with acquisitions of divested assets, we find that 72% of all assets that changed hands as a result of hostile takeovers were sold to public corporations in closely related businesses within 3 years. Only 15% of the assets ended up in private firms, such as those formed when management and leveraged buyout specialists take divisions private (MBOs). And only 4.5% of the assets was bought by public corporations acquiring outside of their core businesses. This last number clearly illustrates the move away from conglomerates.

Has deconglomeration and expansion in core businesses raised efficiency and U.S. competitiveness? Some economists have taken the increase in stock prices of the acquired firms—which is not nearly offset by the modest stock price declines of acquiring firms—to be by itself incontrovertible evidence that efficiency must have improved. We do not take this position, since much evidence shows that the stock market can make large valuation mistakes (*6*). The possibility that the stock market is overly enthusiastic about the takeovers of the 1980s should not be dismissed. After all, the market greeted the conglomerate mergers of the 1960s with share price increases, and most of these mergers failed. Nonetheless, there are reasons to expect the takeovers of the 1980s to raise long-term efficiency.

The fact that many takeovers dismantle conglomerates and allocate divisions to specialists creates a presumption that performance should improve. There is, in fact, evidence that divisions are more productive when they are part of less diversified companies, although this evidence does not establish the link specifically for divested divisions (*7*). There is also evidence that acquired firms are less profitable than the firms buying them (*8*). This suggests that more assets in an industry are being allocated to the organizations that can better manage them. Overall, the evidence recommends cautious optimism about the efficiency of takeovers in the 1980s.

Some Objections to Takeovers

The takeover wave of the 1980s aroused much public concern about reduced competition, employment cuts, and reductions in investment, especially in research and development. These concerns are largely unsupported by the data.

Since most of the mergers in the 1980s have been between firms that compete in product markets, the obvious question is whether these takeovers decrease competition and lead to price increases. After all, mergers from the first two waves of this century had the explicit goal of raising prices. Some takeovers in the 1980s could potentially reduce competition and raise prices, particularly among airlines, gas pipelines, and supermarkets where markets are regional rather than national, and so, easier to dominate. However, gaining significant market power through takeovers in the 1980s seems to be the exception rather than the rule. First, in most cases the market share of the combined companies remains too small for effective market dominance: much smaller than that of 1920s oligopolies let alone the turn of the century trusts. Second, the share price behavior of nonmerging firms in the industry suggests that large profits from decreased competition are not the driving force behind most mergers. Oligopoly theory predicts that when an anticompetitive merger takes place, all firms in the industry should experience a rise in their profits and share prices since they all benefit from industry price increases. Conversely, when an anticompetitive merger is blocked by the antitrust authorities the share prices of all firms in the industry should decline along with those of the merging firms. The evidence, in contrast, shows that share prices of most nonmerging firms in an industry actually rise when a merger is challenged, inconsistent with the importance of decreased competition (*9*). While the evidence is not conclusive, decreased competition and higher consumer prices from takeovers are probably not important in the 1980s.

Table 1. The movement of assets, 1984 to 1986.

Type of asset	Millions of dollars	Percent
Assets that changed hands	68,743	100
Assets that went to strategic buyers	49,660	72
Strategic acquisitions net of selloffs	26,010	38
Selloffs to strategic buyers	23,650	34
Assets that went to MBOs	10,234	15
Direct MBOs net of selloffs	4,834	7
Selloffs to MBOs	5,400	8
Assets that stayed with initial nonstrategic bidders	3,810	5.5
Assets that went to unrelated acquisitions	3,154	4.5
Direct unrelated bidders	373	0.5
Selloffs to unrelated bidders	2,781	4
Selloffs of headquarters, stocks	667	1
Not identified selloffs	1,219	2
Assets that did not change hands (nondivested assets of targets remaining independent)	39,716	
Total value of offers in the sample	108,459	

The second major concern is the effect of hostile takeovers on employment. It has been argued that hostile takeovers represent a breach of employees' trust and transfer wealth from employees to shareholders through wage reductions and employment cuts (*10*). Recent research sheds substantial light on this issue. First, except in isolated episodes, there is no evidence of substantial wage cuts following hostile takeovers (*11*). Second, removal of excess pension assets from pension plans does accelerate after takeovers, which probably means a reduction in expected pensions. On average, however, these removals are small (*12*). Third, layoffs rise after hostile takeovers. Among the 62 targets of hostile takeovers between 1984 and 1986, the total post takeover layoffs were about 26,000 people, which amounts to about 2.5% of the labor force of an average target firm. These layoffs are noticeable for the target firm, but small in the context of the national economy. By comparison, General Electric cut its work force by over 100,000 between 1981 and 1987.

Post takeover layoffs are disproportionately targeted at high-level white collar workers as hostile takeovers lead to reduction of headquarters employment, consolidation of headquarters, and other corporate staff reductions (*4*). When incumbent managers are reluctant to lay off redundant headquarters employees without external pressure, hostile acquirers do the dirty job for them. It is hard to worry too much about these layoffs, since unemployment among educated white collar workers barely exists in the United States.

In sum, transfers from employees clearly do take place after hostile takeovers, but their magnitude is small relative to the wealth gains of the shareholders.

Perhaps the greatest public concern about takeovers is that they reduce investment in physical capital and particularly in R&D. Insufficient investment in physical capital and in R&D is often held responsible for declining U.S. competitiveness, as outdated products come out of outdated plants. An opposing view holds that the trouble with U.S. industry is excessive investment in businesses and technologies that should rationally be abandoned to lower cost foreign rivals (*13*). Such investment only sucks up capital from high-tech industries and high-tech manufacturing where the United States should take the lead. This view makes investment cuts in basic industries a primary source of post takeover efficiency gains. Takeovers are needed because managers in declining industries are reluctant to shrink operations and distribute cash to shareholders.

Investment cuts that follow hostile takeovers have been large in some basic industries, especially the oil industry, where exploration was arguably excessive in the early and mid-1980s. One can also point to sporadic examples of investment cuts in other industries. On the other hand, our own evidence on hostile takeovers 1984 to 1986 suggests that investment cuts are neither the reason for, nor an important consequence of, most hostile takeovers. Of the 62 takeover contests that we study, investment cuts play a central role in at most 12 cases.

Investment is more often reduced after highly leveraged acquisitions, such as leveraged buyouts. In the struggle to meet interest payments after a buyout, good projects as well as bad ones may be abandoned. But these deals represent at most 15 to 20% of the takeover activity during this period (*14*). Not having yet seen a post takeover recession, it is difficult to evaluate the difficulties that these highly leveraged deals will experience. It is important to notice, however, that selloffs usually enable firms to pay off a substantial share of their debt within a few years. In fact, many debt contracts have provisions requiring firms to sell off assets and reduce the debt. On the whole, with the exception of highly leveraged acquisitions there is not much evidence that takeovers result in large capital spending cuts.

With respect to R&D cuts, the evidence is clear. Targets of takeovers are not R&D-intensive companies (*15*). On the contrary, they tend to be companies in mature, capital-intensive industries that are performing poorly and are not at the cutting edge of technology. Because takeover targets do little R&D to begin with, there are no noticeable R&D cuts after takeovers. It is a mistake to believe that R&D cuts are an important motive for or even an important consequence of takeovers.

The concern over debt and over R&D and investment cuts are part of the broader concern, which does not pertain to takeovers alone, that managers of U.S. corporations have short horizons. This concern has been expressed in particular in an influential MIT study, which argues that the economy of the United States is losing its competitiveness because the pressures of debt and of financial markets prevent managers from undertaking long-term projects (*16*).

Although there may be important differences between the United States and Japan in terms of planning horizon and willingness to invest, these differences are only marginally affected by takeovers. The differences appear to run much deeper. Part of the difference may stem from higher savings rates in Japan and more bullish stock market investors, and the rest may be due to a relatively greater emphasis by Japanese managers on growth and market share than on profitability. Takeovers are a minor factor by comparison to these considerations.

In sum, the evidence suggests that the three common concerns about hostile takeovers are exaggerated. The fact that takeovers of the 1980s have helped move assets out of conglomerates and toward more specialized users creates a presumption in their favor.

Public Policy Toward Takeovers

Public policy toward takeovers has taken several forms, including antitrust enforcement, state antitakeover legislation, and changes in tax policy particularly with respect to tax deductibility of interest payments on debt. We consider these policies briefly.

Federal antitrust policy has been quite important for takeovers. The hands off policy in the 1980s permitted the wave of related acquisitions. In a few cases, such as airlines, enforcement should probably have been tighter. However, a return to the antitrust stringency of the 1950s and 1960s, where an acquisition that raised a firm's market share from 5 to 7% could be disallowed, would be a mistake. The failed conglomerate wave was a direct consequence of this policy. In many cases, it might well be best if the firm did not make any acquisitions at all, and simply returned its excess earnings to shareholders. But as long as corporations are committed to survival and growth, and so continue to make acquisitions, the bias toward diversification induced by aggressive antitrust is damaging. For this reason, we would like to see antitrust policy remain largely as it is.

Much more damaging interventions are currently coming from state antitakeover laws, which aim to completely stop hostile takeovers. The usual justification of such laws is that, first, they enable managers to focus on the long term without the pressure of takeovers and, second, they prevent large-scale layoffs. These arguments, although theoretically appealing, do not have a large amount of empirical support; there is certainly little support for the view that large cuts in employment take place. The real reason for the state laws probably has little to do with these two arguments. Rather, these laws reflect the desire of target firms' managers to keep their jobs and their ability to influence legislators. The politics of the state laws are simple: managers and employees are voters as well as contributors, whereas shareholders typically reside out of state and are therefore neither.

State antitakeover laws entrench managers and allow conglomerates to survive. The best alternative to these laws is probably a federal law that subsumes them.

Last, tax policy has had a large effect on takeovers. Of the tax provisions that subsidize takeovers, the most important is tax deductibility of interest payments. If a company pays out $1 of its profit as interest, it can reduce its corporate profits tax base, whereas if it pays out the same $1 as dividends, it cannot have the deduction. This asymmetry allows firms to raise their values through increased use of debt. In this way, tax law subsidizes debt-financed acquisitions.

The extent of this subsidy is not as great as one might think, for several reasons. First, the target firm can itself borrow and buy back its own shares and so keep the gains from increased debt from accruing to the acquirer. Presumably, the acquiring firm can only profit to the extent that it can tolerate more debt, perhaps because it can cut some of the spending or divest divisions. Second, much of the debt is temporary, which greatly limits the value of the tax shield. As we pointed out earlier, divestitures usually lead to rapid reductions in debt.

Despite these limits on the value of the debt subsidy, there is no reason to subsidize debt at all. Accordingly, a limitation on tax deductibility of interest, or alternatively making dividend payments tax deductible as well, would reduce the distortion. An increase in the basic tax rate on corporate profits could keep the latter reform from increasing the budget deficit.

Conclusion

The takeovers of the 1980s, like those of the previous merger waves, partly reflect the desired expansion of large corporations in times of easy access to funds. With the current antitrust stance, this expansion has taken place within the areas of expertise of the acquiring firms and has made corporations more focused. Although the jury is still out on this takeover wave, the disappointing experience with conglomerates suggests that these takeovers are likely to raise efficiency as corporations realize the gains from specialization.

REFERENCES AND NOTES

1. G. S. Stigler, *Am. Econ. Rev.* **40**, 23 (1950).
2. D. C. Mueller's "The Effects of Conglomerate Mergers" [*J. Bank. Financ.* **1**, 315 (1977)] is a survey of these studies. D. J. Ravenscraft and F. M. Scherer's *Mergers, Sell-Offs, and Economic Efficiency* (Brookings Institution, Washington, DC, 1987) is the most recent and detailed study.
3. S. N. Kaplan and M. Weisbach, "Acquisitions and Divestitures: What Is Divested and How Much Does the Market Anticipate?" University of Chicago, mimeo, 1990.
4. S. Bhagat, A. Shleifer, R. W. Vishny, "Hostile Takeovers in the 1980s: The Return to Corporate Specialization," *Brookings Pap. Econ. Act. Microecon.* (1990), p. 1.
5. M. C. Jensen, *Har. Bus. Rev.* **67**, 61 (1989).
6. For a review of this evidence, see A. Shleifer and L. H. Summers, "The Noise Trader Approach to Finance" [*J. Econ. Perspect.* **4**, 19 (1990)].
7. F. R. Lichtenberg, "Industrial De-Diversification and Its Consequences for Productivity," Columbia University, manuscript, 1990.
8. H. Servaes, "Tobin's Q, Agency Costs, and Corporate Control," University of Chicago, mimeo, 1989.
9. R. Stillman, *J. Finan. Econ.* **11**, 225 (1983).
10. A. Shleifer and L. H. Summers, "Breach of Trust in Hostile Takeovers," in *Corporate Takeovers: Causes and Consequences*, A. J. Auerbach, Ed. (Univ. of Chicago Press, Chicago, 1988), pp. 33–68.
11. J. Rosett, "Do Union Wealth Concessions Explain Takeover Premiums? The Evidence on Contract Wages" (NBER Working Paper 3187, National Bureau of Economic Research, Cambridge, MA, November, 1989).
12. J. Pontiff, A. Shleifer, M. Weisbach, "Excess Pension Fund Reversions After Takeovers," University of Rochester, mimeo, 1989.
13. M. C. Jensen, *Am. Econ. Rev.* **76**, 323 (1986).
14. S. N. Kaplan, "The Effects of Management Buyouts on Operating Performance and Value," *J. Finan. Econ.* **24**, 217 (1989).
15. B. H. Hall, "The Impact of Corporate Restructuring on Industrial Research and Development," *Brookings Pap. Econ. Act. Microecon.*, p. 85 (1990).
16. M. L. Dertouzos, R. K. Lester, R. M. Solow, *Made in America* (MIT Press, Cambridge, MA, 1989).

Optical Matter: Crystallization and Binding in Intense Optical Fields

MICHAEL M. BURNS, JEAN-MARC FOURNIER, JENE A. GOLOVCHENKO

Properly fashioned electromagnetic fields coupled to microscopic dielectric objects can be used to create arrays of extended crystalline and noncrystalline structures. Organization can be achieved in two ways: In the first, dielectric matter is transported in direct response to the externally applied standing wave optical fields. In the second, the external optical fields induce interactions between dielectric objects that can also result in the creation of complex structures. In either case, these new ordered structures, whose existence depends on the presence of both light and polarizable matter, are referred to as *optical matter.*

EFFORTS TO ORGANIZE MATTER ON MICROSCOPIC SCALES are playing an increasingly important role in scientific and technological endeavors. Examples are the fabrication of electronic circuits, optical elements, and mechanical machines, as well as the synthesis and modification of the macromolecules central to modern chemistry and biology. At the submicroscopic scale there is an extraordinarily high degree of order in matter due to the natural proclivity of atoms to organize themselves into molecules and extended structures by electron bonding. Here we present a description and demonstration of methods of effecting the organization of matter on length scales characteristic of the wavelength of light, still microscopic but thousands of times the typical separation of atoms. This is accomplished by causing intense light beams to interact with matter under controlled conditions. In contrast to photographic and photolithographic methods which rely on slow chemical transformations, we are here concerned with the rapid organization, manipulation, and transport of matter directly with light.

Our work has been stimulated in part by the increase in understanding that has recently been achieved in the study of laser-induced forces on microscopic matter, and in part by the desire to manipulate and organize matter at length scales comparable with the wavelength of light. It hardly seems necessary to justify interest in this regime of distances today for researchers in disciplines ranging from modern biology to microelectronics and optics. We note however that 50 years ago Land (*1*) faced and solved the problem of orienting microscopic crystals in a lacquer to create the first artificial optical polarizers through various electro- and magneto-static, as well as mechanical forces. In a sense, the following article represents a continuation of that program although at a higher level of spatial organization and by new methods made available through laser technology.

Ashkin and co-workers have carried out pioneering experiments in the area of optical forces on small dielectric objects (*2–4*). These results on optical levitation, optical trapping, and material transport

M. M. Burns and J.-M. Fournier are at the Rowland Institute for Science, Cambridge, MA 02142. J. A. Golovchenko is at Harvard University, Cambridge, MA 02138, and the Rowland Institute.