CHAPTER I. CULTURAL PREPARATION

1: Machines, Utilities, and "The Machine"

During the last century the automatic or semi-automatic machine has come to occupy a large place in our daily routine; and we have tended to attribute to the physical instrument itself the whole complex of habits and methods that created it and accompanied it. Almost every discussion of technology from Marx onward has tended to overemphasize the part played by the more mobile and active parts of our industrial equipment, and has slighted other equally critical elements in our technical heritage.

What is a machine? Apart from the simple machines of classic mechanics, the inclined plane, the pulley, and so forth, the subject remains a confused one. Many of the writers who have discussed the machine age have treated the machine as if it were a very recent phenomenon, and as if the technology of handicraft had employed only tools to transform the environment. These preconceptions are baseless. For the last three thousand years, at least, machines have been an essential part of our older technical heritage. Reuleaux's definition of a machine has remained a classic: "A machine is a combination of resistant bodies so arranged that by their means the mechanical forces of nature can be compelled to do work accompanied by certain determinant motions"; but it does not take us very far. Its place is due to his importance as the first great morphologist of machines, for it leaves out the large class of machines operated by man-power.

Machines have developed out of a complex of non-organic agents for converting energy, for performing work, for enlarging the mechanical or sensory capacities of the human body, or for reducing to a mensurable order and regularity the processes of life. The automaton is the last step in a process that began with the use of one part or another of the human body as a tool. In back of the development of tools and machines lies the attempt to modify the environment in such a way as to fortify and sustain the human organism: the effort is either to extend the powers of the otherwise unarmed organism, or to manufacture outside of the body a set of conditions more favorable toward maintaining its equilibrium and ensuring its survival. Instead of a physiological adaptation to the cold, like the growth of hair or the habit of hibernation, there is an environmental adaptation, such as that made possible by the use of clothes and the erection of shelters.

The essential distinction between a machine and a tool lies in the degree of independence in the operation from the skill and motive power of the operator: the tool lends itself to manipulation, the machine to automatic action. The degree of complexity is unimportant: for, using the tool, the human hand and eye perform complicated actions which are the equivalent, in function, of a well developed machine; while, on the other hand, there are highly effective machines, like the drop hammer, which do very simple tasks, with the aid of a relatively simple mechanism. The difference between tools and machines lies primarily in the degree of automatism they have reached: the skilled tool-user becomes more accurate and more automatic, in short, more mechanical, as his originally voluntary motions settle down into reflexes, and on the other hand, even in the most completely automatic machine, there must intervene somewhere, at the beginning and the end of the process, first in the original design, and finally in the ability to overcome defects and to make repairs, the conscious participation of a human agent.

Moreover, between the tool and the machine there stands another class of objects, the machine-tool: here, in the lathe or the drill, one has the accuracy of the finest machine coupled with the skilled attendance of the workman. When one adds to this mechanical complex an external source of power, the line of division becomes even more difficult to establish. In general, the machine emphasizes specializa-

tion of function, whereas the tool indicates flexibility: a planing machine performs only one operation, whereas a knife can be used to smooth wood, to carve it, to split it, or to pry open a lock, or to drive in a screw. The automatic machine, then, is a very specialized kind of adaptation; it involves the notion of an external source of power, a more or less complicated inter-relation of parts, and a limited kind of activity. From the beginning the machine was a sort of minor organism, designed to perform a single set of functions.

Along with these dynamic elements in technology there is another set, more static in character, but equally important in function. While the growth of machines is the most patent technical fact of the last thousand years, the machine, in the form of the fire-drill or the potter's wheel, has been in existence since at least neolithic times. During the earlier period, some of the most effective adaptations of the environment came, not from the invention of machines, but from the equally admirable invention of utensils, apparatus, and utilities. The basket and the pot stand for the first, the dye vat and the brick-kiln stand for the second, and reservoirs and aqueducts and roads and buildings belong to the third class. The modern period has finally given us the power utility, like the railroad track or the electric transmission line, which functions only through the operation of power machinery. While tools and machines transform the environment by changing the shape and location of objects, utensils and apparatus have been used to effect equally necessary chemical transformations. Tanning, brewing, distilling, dyeing have been as important in man's technical development as smithing or weaving. But most of these processes remained in their traditional state till the middle of the nineteenth century, and it is only since then that they have been influenced in any large degree by the same set of scientific forces and human interests that were developing the modern power-machine.

In the series of objects from utensils to utilities there is the same relation between the workman and the process that one notes in the series between tools and automatic machines: differences in the degree of specialization, the degree of impersonality. But since people's attention is directed most easily to the noisier and more

have been influenced in any large degree by the same

active parts of the environment, the rôle of the utility and the apparatus has been neglected in most discussions of the machine, or, what is almost as bad, these technical instruments have all been clumsily grouped as machines. The point to remember is that both have played an enormous part in the development of the modern environment; and at no stage in history can the two means of adaptation be split apart. Every technological complex includes both: not least our modern one.

When I use the word machines hereafter I shall refer to specific objects like the printing press or the power loom. When I use the term "the machine" I shall employ it as a shorthand reference to the entire technological complex. This will embrace the knowledge and skills and arts derived from industry or implicated in the new technics, and will include various forms of tool, instrument, apparatus and utility as well as machines proper.

2: The Monastery and the Clock

Where did the machine first take form in modern civilization? There was plainly more than one point of origin. Our mechanical civilization represents the convergence of numerous habits, ideas, and modes of living, as well as technical instruments; and some of these were, in the beginning, directly opposed to the civilization they helped to create. But the first manifestation of the new order took place in the general picture of the world: during the first seven centuries of the machine's existence the categories of time and space underwent an extraordinary change, and no aspect of life was left untouched by this transformation. The application of quantitative methods of thought to the study of nature had its first manifestation in the regular measurement of time; and the new mechanical conception of time arose in part out of the routine of the monastery. Alfred Whitehead has emphasized the importance of the scholastic belief in a universe ordered by God as one of the foundations of modern physics: but behind that belief was the presence of order in the institutions of the Church itself.

The technics of the ancient world were still carried on from Constantinople and Baghdad to Sicily and Cordova: hence the early

ception of time arose in part out of the routine of the monastery.

lead taken by Salerno in the scientific and medical advances of the Middle Age. It was, however, in the monasteries of the West that the desire for order and power, other than that expressed in the military domination of weaker men, first manifested itself after the long uncertainty and bloody confusion that attended the breakdown of the Roman Empire. Within the walls of the monastery was sanctuary: under the rule of the order surprise and doubt and caprice and irregularity were put at bay. Opposed to the erratic fluctuations and pulsations of the worldly life was the iron discipline of the rule. Benedict added a seventh period to the devotions of the day, and in the seventh century, by a bull of Pope Sabinianus, it was decreed that the bells of the monastery be rung seven times in the twenty-four hours. These punctuation marks in the day were known as the canonical hours, and some means of keeping count of them and ensuring their regular repetition became necessary.

According to a now discredited legend, the first modern mechanical clock, worked by falling weights, was invented by the monk named Gerbert who afterwards became Pope Sylvester II near the close of the tenth century. This clock was probably only a water clock, one of those bequests of the ancient world either left over directly from the days of the Romans, like the water-wheel itself, or coming back again into the West through the Arabs. But the legend, as so often happens, is accurate in its implications if not in its facts. The monastery was the seat of a regular life, and an instrument for striking the hours at intervals or for reminding the bell-ringer that it was time to strike the bells, was an almost inevitable product of this life. If the mechanical clock did not appear until the cities of the thirteenth century demanded an orderly routine, the habit of order itself and the earnest regulation of time-sequences had become almost second nature in the monastery. Coulton agrees with Sombart in looking upon the Benedictines, the great working order, as perhaps the original founders of modern capitalism: their rule certainly took the curse off work and their vigorous engineering enterprises may even have robbed warfare of some of its glamor. So one is not straining the facts when one suggests that the monasteries—at one time there were 40,000 under the Benedictine rule—helped to give human

second nature in the monastery. Coulton agrees with

enterprise the regular collective beat and rhythm of the machine; for the clock is not merely a means of keeping track of the hours, but of synchronizing the actions of men.

Was it by reason of the collective Christian desire to provide for the welfare of souls in eternity by regular prayers and devotions that time-keeping and the habits of temporal order took hold of men's minds: habits that capitalist civilization presently turned to good account? One must perhaps accept the irony of this paradox. At all events, by the thirteenth century there are definite records of mechanical clocks, and by 1370 a well-designed "modern" clock had been built by Heinrich von Wyck at Paris. Meanwhile, bell towers had come into existence, and the new clocks, if they did not have, till the fourteenth century, a dial and a hand that translated the movement of time into a movement through space, at all events struck the hours. The clouds that could paralyze the sundial, the freezing that could stop the water clock on a winter night, were no longer obstacles to time-keeping: summer or winter, day or night, one was aware of the measured clank of the clock. The instrument presently spread outside the monastery; and the regular striking of the bells brought a new regularity into the life of the workman and the merchant. The bells of the clock tower almost defined urban existence. Time-keeping passed into time-serving and time-accounting and time-rationing. As this took place, Eternity ceased gradually to serve as the measure and focus of human actions.

The clock, not the steam-engine, is the key-machine of the modern industrial age. For every phase of its development the clock is both the outstanding fact and the typical symbol of the machine: even today no other machine is so ubiquitous. Here, at the very beginning of modern technics, appeared prophetically the accurate automatic machine which, only after centuries of further effort, was also to prove the final consummation of this technics in every department of industrial activity. There had been power-machines, such as the water-mill, before the clock; and there had also been various kinds of automata, to awaken the wonder of the populace in the temple, or to please the idle fancy of some Moslem caliph: machines one finds illustrated in Hero and Al-Jazari. But here was a new kind of

power-machine, in which the source of power and the transmission were of such a nature as to ensure the even flow of energy throughout the works and to make possible regular production and a standardized product. In its relationship to determinable quantities of energy, to standardization, to automatic action, and finally to its own special product, accurate timing, the clock has been the foremost machine in modern technics: and at each period it has remained in the lead: it marks a perfection toward which other machines aspire. The clock, moreover, served as a model for many other kinds of mechanical works, and the analysis of motion that accompanied the perfection of the clock, with the various types of gearing and transmission that were elaborated, contributed to the success of quite different kinds of machine. Smiths could have hammered thousands of suits of armor or thousands of iron cannon, wheelwrights could have shaped thousands of great water-wheels or crude gears, without inventing any of the special types of movement developed in clockwork, and without any of the accuracy of measurement and fineness of articulation that finally produced the accurate eighteenth century chronometer.

The clock, moreover, is a piece of power-machinery whose "product" is seconds and minutes: by its essential nature it dissociated time from human events and helped create the belief in an independent world of mathematically measurable sequences: the special world of science. There is relatively little foundation for this belief in common human experience: throughout the year the days are of uneven duration, and not merely does the relation between day and night steadily change, but a slight journey from East to West alters astronomical time by a certain number of minutes. In terms of the human organism itself, mechanical time is even more foreign: while human life has regularities of its own, the beat of the pulse, the breathing of the lungs, these change from hour to hour with mood and action, and in the longer span of days, time is measured not by the calendar but by the events that occupy it. The shepherd measures from the time the ewes lambed; the farmer measures back to the day of sowing or forward to the harvest: if growth has its own duration and regularities, behind it are not simply matter and motion

prove the final consummation of this technics in every department

but the facts of development: in short, history. And while mechanical time is strung out in a succession of mathematically isolated instants, organic time—what Bergson calls duration—is cumulative in its effects. Though mechanical time can, in a sense, be speeded up or run backward, like the hands of a clock or the images of a moving picture, organic time moves in only one direction—through the cycle of birth, growth, development, decay, and death—and the past that is already dead remains present in the future that has still to be born.

Around 1345, according to Thorndike, the division of hours into sixty minutes and of minutes into sixty seconds became common: it was this abstract framework of divided time that became more and more the point of reference for both action and thought, and in the effort to arrive at accuracy in this department, the astronomical exploration of the sky focussed attention further upon the regular, implacable movements of the heavenly bodies through space. Early in the sixteenth century a young Nuremberg mechanic, Peter Henlein, is supposed to have created "many-wheeled watches out of small bits of iron" and by the end of the century the small domestic clock had been introduced in England and Holland. As with the motor car and the airplane, the richer classes first took over the new mechanism and popularized it: partly because they alone could afford it, partly because the new bourgeoisie were the first to discover that, as Franklin later put it, "time is money." To become "as regular as clockwork" was the bourgeois ideal, and to own a watch was for long a definite symbol of success. The increasing tempo of civilization led to a demand for greater power: and in turn power quickened the tempo.

Now, the orderly punctual life that first took shape in the monasteries is not native to mankind, although by now Western peoples are so thoroughly regimented by the clock that it is "second nature" and they look upon its observance as a fact of nature. Many Eastern civilizations have flourished on a loose basis in time: the Hindus have in fact been so indifferent to time that they lack even an authentic chronology of the years. Only yesterday, in the midst of the industrializations of Soviet Russia, did a society come into exist-

ence to further the carrying of watches there and to propagandize the benefits of punctuality. The popularization of time-keeping, which followed the production of the cheap standardized watch, first in Geneva, then in America around the middle of the last century, was essential to a well-articulated system of transportation and production.

To keep time was once a peculiar attribute of music: it gave industrial value to the workshop song or the tattoo or the chantey of the sailors tugging at a rope. But the effect of the mechanical clock is more pervasive and strict: it presides over the day from the hour of rising to the hour of rest. When one thinks of the day as an abstract span of time, one does not go to bed with the chickens on a winter's night: one invents wicks, chimneys, lamps, gaslights, electric lamps, so as to use all the hours belonging to the day. When one thinks of time, not as a sequence of experiences, but as a collection of hours, minutes, and seconds, the habits of adding time and saving time come into existence. Time took on the character of an enclosed space: it could be divided, it could be filled up, it could even be expanded by the invention of labor-saving instruments.

Abstract time became the new medium of existence. Organic functions themselves were regulated by it: one ate, not upon feeling hungry, but when prompted by the clock: one slept, not when one was tired, but when the clock sanctioned it. A generalized time-consciousness accompanied the wider use of clocks: dissociating time from organic sequences, it became easier for the men of the Renascence to indulge the fantasy of reviving the classic past or of reliving the splendors of antique Roman civilization: the cult of history, appearing first in daily ritual, finally abstracted itself as a special discipline. In the seventeenth century journalism and periodic literature made their appearance: even in dress, following the lead of Venice as fashion-center, people altered styles every year rather than every generation.

The gain in mechanical efficiency through co-ordination and through the closer articulation of the day's events cannot be overestimated: while this increase cannot be measured in mere horsepower, one has only to imagine its absence today to foresee the speedy disruption and eventual collapse of our entire society. The

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modern industrial régime could do without coal and iron and steam easier than it could do without the clock.

3: Space, Distance, Movement

"A child and an adult, an Australian primitive and a European, a man of the Middle Ages and a contemporary, are distinguished not only by a difference in degree, but by a difference in kind by their methods of pictorial representation."

Dagobert Frey, whose words I have just quoted, has made a penetrating study of the difference in spatial conceptions between the early Middle Ages and the Renascence: he has re-enforced by a wealth of specific detail, the generalization that no two cultures live conceptually in the same kind of time and space. Space and time, like language itself, are works of art, and like language they help condition and direct practical action. Long before Kant announced that time and space were categories of the mind, long before the mathematicians discovered that there were conceivable and rational forms of space other than the form described by Euclid, mankind at large had acted on this premise. Like the Englishman in France who thought that bread was the right name for *le pain* each culture believes that every other kind of space and time is an approximation to or a perversion of the real space and time in which *it* lives.

During the Middle Ages spatial relations tended to be organized as symbols and values. The highest object in the city was the church spire which pointed toward heaven and dominated all the lesser buildings, as the church dominated their hopes and fears. Space was divided arbitrarily to represent the seven virtues or the twelve apostles or the ten commandments or the trinity. Without constant symbolic reference to the fables and myths of Christianity the rationale of medieval space would collapse. Even the most rational minds were not exempt: Roger Bacon was a careful student of optics, but after he had described the seven coverings of the eye he added that by such means God had willed to express in our bodies an image of the seven gifts of the spirit.

Size signified importance: to represent human beings of entirely different sizes on the same plane of vision and at the same distance

from the observer was entirely possible for the medieval artist. This same habit applies not only to the representation of real objects but to the organization of terrestrial experience by means of the map. In medieval cartography the water and the land masses of the earth, even when approximately known, may be represented in an arbitrary figure like a tree, with no regard for the actual relations as experienced by a traveller, and with no interest in anything except the allegorical correspondence.

One further characteristic of medieval space must be noted: space and time form two relatively independent systems. First: the medieval artist introduced other times within his own spatial world, as when he projected the events of Christ's life within a contemporary Italian city, without the slightest feeling that the passage of time has made a difference, just as in Chaucer the classical legend of Troilus and Cressida is related as if it were a contemporary story. When a medieval chronicler mentions the King, as the author of The Wandering Scholars remarks, it is sometimes a little difficult to find out whether he is talking about Caesar or Alexander the Great or his own monarch: each is equally near to him. Indeed, the word anachronism is meaningless when applied to medieval art: it is only when one related events to a co-ordinated frame of time and space that being out of time or being untrue to time became disconcerting. Similarly, in Botticelli's The Three Miracles of St. Zenobius, three different times are presented upon a single stage.

Because of this separation of time and space, things could appear and disappear suddenly, unaccountably: the dropping of a ship below the horizon no more needed an explanation than the dropping of a demon down the chimney. There was no mystery about the past from which they had emerged, no speculation as to the future toward which they were bound: objects swam into vision and sank out of it with something of the same mystery in which the coming and going of adults affects the experience of young children, whose first graphic efforts so much resemble in their organization the world of the medieval artist. In this symbolic world of space and time everything was either a mystery or a miracle. The connecting link between events was the cosmic and religious order: the true order of space was Heaven, even as the true order of time was Eternity.

Between the fourteenth and the seventeenth century a revolutionary change in the conception of space took place in Western Europe. Space as a hierarchy of values was replaced by space as a system of magnitudes. One of the indications of this new orientation was the closer study of the relations of objects in space and the discovery of the laws of perspective and the systematic organization of pictures within the new frame fixed by the foreground, the horizon and the vanishing point. Perspective turned the symbolic relation of objects into a visual relation: the visual in turn became a quantitative relation. In the new picture of the world, size meant not human or divine importance, but distance. Bodies did not exist separately as absolute magnitudes: they were co-ordinated with other bodies within the same frame of vision and must be in scale. To achieve this scale, there must be an accurate representation of the object itself, a point for point correspondence between the picture and the image: hence a fresh interest in external nature and in questions of fact. The division of the canvas into squares and the accurate observation of the world through this abstract checkerboard marked the new technique of the painter, from Paolo Ucello onward.

The new interest in perspective brought depth into the picture and distance into the mind. In the older pictures, one's eye jumped from one part to another, picking up symbolic crumbs as taste and fancy dictated: in the new pictures, one's eye followed the lines of linear perspective along streets, buildings, tessellated pavements whose parallel lines the painter purposely introduced in order to make the eye itself travel. Even the objects in the foreground were sometimes grotesquely placed and foreshortened in order to create the same illusion. Movement became a new source of value: movement for its own sake. The measured space of the picture re-enforced the measured time of the clock.

Within this new ideal network of space and time all events now took place; and the most satisfactory event within this system was uniform motion in a straight line, for such motion lent itself to accurate representation within the system of spatial and temporal

co-ordinates. One further consequence of this spatial order must be noted: to place a thing and to time it became essential to one's understanding of it. In Renascence space, the existence of objects must be accounted for: their passage through time and space is a clue to their appearance at any particular moment in any particular place. The unknown is therefore no less determinate than the known: given the roundness of the globe, the position of the Indies could be assumed and the time-distance calculated. The very existence of such an order was an incentive to explore it and to fill up the parts that were unknown.

What the painters demonstrated in their application of perspective, the cartographers established in the same century in their new maps. The Hereford Map of 1314 might have been done by a child: it was practically worthless for navigation. That of Ucello's contemporary, Andrea Banco, 1436, was conceived on rational lines, and represented a gain in conception as well as in practical accuracy. By laying down the invisible lines of latitude and longitude, the cartographers paved the way for later explorers, like Columbus: as with the later scientific method, the abstract system gave rational expectations, even if on the basis of inaccurate knowledge. No longer was it necessary for the navigator to hug the shore line: he could launch out into the unknown, set his course toward an arbitrary point, and return approximately to the place of departure. Both Eden and Heaven were outside the new space; and though they lingered on as the ostensible subjects of painting, the real subjects were Time and Space and Nature and Man.

Presently, on the basis laid down by the painter and the cartographer, an interest in space as such, in movement as such, in locomotion as such, arose. In back of this interest were of course more concrete alterations: roads had become more secure, vessels were being built more soundly, above all, new inventions—the magnetic needle, the astrolabe, the rudder—had made it possible to chart and to hold a more accurate course at sea. The gold of the Indies and the fabled fountains of youth and the happy isles of endless sensual delight doubtless beckoned too: but the presence of these tangible goals does not lessen the importance of the new schemata. The categories of time and space, once practically dissociated, had become united: and the abstractions of measured time and measured space undermined the earlier conceptions of infinity and eternity, since measurement must begin with an arbitrary here and now even if space and time be empty. The itch to *use* space and time had broken out: and once they were co-ordinated with movement, they could be contracted or expanded: the conquest of space and time had begun. (It is interesting, however, to note that the very concept of acceleration, which is part of our daily mechanical experience, was not formulated till the seventeenth century.)

The signs of this conquest are many: they came forth in rapid succession. In military arts the cross-bow and the ballista were revived and extended, and on their heels came more powerful weapons for annihilating distance—the cannon and later the musket. Leonardo conceived an airplane and built one. Fantastic projects for flight were canvassed. In 1420 Fontana described a velocipede: in 1589 Gilles de Bom of Antwerp apparently built a man-propelled wagon: restless preludes to the vast efforts and initiatives of the nineteenth century. As with so many elements in our culture, the original impulse was imparted to this movement by the Arabs: as early as 880 Abû l-Qâsim had attempted flight, and in 1065 Oliver of Malmesbury had killed himself in an attempt to soar from a high place: but from the fifteenth century on the desire to conquer the air became a recurrent preoccupation of inventive minds; and it was close enough to popular thought to make the report of a flight from Portugal to Vienna serve as a news hoax in 1709.

The new attitude toward time and space infected the workshop and the counting house, the army and the city. The tempo became faster: the magnitudes became greater: conceptually, modern culture launched itself into space and gave itself over to movement. What Max Weber called the "romanticism of numbers" grew naturally out of this interest. In time-keeping, in trading, in fighting men counted numbers; and finally, as the habit grew, only numbers counted.

4: The Influence of Capitalism

The romanticism of numbers had still another aspect, important for the development of scientific habits of thought. This was the rise of capitalism, and the change from a barter economy, facilitated by small supplies of variable local coinage, to a money economy with an international credit structure and a constant reference to the abstract symbols of wealth: gold, drafts, bills of exchange, eventually merely numbers.

From the standpoint of technique, this structure had its origin in the towns of Northern Italy, particularly Florence and Venice, in the fourteenth century; two hundred years later there was in existence in Antwerp an international bourse, devoted to aiding speculation in shipments from foreign ports and in money itself. By the middle of the sixteenth century book-keeping by double entry, bills of exchange, letters of credit, and speculation in "futures" were all developed in essentially their modern form. Whereas the procedures of science were not refined and codified until after Galileo and Newton, finance had emerged in its present-day dress at the very beginning of the machine age: Jacob Fugger and J. Pierpont Morgan could understand each other's methods and point of view and temperament far better than Paracelsus and Einstein.

The development of capitalism brought the new habits of abstraction and calculation into the lives of city people: only the country folk, still existing on their more primitive local basis, were partly immune. Capitalism turned people from tangibles to intangibles: its symbol, as Sombart observes, is the account book: "its life-value lies in its profit and loss account." The "economy of acquisition," which had hitherto been practiced by rare and fabulous creatures like Midas and Croesus, became once more the everyday mode: it tended to replace the direct "economy of needs" and to substitute money-values for life-values. The whole process of business took on more and more an abstract form; it was concerned with non-commodities, imaginary futures, hypothetical gains.

Karl Marx well summed up this new process of transmutation: "Since money does not disclose what has been transformed into it,

replace the direct "economy of needs" and to substitute money-values

everything, whether a commodity or not, is convertible into gold. Everything becomes saleable and purchasable. Circulation is the great social retort into which everything is thrown and out of which everything is recovered as crystallized money. Not even the bones of the saints are able to withstand this alchemy; and still less able to withstand it are more delicate things, sacrosanct things which are outside the commercial traffic of men. Just as all qualitative differences between commodities are effaced in money, so money, a radical leveller, effaces all distinctions. But money itself is a commodity, an external object, capable of becoming the private property of an individual. Thus social power becomes private power in the hands of a private person."

This last fact was particularly important for life and thought: the quest of power by means of abstractions. One abstraction re-enforced the other. Time was money: money was power: power required the furtherance of trade and production: production was diverted from the channels of direct use into those of remote trade, toward the acquisition of larger profits, with a larger margin for new capital expenditures for wars, foreign conquests, mines, productive enterprises . . . more money and more power. Of all forms of wealth, money alone is without assignable limits. The prince who might desire to build five palaces would hesitate to build five thousand: but what was to prevent him from seeking by conquest and taxes to multiply by thousands the riches in his treasury? Under a money economy, to speed up the process of production was to speed up the turnover: more money. And as the emphasis upon money grew in part out of the increasing mobility of late medieval society, with its international trade, so did the resulting money economy promote more trade: landed wealth, humanized wealth, houses, paintings, sculptures, books, even gold itself were all relatively difficult to transport, whereas money could be transported after pronouncing the proper abracadabra by a simple algebraic operation on one side or another of the ledger.

In time, men were more at home with abstractions than they were with the goods they represented. The typical operations of finance were the acquisition or the exchange of magnitudes. "Even the day-

dreams of the pecuniary day-dreamer," as Veblen observed, "take shape as a calculus of profit and loss computed in standard units of an impersonal magnitude." Men became powerful to the extent that they neglected the real world of wheat and wool, food and clothes, and centered their attention on the purely quantitative representation of it in tokens and symbols: to think in terms of mere weight and number, to make quantity not alone an indication of value but the criterion of value—that was the contribution of capitalism to the mechanical world-picture. So the abstractions of capitalism preceded the abstractions of modern science and re-enforced at every point its typical lessons and its typical methods of procedure. The clarification and the convenience, particularly for long distance trading in space and time were great: but the social price of these economies was a high one. Mark Kepler's words, published in 1595: "As the ear is made to perceive sound and the eye to perceive color, so the mind of man has been formed to understand, not all sorts of things, but quantities. It perceives any given thing more clearly in proportion as that thing is close to bare quantities as to its origins, but the further a thing recedes from quantities, the more darkness and error inheres in it."

Was it an accident that the founders and patrons of the Royal Society in London—indeed some of the first experimenters in the physical sciences—were merchants from the City? King Charles II might laugh uncontrollably when he heard that these gentlemen had spent their time weighing air; but their instincts were justified, their procedure was correct: the method itself belonged to their tradition, and there was money in it. The power that was science and the power that was money were, in final analysis, the same kind of power: the power of abstraction, measurement, quantification.

But it was not merely in the promotion of abstract habits of thought and pragmatic interests and quantitative estimations that capitalism prepared the way for modern technics. From the beginning machines and factory production, like big guns and armaments, made direct demands for capital far above the small advances necessary to provide the old-style handicraft worker with tools or keep him alive. The freedom to operate independent workshops and factories, to use

tively difficult to transport, whereas money could be transported after

machines and profit by them, went to those who had command of capital. While the feudal families, with their command over the land, often had a monopoly over such natural resources as were found in the earth, and often retained an interest in glass-making, coal-mining, and iron-works right down to modern times, the new mechanical inventions lent themselves to exploitation by the merchant classes. The incentive to mechanization lay in the greater profits that could be extracted through the multiplied power and efficiency of the machine.

Thus, although capitalism and technics must be clearly distinguished at every stage, one conditioned the other and reacted upon it. The merchant accumulated capital by widening the scale of his operations, quickening his turnover, and discovering new territories for exploitation: the inventor carried on a parallel process by exploiting new methods of production and devising new things to be produced. Sometimes trade appeared as a rival to the machine by offering greater opportunities for profit: sometimes it curbed further developments in order to increase the profit of a particular monopoly: both motives are still operative in capitalist society. From the first, there were disparities and conflicts between these two forms of exploitation: but trade was the older partner and exercised a higher authority. It was trade that gathered up new materials from the Indies and from the Americas, new foods, new cereals, tobacco, furs: it was trade that found a new market for the trash that was turned out by eighteenth century mass-production: it was trade—abetted by war—that developed the large-scale enterprises and the administrative capacity and method that made it possible to create the industrial system as a whole and weld together its various parts.

Whether machines would have been invented so rapidly and pushed so zealously without the extra incentive of commercial profit is extremely doubtful: for all the more skilled handicraft occupations were deeply entrenched, and the introduction of printing, for example, was delayed as much as twenty years in Paris by the bitter opposition of the guild of scribes and copyists. But while technics undoubtedly owes an honest debt to capitalism, as it does likewise to war, it was nevertheless unfortunate that the machine was condi-

is extremely doubtful: for all the more skilled handicraft occupations

tioned, at the outset, by these foreign institutions and took on characteristics that had nothing essentially to do with the technical processes or the forms of work. Capitalism utilized the machine, not to further social welfare, but to increase private profit: mechanical instruments were used for the aggrandizement of the ruling classes. It was because of capitalism that the handicraft industries in both Europe and other parts of the world were recklessly destroyed by machine products, even when the latter were inferior to the thing they replaced: for the prestige of improvement and success and power was with the machine, even when it improved nothing, even when technically speaking it was a failure. It was because of the possibilities of profit that the place of the machine was overemphasized and the degree of regimentation pushed beyond what was necessary to harmony or efficiency. It was because of certain traits in private capitalism that the machine—which was a neutral agent—has often seemed, and in fact has sometimes been, a malicious element in society, careless of human life, indifferent to human interests. The machine has suffered for the sins of capitalism; contrariwise, capitalism has often taken credit for the virtues of the machine.

By supporting the machine, capitalism quickened its pace, and gave a special incentive to preoccupation with mechanical improvements: though it often failed to reward the inventor, it succeeded by blandishments and promises in stimulating him to further effort. In many departments the pace was over-accelerated, and the stimulus was over-applied: indeed, the necessity to promote continual changes and improvements, which has been characteristic of capitalism, introduced an element of instability into technics and kept society from assimilating its mechanical improvements and integrating them in an appropriate social pattern. As capitalism itself has developed and expanded, these vices have in fact grown more enormous, and the dangers to society as a whole have likewise grown proportionately. Enough here to notice the close historical association of modern technics and modern capitalism, and to point out that, for all this historical development, there is no necessary connection between them. Capitalism has existed in other civilizations, which had a relatively low technical development; and technics made steady im-

Enough here to notice the close historical association of modern

provements from the tenth to the fifteenth century without the special incentive of capitalism. But the style of the machine has up to the present been powerfully influenced by capitalism: the emphasis upon bigness, for example, is a commercial trait; it appeared in guild halls and merchants' houses long before it was evident in technics, with its originally modest scale of operations.

5: From Fable to Fact

Meanwhile, with the transformation of the concepts of time and space went a change in the direction of interest from the heavenly world to the natural one. Around the twelfth century the supernatural world, in which the European mind had been enveloped as in a cloud from the decay of the classic schools of thought onward, began to lift: the beautiful culture of Provence whose language Dante himself had thought perhaps to use for his Divine Comedy, was the first bud of the new order: a bud destined to be savagely blighted by the Albigensian crusade.

Every culture lives within its dream. That of Christianity was one in which a fabulous heavenly world, filled with gods, saints, devils, demons, angels, archangels, cherubim and seraphim and dominions and powers, shot its fantastically magnified shapes and images across the actual life of earthborn man. This dream pervades the life of a culture as the fantasies of night dominate the mind of a sleeper: it is reality—while the sleep lasts. But, like the sleeper, a culture lives within an objective world that goes on through its sleeping or waking, and sometimes breaks into the dream, like a noise, to modify it or to make further sleep impossible.

By a slow natural process, the world of nature broke in upon the medieval dream of hell and paradise and eternity: in the fresh naturalistic sculpture of the thirteenth century churches one can watch the first uneasy stir of the sleeper, as the light of morning strikes his eyes. At first, the craftsman's interest in nature was a confused one: side by side with the fine carvings of oak leaves and hawthorn sprays, faithfully copied, tenderly arranged, the sculptor still created strange monsters, gargoyles, chimeras, legendary beasts. But the interest in nature steadily broadened and became more con-

suming. The naïve feeling of the thirteenth century artist turned into the systematic exploration of the sixteenth century botanists and physiologists.

"In the Middle Ages," as Emile Mâle said, "the idea of a thing which a man formed for himself was always more real than the actual thing itself, and we see why these mystical centuries had no conception of what men now call science. The study of things for their own sake held no meaning for the thoughtful man. . . . The task for the student of nature was to discern the eternal truth that God would have each thing express." In escaping this attitude, the vulgar had an advantage over the learned: their minds were less capable of forging their own shackles. A rational common sense interest in Nature was not a product of the new classical learning of the Renascence; rather, one must say, that a few centuries after it had flourished among the peasants and the masons, it made its way by another route into the court and the study and the university. Villard de Honnecourt's notebook, the precious bequest of a great master-mason, has drawings of a bear, a swan, a grasshopper, a fly, a dragonfly, a lobster, a lion and a pair of parroquets, all done directly from life. The book of Nature reappeared, as in a palimpsest, through the heavenly book of the Word.

During the Middle Ages the external world had had no conceptual hold upon the mind. Natural facts were insignificant compared with the divine order and intention which Christ and his Church had revealed: the visible world was merely a pledge and a symbol of that Eternal World of whose blisses and damnations it gave such a keen foretaste. People ate and drank and mated, basked in the sun and grew solemn under the stars; but there was little meaning in this immediate state: whatever significance the items of daily life had was as stage accessories and costumes and rehearsals for the drama of Man's pilgrimage through eternity. How far could the mind go in scientific mensuration and observation as long as the mystic numbers three and four and seven and nine and twelve filled every relation with an allegorical significance. Before the sequences in nature could be studied, it was necessary to discipline the imagination and sharpen the vision: mystic second sight must be converted into factual first sight. The artists had a fuller part in this discipline than they have usually been credited with. In enumerating the many parts of nature that cannot be studied without the "aid and intervening of mathematics," Francis Bacon properly includes perspective, music, architecture, and engineering along with the sciences of astronomy and cosmography.

The change in attitude toward nature manifested itself in solitary figures long before it became common. Roger Bacon's experimental precepts and his special researches in optics have long been commonplace knowledge; indeed, like the scientific vision of his Elizabethan namesake they have been somewhat overrated: their significance lies in the fact that they represented a general trend. In the thirteenth century, the pupils of Albertus Magnus were led by a new curiosity to explore their environment, while Absalon of St. Victor complained that the students wished to study "the confórmation of the globe, the nature of the elements, the place of the stars, the nature of animals, the violence of the wind, the life of herbs and roots." Dante and Petrarch, unlike most medieval men, no longer avoided mountains as mere terrifying obstacles that increased the hardships of travel: they sought them and climbed them, for the exaltation that comes from the conquest of distance and the attainment of a bird's-eye view. Later, Leonardo explored the hills of Tuscany, discovered fossils, made correct interpretations of the processes of geology: Agricola, urged on by his interest in mining, did the same. The herbals and treatises on natural history that came out during the fifteenth and sixteenth centuries, though they still mingled fable and conjecture with fact, were resolute steps toward the delineation of nature: their admirable pictures still witness this. And the little books on the seasons and the routine of daily life moved in the same direction. The great painters were not far behind. The Sistine Chapel, no less than Rembrandt's famous picture, was an anatomy lesson, and Leonardo was a worthy predecessor to Vesalius, whose life overlapped his. In the sixteenth century, according to Beckmann, there were numerous private natural history collections, and in 1659 Elias Ashmole purchased the Tradescant collection, which he later presented to Oxford.

The discovery of nature as a whole was the most important part of that era of discovery which began for the Western World with the Crusades and the travels of Marco Polo and the southward ventures of the Portuguese. Nature existed to be explored, to be invaded, to be conquered, and finally, to be understood. Dissolving, the medieval dream disclosed the world of nature, as a lifting mist opens to view the rocks and trees and herds on a hillside, whose existence had been heralded only by the occasional tinkling of bells or the lowing of a cow. Unfortunately, the medieval habit of separating the soul of man from the life of the material world persisted, though the theology that supported it was weakened; for as soon as the procedure of exploration was definitely outlined in the philosophy and mechanics of the seventeenth century man himself was excluded from the picture. Technics perhaps temporarily profited by this exclusion; but in the long run the result was to prove unfortunate. In attempting to seize power man tended to reduce himself to an abstraction, or, what comes to almost the same thing, to eliminate every part of himself except that which was bent on seizing power.

6: The Obstacle of Animism

The great series of technical improvements that began to crystallize around the sixteenth century rested on a dissociation of the animate and the mechanical. Perhaps the greatest difficulty in the way of this dissociation was the persistence of inveterate habits of animistic thinking. Despite animism, such dissociations had indeed been made in the past: one of the greatest of such acts was the invention of the wheel. Even in the relatively advanced civilization of the Assyrians one sees representations of great statues being moved across bare ground on a sledge. Doubtless the notion of the wheel came originally from observing that rolling a log was easier than shoving it: but trees existed for untold years and the trimming of trees had gone on for many thousands, in all likelihood, before some neolithic inventor performed the stunning act of dissociation that made possible the cart.

So long as every object, animate or inanimate, was looked upon as the dwelling place of a spirit, so long as one expected a tree or a

direction. The great painters were not far behind. The Sistine Chapel,
for untold years and the trimming

ship to behave like a living creature, it was next to impossible to isolate as a mechanical sequence the special function one sought to serve. Just as the Egyptian workman, when he made the leg of a chair, fashioned it to represent the leg of a bullock, so the desire naïvely to reproduce the organic, and to conjure up giants and djinns for power, instead of contriving their abstract equivalent, retarded the development of the machine. Nature often assists in such abstraction: the swan's use of its wing may have suggested the sail, even as the hornet's nest suggested paper. Conversely, the body itself is a sort of microcosm of the machine: the arms are levers, the lungs are bellows, the eyes are lenses, the heart is a pump, the fist is a hammer, the nerves are a telegraph system connected with a central station: but on the whole, the mechanical instruments were invented before the physiological functions were accurately described. The most ineffective kind of machine is the *realistic* mechanical imitation of a man or another animal: technics remembers Vaucanson for his loom, rather than for his life-like mechanical duck, which not merely ate food but went through the routine of digestion and excretion.

The original advances in modern technics became possible only when a mechanical system could be isolated from the entire tissue of relations. Not merely did the first airplane, like that of Leonardo, attempt to reproduce the motion of birds' wings: as late as 1897 Ader's batlike airplane, which now hangs in the Conservatoire des Arts et Métiers in Paris had its ribs fashioned like a bat's body, and the very propellers, as if to exhaust all the zoological possibilities, were made of thin, split wood, as much as possible like birds' feathers. Similarly, the belief that reciprocating motion, as in the movement of the arms and legs, was the "natural" form of motion was used to justify opposition to the original conception of the turbine. Branca's plan of a steam-engine at the beginning of the seventeenth century showed the boiler in the form of the head and torso of a man. Circular motion, one of the most useful and frequent attributes of a fully developed machine is, curiously, one of the least observable motions in nature: even the stars do not describe a circular course, and except for the rotifers, man himself, in occasional dances and handsprings, is the chief exponent of rotary motion.

The specific triumph of the technical imagination rested on the ability to dissociate lifting power from the arm and create a crane: to dissociate work from the action of men and animals and create the water-mill: to dissociate light from the cumbustion of wood and oil and create the electric lamp. For thousands of years animism had stood in the way of this development; for it had concealed the entire face of nature behind a scrawl of human forms: even the stars were grouped together in the living figures of Castor and Pollux or the Bull on the faintest points of resemblance. Life, not content with its own province, had flowed incontinently into stones, rivers, stars, and all the natural elements: the external environment, because it was so immediately part of man, remained capricious, mischievous, a reflection of his own disordered urges and fears.

Since the world seemed, in essence, animistic, and since these "external" powers threatened man, the only method of escape that his own will-to-power could follow was either the discipline of the self or the conquest of other men: the way of religion or the way of war. I shall discuss, in another place, the special contribution that the technique and animus of warfare made to the development of the machine; as for the discipline of the personality it was essentially, during the Middle Ages, the province of the Church, and it had gone farthest, of course, not among the peasants and nobles, still clinging to essentially pagan ways of thought, with which the Church had expediently compromised: it had gone farthest in the monasteries and the universities.

Here animism was extruded by a sense of the omnipotence of a single Spirit, refined, by the very enlargement of His duties, out of any semblance of merely human or animal capacities. God had created an orderly world, and his Law prevailed in it. His acts were perhaps inscrutable; but they were not capricious: the whole burden of the religious life was to create an attitude of humility toward the ways of God and the world he had created. If the underlying faith of the Middle Ages remained superstitious and animistic, the metaphysical doctrines of the Schoolmen were in fact anti-animistic: the gist of the matter was that God's world was not man's, and that only the church could form a bridge between man and the absolute.

of the religious life was to

The meaning of this division did not fully become apparent until the Schoolmen themselves had fallen into disrepute and their inheritors, like Descartes, had begun to take advantage of the old breach by describing on a purely mechanical basis the entire world of nature—leaving out only the Church's special province, the soul of man. It was by reason of the Church's belief in an orderly independent world, as Whitehead has shown in Science and the Modern World, that the work of science could go on so confidently. The humanists of the sixteenth century might frequently be sceptics and atheists, scandalously mocking the Church even when they remained within its fold: it is perhaps no accident that the serious scientists of the seventeenth century, like Galileo, Descartes, Leibniz, Newton, Pascal, were so uniformly devout men. The next step in development, partly made by Descartes himself, was the transfer of order from God to the Machine. For God became in the eighteenth century the Eternal Clockmaker who, having conceived and created and wound up the clock of the universe, had no further responsibility until the machine ultimately broke up—or, as the nineteenth century thought, until the works ran down.

The method of science and technology, in their developed forms, implies a sterilization of the self, an elimination, as far as possible, of the human bias and preference, including the human pleasure in man's own image and the instinctive belief in the immediate presentations of his fantasies. What better preparation could a whole culture have for such an effort than the spread of the monastic system and the multiplication of a host of separate communities, dedicated to the living of a humble and self-abnegating life, under a strict rule? Here, in the monastery, was a relatively non-animistic, non-organic world: the temptations of the body were minimized in theory and, despite strain and irregularity, often minimized in practice—more often, at all events, than in secular life. The effort to exalt the individual self was suspended in the collective routine.

Like the machine, the monastery was incapable of self-perpetuation except by renewal from without. And apart from the fact that women were similarly organized in nunneries, the monastery was like the army, a strictly masculine world. Like the army, again, it sharpened

and disciplined and focussed the masculine will-to-power: a succession of military leaders came from the religious orders, while the leader of the order that exemplified the ideals of the Counter-Reformation began his life as a soldier. One of the first experimental scientists, Roger Bacon, was a monk; so, again, was Michael Stifel, who in 1544 widened the use of symbols in algebraic equations; the monks stood high in the roll of mechanics and inventors. The spiritual routine of the monastery, if it did not positively favor the machine, at least nullified many of the influences that worked against it. And unlike the similar discipline of the Buddhists, that of the Western monks gave rise to more fertile and complex kinds of machinery than prayer wheels.

In still another way did the institutions of the Church perhaps prepare the way for the machine: in their contempt for the body. Now respect for the body and its organs is deep in all the classic cultures of the past. Sometimes, in being imaginatively projected, the body may be displaced symbolically by the parts or organs of another animal, as in the Egyptian Horus: but the substitution is made for the sake of intensifying some organic quality, the power of muscle, eye, genitals. The phalluses that were carried in a religious procession were greater and more powerful, by representation, than the actual human organs: so, too, the images of the gods might attain heroic size, to accentuate their vitality. The whole ritual of life in the old cultures tended to emphasize respect for the body and to dwell on its beauties and delights: even the monks who painted the Ajanta caves of India were under its spell. The enthronement of the human form in sculpture, and the care of the body in the palestra of the Greeks or the baths of the Romans, re-enforced this inner feeling for the organic. The legend about Procrustes typifies the horror and the resentment that classic peoples felt against the mutilation of the body: one made beds to fit human beings, one did not chop off legs or heads to fit beds.

This affirmative sense of the body surely never disappeared, even during the severest triumphs of Christianity: every new pair of lovers recovers it through their physical delight in each other. Similarly, the prevalence of gluttony as a sin during the Middle Ages was a

vidual self was suspended in the collective routine.

witness to the importance of the belly. But the systematic teachings of the Church were directed against the body and its culture: if on one hand it was a Temple of the Holy Ghost, it was also vile and sinful by nature: the flesh tended to corruption, and to achieve the pious ends of life one must mortify it and subdue it, lessening its appetites by fasting and abstention. Such was the letter of the Church's teaching; and while one cannot suppose that the mass of humanity kept close to the letter, the feeling against the body's exposure, its uses, its celebration, was there.

While public bath houses were common in the Middle Ages, contrary to the complacent superstition that developed after the Renascence abandoned them, those who were truly holy neglected to bathe the body; they chafed their skin in hair shirts, they whipped themselves, they turned their eyes with charitable interest upon the sore and leprous and deformed. Hating the body, the orthodox minds of the Middle Ages were prepared to do it violence. Instead of resenting the machines that could counterfeit this or that action of the body, they could welcome them. The forms of the machine were no more ugly or repulsive than the bodies of crippled and battered men and women, or, if they were repulsive and ugly, they were that much further away from being a temptation to the flesh. The writer in the Nürnberg Chronicle in 1398 might say that "wheeled engines performing strange tasks and shows and follies come directly from the devil"—but in spite of itself, the Church was creating devil's disciples.

The fact is, at all events, that the machine came most slowly into agriculture, with its life-conserving, life-maintaining functions, while it prospered lustily precisely in those parts of the environment where the body was most infamously treated by custom: namely, in the monastery, in the mine, on the battlefield.

7: The Road Through Magic

Between fantasy and exact knowledge, between drama and technology, there is an intermediate station: that of magic. It was in magic that the general conquest of the external environment was decisively instituted. Without the order that the Church provided the campaign would possibly have been unthinkable; but without the wild, scrambled daring of the magicians the first positions would not have been taken. For the magicians not only believed in marvels but audaciously sought to work them: by their straining after the exceptional, the natural philosophers who followed them were first given a clue to the regular.

The dream of conquering nature is one of the oldest that has flowed and ebbed in man's mind. Each great epoch in human history in which this will has found a positive outlet marks a rise in human culture and a permanent contribution to man's security and well-being. Prometheus, the fire-bringer, stands at the beginning of man's conquest: for fire not merely made possible the easier digestion of foods, but its flames kept off predatory animals, and around the warmth of it, during the colder seasons of the year, an active social life became possible, beyond the mere huddle and vacuity of the winter's sleep. The slow advances in making tools and weapons and utensils that marked the earlier stone periods were a pedestrian conquest of the environment: gains by inches. In the neolithic period came the first great lift, with the domestication of plants and animals, the making of orderly and effective astronomical observations, and the spread of a relatively peaceful big-stone civilization in many lands separated over the planet. Fire-making, agriculture, pottery, astronomy, were marvellous collective leaps: dominations rather than adaptations. For thousands of years men must have dreamed, vainly, of further short-cuts and controls.

Beyond the great and perhaps relatively short period of neolithic invention the advances, up to the tenth century of our own era, had been relatively small except in the use of metals. But the hope of some larger conquest, some more fundamental reversal of man's dependent relation upon a merciless and indifferent external world continued to haunt his dreams and even his prayers: the myths and fairy stories are a testimony to his desire for plenitude and power, for freedom of movement and length of days.

Looking at the bird, men dreamed of flight: perhaps one of the most universal of man's envies and desires: Daedalus among the Greeks, Ayar Katsi, the flying man, among the Peruvian Indians, to say nothing of Rah and Neith, Astarte and Psyche, or the Angels of Christianity. In the thirteenth century, this dream reappeared prophetically in the mind of Roger Bacon. The flying carpet of the Arabian Nights, the seven-leagued boots, the wishing ring, were all evidences of the desire to fly, to travel fast, to diminish space, to remove the obstacle of distance. Along with this went a fairly constant desire to deliver the body from its infirmities, from its early aging, which dries up its powers, and from the diseases that threaten life even in the midst of vigor and youth. The gods may be defined as beings of somewhat more than human stature that have these powers of defying space and time and the cycle of growth and decay: even in the Christian legend the ability to make the lame walk and the blind see is one of the proofs of godhood. Imhotep and Aesculapius, by reason of their skill in the medical arts, were raised into deities by the Egyptians and the Greeks. Oppressed by want and starvation, the dream of the horn of plenty and the Earthly Paradise continued to haunt man.

It was in the North that these myths of extended powers took on an added firmness, perhaps, from the actual achievements of the miners and smiths: one remembers Thor, master of the thunder, whose magic hammer made him so potent: one remembers Loki, the cunning and mischievous god of fire: one remembers the gnomes who created the magic armor and weapons of Siegfried—Ilmarinen of the Finns, who made a steel eagle, and Wieland, the fabulous German smith, who made feather clothes for flight. Back of all these fables, these collective wishes and utopias, lay the desire to prevail over the brute nature of things.

But the very dreams that exhibited these desires were a revelation of the difficulty of achieving them. The dream gives direction to human activity and both expresses the inner urge of the organism and conjures up appropriate goals. But when the dream strides too far ahead of fact, it tends to short-circuit action: the anticipatory subjective pleasure serves as a surrogate for the thought and contrivance and action that might give it a foothold in reality. The disembodied desire, unconnected with the conditions of its fulfillment or with its means of expression, leads nowhere: at most it contributes

to an inner equilibrium. How difficult was the discipline required before mechanical invention became possible one sees in the part played by magic in the fifteenth and sixteenth centuries.

Magic, like pure fantasy, was a short cut to knowledge and power. But even in the most primitive form of shamanism, magic involves a drama and an action: if one wishes to kill one's enemy by magic, one must at least mould a wax figure and stick pins into it; and similarly, if the need for gold in early capitalism promoted a grand quest for the means of transmuting base metals into noble ones, it was accompanied by fumbling and frantic attempts to manipulate the external environment. Under magic, the experimenter acknowledged that it was necessary to have a sow's ear before one could make a silk purse: this was a real advance toward matter-of-fact. "The operations," as Lynn Thorndike well says of magic, "were supposed to be efficacious here in the world of external reality": magic presupposed a public demonstration rather than a merely private gratification.

No one can put his finger on the place where magic became science, where empiricism became systematic experimentalism, where alchemy became chemistry, where astrology became astronomy, in short, where the need for immediate human results and gratifications ceased to leave its smudgy imprint. Magic was marked above all perhaps by two unscientific qualities: by secrets and mystifications, and by a certain impatience for "results." According to Agricola the transmutationists of the sixteenth century did not hesitate to conceal gold in a pellet of ore, in order to make their experiment come out successfully: similar dodges, like a concealed clock-winder, were used in the numerous perpetual motion machines that were put forward. Everywhere the dross of fraud and charlatanism mingled with the occasional grains of scientific knowledge that magic utilized or produced.

But the instruments of research were developed before a method of procedure was found; and if gold did not come out of lead in the experiments of the alchemists, they are not to be reproached for their ineptitude but congratulated on their audacity: their imaginations sniffed quarry in a cave they could not penetrate, and their

human activity and both expresses the inner urge of the organism
or produced.

baying and pointing finally called the hunters to the spot. Something more important than gold came out of the researches of the alchemists: the retort and the furnace and the alembic: the habit of manipulation by crushing, grinding, firing, distilling, dissolving—valuable apparatus for real experiments, valuable methods for real science. The source of authority for the magicians ceased to be Aristotle and the Fathers of the Church: they relied upon what their hands could do and their eyes could see, with the aid of mortar and pestle and furnace. Magic rested on demonstration rather than dialectic: more than anything else, perhaps, except painting, it released European thought from the tyranny of the written text.

In sum, magic turned men's minds to the external world: it suggested the need of manipulating it: it helped create the tools for successfully achieving this, and it sharpened observation as to the results. The philosopher's stone was not found, but the science of chemistry emerged, to enrich us far beyond the simple dreams of the gold-seekers. The herbalist, zealous in his quest for simples and cure-alls, led the way for the intensive explorations of the botanist and the physician: despite our boasts of accurate coal tar drugs, one must not forget that one of the few genuine specifics in medicine, quinine, comes from the cinchona bark, and that chaulmoogra oil, used with success in treating leprosy, likewise comes from an exotic tree. As children's play anticipates crudely adult life, so did magic anticipate modern science and technology: it was chiefly the lack of direction that was fantastic: the difficulty was not in using the instrument but in finding a field where it could be applied and finding the right system for applying it. Much of seventeenth century science, though no longer tainted with charlatanism, was just as fantastic. It needed centuries of systematic effort to develop the technique which has given us Ehrlich's salvarsan or Bayer 207. But magic was the bridge that united fantasy with technology: the dream of power with the engines of fulfillment. The subjective confidence of the magicians, seeking to inflate their private egos with boundless wealth and mysterious energies, surmounted even their practical failures: their fiery hopes, their crazy dreams, their cracked homunculi continued

to gleam in the ashes: to have dreamed so riotously was to make the technics that followed less incredible and hence less impossible.

8: Social Regimentation

If mechanical thinking and ingenious experiment produced the machine, regimentation gave it a soil to grow in: the social process worked hand in hand with the new ideology and the new technics. Long before the peoples of the Western World turned to the machine, mechanism as an element in social life had come into existence. Before inventors created engines to take the place of men, the leaders of men had drilled and regimented multitudes of human beings: they had discovered how to reduce men to machines. The slaves and peasants who hauled the stones for the pyramids, pulling in rhythm to the crack of the whip, the slaves working in the Roman galley, each man chained to his seat and unable to perform any other motion than the limited mechanical one, the order and march and system of attack of the Macedonian phalanx—these were all machine phenomena. Whatever limits the actions and movements of human beings to their bare mechanical elements belongs to the physiology, if not to the mechanics, of the machine age.

From the fifteenth century on invention and regimentation worked reciprocally. The increase in the number and kinds of machines, mills, guns, clocks, lifelike automata, must have suggested mechanical attributes for men and extended the analogies of mechanism to more subtle and complex organic facts: by the seventeenth century this turn of interest disclosed itself in philosophy. Descartes, in analyzing the physiology of the human body, remarks that its functioning apart from the guidance of the will does not "appear at all strange to those who are acquainted with the variety of movements performed by the different automata, or moving machines fabricated by human industry, and with the help of but a few pieces compared with the great multitude of bones, nerves, arteries, veins, and other parts that are found in the body of each animal. Such persons will look upon this body as a machine made by the hand of God." But the opposite process was also true: the mechanization of human habits prepared the way for mechanical imitations.

To the degree that fear and disruption prevail in society, men tend to seek an absolute: if it does not exist, they project it. Regimentation gave the men of the period a finality they could discover nowhere else. If one of the phenomena of the breakdown of the medieval order was the turbulence that made men freebooters, discoverers, pioneers, breaking away from the tameness of the old ways and the rigor of self-imposed disciplines, the other phenomenon, related to it, but compulsively drawing society into a regimented mould, was the methodical routine of the drillmaster and the book-keeper, the soldier and the bureaucrat. These masters of regimentation gained full ascendency in the seventeenth century. The new bourgeoisie, in counting house and shop, reduced life to a careful, uninterrupted routine: so long for business: so long for dinner: so long for pleasure —all carefully measured out, as methodical as the sexual intercourse of Tristram Shandy's father, which coincided, symbolically, with the monthly winding of the clock. Timed payments: timed contracts: timed work: timed meals: from this period on nothing was quite free from the stamp of the calendar or the clock. Waste of time became for protestant religious preachers, like Richard Baxter, one of the most heinous sins. To spend time in mere sociability, or even in sleep, was reprehensible.

The ideal man of the new order was Robinson Crusoe. No wonder he indoctrinated children with his virtues for two centuries, and served as the model for a score of sage discourses on the Economic Man. Robinson Crusoe was all the more representative as a tale not only because it was the work of one of the new breed of writers, the professional journalists, but because it combines in a single setting the element of catastrophe and adventure with the necessity for invention. In the new economic system every man was for himself. The dominant virtues were thrift, foresight, skillful adaptation of means. Invention took the place of image-making and ritual; experiment took the place of contemplation; demonstration took the place of deductive logic and authority. Even alone on a desert island the sober middle class virtues would carry one through. . . .

Protestantism re-enforced these lessons of middle class sobriety and gave them God's sanction. True: the main devices of finance

self. The dominant virtues were thrift, foresight, skillful adaptation

were a product of Catholic Europe, and Protestantism has received undeserved praise as a liberating force from medieval routine and undeserved censure as the original source and spiritual justification of modern capitalism. But the peculiar office of Protestantism was to unite finance to the concept of a godly life and to turn the asceticism countenanced by religion into a device for concentration upon worldly goods and worldly advancement. Protestantism rested firmly on the abstractions of print and money. Religion was to be found, not simply in the fellowship of religious spirits, connected historically through the Church and communicating with God through an elaborate ritual: it was to be found in the word itself: the word without its communal background. In the last analysis, the individual must fend for himself in heaven, as he did on the exchange. The expression of collective beliefs through the arts was a snare: so the Protestant stripped the images from his Cathedral and left the bare stones of engineering: he distrusted all painting, except perhaps portrait painting, which mirrored his righteousness; and he looked upon the theater and the dance as a lewdness of the devil. Life, in all its sensuous variety and warm delight, was drained out of the Protestant's world of thought: the organic disappeared. Time was real: keep it! Labor was real: exert it! Money was real: save it! Space was real: conquer it! Matter was real: measure it! These were the realities and the imperatives of the middle class philosophy. Apart from the surviving scheme of divine salvation all its impulses were already put under the rule of weight and measure and quantity: day and life were completely regimented. In the eighteenth century Benjamin Franklin, who had perhaps been anticipated by the Jesuits, capped the process by inventing a system of moral book-keeping.

How was it that the power motive became isolated and intensified toward the close of the Middle Ages?

Each element in life forms part of a cultural mesh: one part implicates, restrains, helps to express the other. During this period the mesh was broken, and a fragment escaped and launched itself on a separate career—the will to dominate the environment. To dominate, not to cultivate: to seize power, not to achieve form. One cannot, plainly, embrace a complex series of events in such simple terms

Each element in life forms part of a cultural mesh: one part

alone. Another factor in the change may have been due to an intensified sense of inferiority: this perhaps arose through the humiliating disparity between man's ideal pretensions and his real accomplishments—between the charity and peace preached by the Church and its eternal wars and feuds and animosities, between the holy life as preached by the saints and the lascivious life as lived by the Renascence Popes, between the belief in heaven and the squalid disorder and distress of actual existence. Failing redemption by grace, harmonization of desires, the Christian virtues, people sought, perhaps, to wipe out their sense of inferiority and overcome their frustration by seeking power.

At all events, the old synthesis had broken down in thought and in social action. In no little degree, it had broken down because it was an inadequate one: a closed, perhaps fundamentally neurotic conception of human life and destiny, which originally had sprung out of the misery and terror that had attended both the brutality of imperialistic Rome and its ultimate putrefaction and decay. So remote were the attitudes and concepts of Christianity from the facts of the natural world and of human life, that once the world itself was opened up by navigation and exploration, by the new cosmology, by new methods of observation and experiment, there was no returning to the broken shell of the old order. The split between the Heavenly system and the Earthly one had become too grave to be overlooked, too wide to be bridged: human life had a destiny outside that shell. The crudest science touched closer to contemporary truth than the most refined scholasticism: the clumsiest steam engine or spinning jenny had more efficiency than the soundest guild regulation, and the paltriest factory and iron bridge had more promise for architecture than the most masterly buildings of Wren and Adam; the first yard of cloth woven by machine, the first plain iron casting, had potentially more esthetic interest than jewelry fashioned by a Cellini or the canvas covered by a Reynolds. In short: a live machine was better than a dead organism; and the organism of medieval culture was dead.

From the fifteenth century to the seventeenth men lived in an empty world: a world that was daily growing emptier. They said

their prayers, they repeated their formulas; they even sought to retrieve the holiness they had lost by resurrecting superstitions they had long abandoned: hence the fierceness and hollow fanaticism of the Counter-Reformation, its burning of heretics, its persecution of witches, precisely in the midst of the growing "enlightenment." They threw themselves back into the medieval dream with a new intensity of feeling, if not conviction: they carved and painted and wrote—who indeed ever hewed more mightily in stone than Michelangelo, who wrote with more spectacular ecstasy and vigor than Shakespeare? But beneath the surface occupied by these works of art and thought was a dead world, an empty world, a void that no amount of dash and bravura could fill up. The arts shot up into the air in a hundred pulsing fountains, for it is just at the moment of cultural and social dissolution that the mind often works with a freedom and intensity that is not possible when the social pattern is stable and life as a whole is more satisfactory: but the idolum itself had become empty.

Men no longer believed, without practical reservations, in heaven and hell and the communion of the saints: still less did they believe in the smooth gods and goddesses and sylphs and muses whom they used, with elegant but meaningless gestures, to adorn their thoughts and embellish their environment: these supernatural figures, though they were human in origin and in consonance with certain stable human needs, had become wraiths. Observe the infant Jesus of a thirteenth century altarpiece: the infant lies on an altar, apart; the Virgin is transfixed and beatified by the presence of the Holy Ghost: the myth is real. Observe the Holy Families of the sixteenth and seventeenth century painting: fashionable young ladies are coddling their well-fed human infants: the myth has died. First only the gorgeous clothes are left: finally a doll takes the place of the living child: a mechanical puppet. Mechanics became the new religion, and it gave to the world a new Messiah: the machine.

9: The Mechanical Universe

The issues of practical life found their justification and their appropriate frame of ideas in the natural philosophy of the seven-

had potentially more esthetic interest than jewelry fashioned by a
living child: a mechanical puppet. Mechanics became the new re-

teenth century: this philosophy has remained, in effect, the working creed of technics, even though its ideology has been challenged, modified, amplified, and in part undermined by the further pursuit of science itself. A series of thinkers, Bacon, Descartes, Galileo, Newton, Pascal, defined the province of science, elaborated its special technique of research, and demonstrated its efficacy.

At the beginning of the seventeenth century there were only scattered efforts of thought, some scholastic, some Aristotelian, some mathematical and scientific, as in the astronomical observations of Copernicus, Tycho Brahe, and Kepler: the machine had had only an incidental part to play in these intellectual advances. At the end, despite the relative sterility of invention itself during this century, there existed a fully articulated philosophy of the universe, on purely mechanical lines, which served as a starting point for all the physical sciences and for further technical improvements: the mechanical *Weltbild* had come into existence. Mechanics set the pattern of successful research and shrewd application. Up to this time the biological sciences had paralleled the physical sciences: thereafter, for at least a century and a half, they played second fiddle; and it was not until after 1860 that biological facts were recognized as an important basis for technics.

By what means was the new mechanical picture put together? And how did it come to provide such an excellent soil for the propagation of inventions and the spread of machines?

The method of the physical sciences rested fundamentally upon a few simple principles. First: the elimination of qualities, and the reduction of the complex to the simple by paying attention only to those aspects of events which could be weighed, measured, or counted, and to the particular kind of space-time sequence that could be controlled and repeated—or, as in astronomy, whose repetition could be predicted. Second: concentration upon the outer world, and the elimination or neutralization of the observer as respects the *data* with which he works. Third: isolation: limitation of the field: specialization of interest and subdivision of labor. In short, what the physical sciences call the world is not the total object of common human experience: it is just those aspects of this experience

that lend themselves to accurate factual observation and to generalized statements. One may define a mechanical system as one in which any random sample of the whole will serve in place of the whole: an ounce of pure water in the laboratory is supposed to have the same properties as a hundred cubic feet of equally pure water in the cistern and the environment of the object is not supposed to affect its behavior. Our modern concepts of space and time make it seem doubtful if any pure mechanical system really exists: but the original bias of natural philosophy was to discard organic complexes and to seek isolates which could be described, *for practical purposes*, as if they completely represented the "physical world" from which they had been extracted.

This elimination of the organic had the justification not only of practical interest but of history itself. Whereas Socrates had turned his back upon the Ionian philosophers because he was more concerned to learn about man's dilemmas than to learn about trees, rivers, and stars, all that could be called positive knowledge, which had survived the rise and fall of human societies, were just such non-vital truths as the Pythagorean theorem. In contrast to the cycles of taste, doctrine, fashion, there had been a steady accretion of mathematical and physical knowledge. In this development, the study of astronomy had been a great aid: the stars could not be cajoled or perverted: their courses were visible to the naked eye and could be followed by any patient observer.

Compare the complex phenomenon of an ox moving over a winding uneven road with the movements of a planet: it is easier to trace an entire orbit than to plot the varying rate of speed and the changes of position that takes place in the nearer and more familiar object. *To fix attention upon a mechanical system was the first step toward creating system:* an important victory for rational thought. By centering effort upon the non-historic and the inorganic, the physical sciences clarified the entire procedure of analysis: for the field to which they confined their attention was one in which the method could be pushed farthest without being too palpably inadequate or encountering too many special difficulties. But the real physical world was still not simple enough for the scientific method in its first stages of development: it was necessary to reduce it to such elements as could be ordered in terms of space, time, mass, motion, quantity. The amount of elimination and rejection that accompanied this was excellently described by Galileo, who gave the process such a strong impetus. One must quote him in full:

"As soon as I form a conception of a material or corporeal substance, I simultaneously feel the necessity of conceiving that it has boundaries of some shape or other; that relatively to others it is great or small; that it is in this or that place, in this or that time; that it is in motion or at rest; that it touches, or does not touch, another body; that it is unique, rare, or common; nor can I, by any act of imagination, disjoin it from these qualities. But I do not find myself absolutely compelled to apprehend it as necessarily accompanied by such conditions as that it must be white or red, bitter or sweet, sonorous or silent, smelling sweetly or disagreeably; and if the senses had not pointed out these qualities language and imagination alone could never have arrived at them. Therefore I think that these tastes, smells, colors, etc., with regard to the object in which they appear to reside, are nothing more than mere names. They exist only in the sensitive body, for when the living creature is removed all these qualities are carried off and annihilated, although we have imposed particular names upon them, and would fain persuade ourselves that they truly and in fact exist. I do not believe that there exists anything in external bodies for exciting tastes, smells, and sounds, etc., except size, shape, quantity, and motion."

In other words, physical science confined itself to the so-called primary qualities: the secondary qualities are spurned as subjective. But a primary quality is no more ultimate or elementary than a secondary quality, and a sensitive body is no less real than an insensitive body. Biologically speaking, smell was highly important for survival: more so, perhaps, than the ability to discriminate distance or weight: for it is the chief means of determining whether food is fit to eat, and pleasure in odors not merely refined the process of eating but gave a special association to the visible symbols of erotic interest, sublimated finally in perfume. The primary qualities could be called prime only in terms of mathematical

analysis, because they had, as an ultimate point of reference, an independent measuring stick for time and space, a clock, a ruler, a balance.

The value of concentrating upon primary qualities was that it neutralized in experiment and analysis the sensory and emotional reactions of the observer: apart from the process of thinking, he became an instrument of record. In this manner, scientific technique became communal, impersonal, objective, within its limited field, the purely conventional "material world." This technique resulted in a valuable moralization of thought: the standards, first worked out in realms foreign to man's personal aims and immediate interests, were equally applicable to more complex aspects of reality that stood closer to his hopes, loves, ambitions. But the first effect of this advance in clarity and in sobriety of thought was to devaluate every department of experience except that which lent itself to mathematical investigation. When the Royal Society was founded in England, the humanities were deliberately excluded.

In general, the practice of the physical sciences meant an intensification of the senses: the eye had never before been so sharp, the ear so keen, the hand so accurate. Hooke, who had seen how glasses improved seeing, doubted not that "there may be found Mechanical Inventions to improve our other senses, of hearing, smelling, tasting, touching." But with this gain in accuracy, went a deformation of experience as a whole. The instruments of science were helpless in the realm of qualities. The qualitative was reduced to the subjective: the subjective was dismissed as unreal, and the unseen and unmeasurable non-existent. Intuition and feeling did not affect mechanical process or mechanical explanations. Much could be accomplished by the new science and the new technics because much that was associated with life and work in the past—art, poetry, organic rhythm, fantasy—was deliberately eliminated. As the outer world of perception grew in importance, the inner world of feeling became more and more impotent.

The division of labor and the specialization in single parts of an operation, which already had begun to characterize the economic life of the seventeenth century, prevailed in the world of thought:

they were expressions of the same desire for mechanical accuracy and for quick results. The field of research was progressively divided up, and small parts of it were subject to intensive examination: in small measures, so to say, truth might perfect be. This restriction was a great practical device. To know the complete nature of an object does not necessarily make one fit to work with it: for complete knowledge requires a plenitude of time: moreover, it tends finally to a sort of identification which lacks precisely the cool aloofness that enables one to handle it and manipulate it for external ends. If one wishes to eat a chicken, one had better treat it as food from the beginning, and not give it too much friendly attention or human sympathy or even esthetic appreciation: if one treats the life of the chicken as an end, one may even with Brahminical thoroughness preserve the lice in its feathers as well as the bird. Selectivity is an operation necessarily adopted by the organism to keep it from being overwhelmed with irrelevant sensations and comprehensions. Science gave this inevitable selectivity a new rationale: it singled out the most negotiable set of relations, mass, weight, number, motion.

Unfortunately, isolation and abstraction, while important to orderly research and refined symbolic representation, are likewise conditions under which real organisms die, or at least cease to function effectively. The rejection of experience in its original whole, besides abolishing images and disparaging the non-instrumental aspects of thought, had another grave result: on the positive side, it was a belief in the dead; for the vital processes often escape close observation so long as the organism is alive. In short, the accuracy and simplicity of science, though they were responsible for its colossal practical achievements, were not an approach to objective reality but a departure from it. In their desire to achieve exact results the physical sciences scorned true objectivity: individually, one side of the personality was paralyzed; collectively, one side of experience was ignored. To substitute mechanical or two-way time for history, the dissected corpse for the living body, dismantled units called "individuals" for men-in-groups, or in general the mechanically measurable or reproducible for the inaccessible and the complicated and the organically whole, is to achieve a limited practical mastery

at the expense of truth and of the larger efficiency that depends on truth.

By confining his operations to those aspects of reality which had, so to say, market value, and by isolating and dismembering the corpus of experience, the physical scientist created a habit of mind favorable to discrete practical inventions: at the same time it was highly unfavorable to all those forms of art for which the secondary qualities and the individualized receptors and motivators of the artist were of fundamental importance. By his consistent metaphysical principles and his factual method of research, the physical scientist denuded the world of natural and organic objects and turned his back upon real experience: he substituted for the body and blood of reality a skeleton of effective abstractions which he could manipulate with appropriate wires and pulleys.

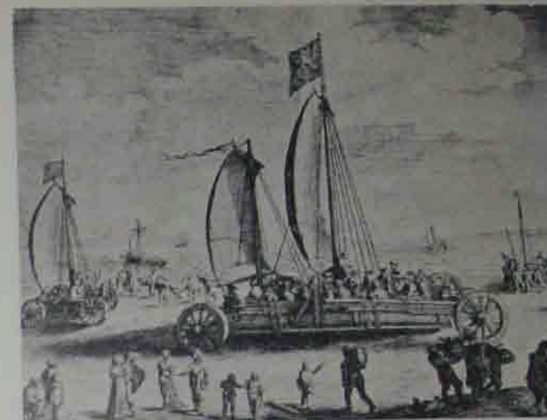
What was left was the bare, depopulated world of matter and motion: a wasteland. In order to thrive at all, it was necessary for the inheritors of the seventeenth century idolum to fill the world up again with new organisms, devised to represent the new realities of physical science. Machines—and machines alone—completely met the requirements of the new scientific method and point of view: they fulfilled the definition of "reality" far more perfectly than living organisms. And once the mechanical world-picture was established, machines could thrive and multiply and dominate existence: their competitors had been exterminated or had been consigned to a penumbral universe in which only artists and lovers and breeders of animals dared to believe. Were machines not conceived in terms of primary qualities alone, without regard to appearance, sound, or any other sort of sensory stimulation? If science presented an ultimate reality, then the machine was, like the law in Gilbert's ballad, the true embodiment of everything that was excellent. Indeed in this empty, denuded world, the invention of machines became a duty. By renouncing a large part of his humanity, a man could achieve godhood: he dawned on this second chaos and created the machine in his own image: the image of power, but power ripped loose from his flesh and isolated from his humanity.

10: The Duty to Invent

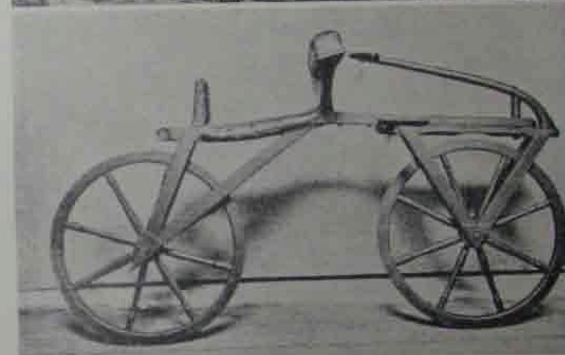
The principles that had proved effective in the development of the scientific method were, with appropriate changes, those that served as a foundation for invention. Technics is a translation into appropriate, practical forms of the theoretic truths, implicit or formulated, anticipated or discovered, of science. Science and technics form two independent yet related worlds: sometimes converging, sometimes drawing apart. Mainly empirical inventions, like the steam-engine, may suggest Carnot's researches in thermodynamics: abstract physical investigation, like Faraday's with the magnetic field, may lead directly to the invention of the dynamo. From the geometry and astronomy of Egypt and Mesopotamia, both closely connected with the practice of agriculture to the latest researches in electro-physics, Leonardo's dictum holds true: Science is the captain and practice the soldiers. But sometimes the soldiers win the battle without leadership, and sometimes the captain, by intelligent strategy, obtains victory without actually engaging in battle.

The displacement of the living and the organic took place rapidly with the early development of the machine. For the machine was a counterfeit of nature, nature analyzed, regulated, narrowed, controlled by the mind of men. The ultimate goal of its development was however not the mere conquest of nature but her resynthesis: dismembered by thought, nature was put together again in new combinations: material syntheses in chemistry, mechanical syntheses in engineering. The unwillingness to accept the natural environment as a fixed and final condition of man's existence had always contributed both to his art and his technics: but from the seventeenth century, the attitude became compulsive, and it was to technics that he turned for fulfillment. Steam engines displaced horse power, iron and concrete displaced wood, aniline dyes replaced vegetable dyes, and so on down the line, with here and there a gap. Sometimes the new product was superior practically or esthetically to the old, as in the infinite superiority of the electric lamp over the tallow candle: sometimes the new product remained inferior in quality, as rayon is still inferior to natural silk: but in either event the gain was in

I. ANTICIPATIONS OF SPEED



1: Rapid land locomotion: the sail-wagon (1598) used by Prince Maurice of Orange, one of the first commanders to introduce modern drill. The desire for speed, proclaimed by Roger Bacon in the thirteenth century, had become insistent by the sixteenth century. Hence skates for sport.
(Courtesy, Deutsches Museum, München)



2: [illegible] bicycle, invented by [illegible]. Note that [illegible] automobile also [illegible] for propulsion. The original bicycle was built of wood. After various experiments in high wheels, the machine returned to its original lines.
(Courtesy, Deutsches Museum, München)

3: Henson [illegible]'s flying machine, built [illegible] patented by Henson in [illegible] first to follow the [illegible] birds.
(Courtesy [illegible] the Science Museum: London)

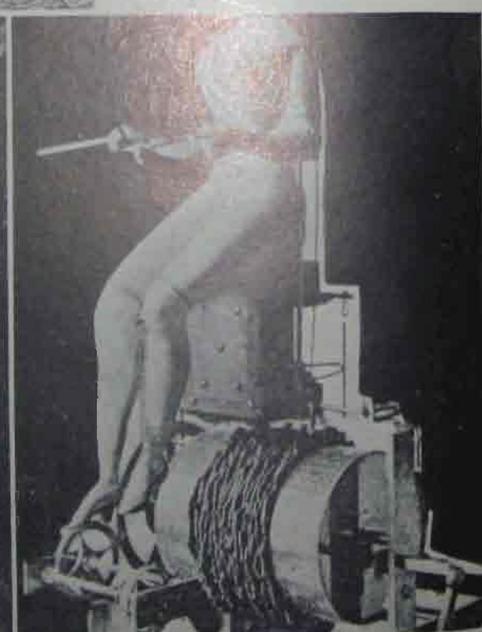
4: Church's steam-driven passenger coach: one of many types of steam automobile driven off the roads in the 1830's by railway monopolies. The development of the automobile awaited rubber tires, heavy-surfaced roads, and liquid fuel.
(Courtesy, Deutsches Museum, München)

and so on down the line, with here and there a gap. Sometimes the
coach: one of many types of steam

1: Dawn of naturalism in the twelfth century.
(*Saint Lazare d'Autun, France*)

2: Engraving from Dürer's treatise on perspective. Scientific accuracy in representation: co-ordination of size, distance, and movement. Beginning of the cartesian logic of science.

3: Tintoretto's Susanna and the Elders: the complete picture shows a mirror at Susanna's feet: See Chapter II, Section 9, also Chapter III, Section 6.



4: Eighteenth century automaton, or the clockwork Venus: the penultimate step from naturalism to mechanism. The next move is to remove the organic symbol entirely.

the creation of an equivalent product or synthesis which was less dependent upon uncertain organic variations and irregularities in either the product itself or the labor applied to it than was the original.

Often the knowledge upon which the displacement was made was insufficient and the result was sometimes disastrous. The history of the last thousand years abounds in examples of apparent mechanical and scientific triumphs which were fundamentally unsound. One need only mention bleeding in medicine, the use of common window glass which excluded the important ultra-violet rays, the establishment of the post-Liebig dietary on the basis of mere energy replacement, the use of the elevated toilet seat, the introduction of steam heat, which dries the air excessively—but the list is a long and somewhat appalling one. The point is that invention had become a duty, and the desire to use the new marvels of technics, like a child's delighted bewilderment over new toys, was not in the main guided by critical discernment: people agreed that inventions were good, whether or not they actually provided benefits, just as they agreed that child-bearing was good, whether the offspring proved a blessing to society or a nuisance.

Mechanical invention, even more than science, was the answer to a dwindling faith and a faltering life-impulse. The meandering energies of men, which had flowed over into meadow and garden, had crept into grotto and cave, during the Renascence, were turned by invention into a confined head of water above a turbine: they could sparkle and ripple and cool and revive and delight no more: they were harnessed for a narrow and definite purpose: to move wheels and multiply society's capacity for work. To live was to work: *what other life indeed do machines know?* Faith had at last found a new object, not the moving of mountains, but the moving of engines and machines. Power: the application of power to motion, and the application of motion to production, and of production to money-making, and so the further increase of power—this was the worthiest object that a mechanical habit of mind and a mechanical mode of action put before men. As everyone recognizes, a thousand salutary instruments came out of the new technics; but in origin from the seventeenth century on the machine served as a substitute religion,

ing, and so the further increase of power—this was the worthiest

and a vital religion does not need the justification of mere utility.

The religion of the machine needed such support as little as the transcendental faiths it supplanted: for the mission of religion is to provide an ultimate significance and motive-force: the necessity of invention was a dogma, and the ritual of a mechanical routine was the binding element in the faith. In the eighteenth century, Mechanical Societies sprang into existence, to propagate the creed with greater zeal: they preached the gospel of work, justification by faith in mechanical science, and salvation by the machine. Without the missionary enthusiasm of the enterprisers and industrialists and engineers and even the untutored mechanics from the eighteenth century onward, it would be impossible to explain the rush of converts and the accelerated tempo of mechanical improvement. The impersonal procedure of science, the hard-headed contrivances of mechanics, the rational calculus of the utilitarians—these interests captured emotion, all the more because the golden paradise of financial success lay beyond.

In their compilation of inventions and discoveries, Darmstaedter and Du Bois-Reymond enumerated the following inventors: between 1700 and 1750—170: between 1750 and 1800—344: between 1800 and 1850—861: between 1850 and 1900—1150. Even allowing for the foreshortening brought about automatically by historical perspective, one cannot doubt the increased acceleration between 1700 and 1850. Technics had seized the imagination: the engines themselves and the goods they produced both seemed immediately desirable. While much good came through invention, much invention came irrespective of the good. If the sanction of utility had been uppermost, invention would have proceeded most rapidly in the departments where human need was sharpest, in food, shelter, and clothing: but although the last department undoubtedly advanced, the farm and the common dwelling house were much slower to profit by the new mechanical technology than were the battlefield and the mine, while the conversion of gains in energy into a life abundant took place much more slowly after the seventeenth century than it had done during the previous seven hundred years.

Once in existence, the machine tended to justify itself by silently

taking over departments of life neglected in its ideology. Virtuosity is an important element in the development of technics: the interest in the materials as such, the pride of mastery over tools, the skilled manipulation of form. The machine crystallized in new patterns the whole set of independent interests which Thorstein Veblen grouped loosely under "the instinct of workmanship," and enriched technics as a whole even when it temporarily depleted handicraft. The very sensual and contemplative responses, excluded from love-making and song and fantasy by the concentration upon the mechanical means of production, were not of course finally excluded from life: they re-entered it in association with the technical arts themselves, and the machine, often lovingly personified as a living creature, as with Kipling's engineers, absorbed the affection and care of both inventor and workman. Cranks, pistons, screws, valves, sinuous motions, pulsations, rhythms, murmurs, sleek surfaces, all are virtual counterparts of the organs and functions of the body, and they stimulated and absorbed some of the natural affections. But when that stage was reached, the machine was no longer a means and its operations were not merely mechanical and causal, but human and final: it contributed, like any other work of art, to an organic equilibrium. This development of value within the machine complex itself, apart from the value of the products created by it, was, as we shall see at a later stage, a profoundly important result of the new technology.

11: Practical Anticipations

From the beginning, the practical value of science was uppermost in the minds of its exponents, even in those who single-mindedly pursued abstract truth, and who were as indifferent to its popularization as Gauss and Weber, the scientists who invented the telegraph for their private communication. "If my judgment be of any weight," said Francis Bacon in The Advancement of Learning, "the use of history mechanical is of all others the most radical and fundamental towards natural philosophy: such natural philosophy as shall not vanish in the fume of subtile, sublime, or delectable speculation, but such as shall be operative to the endowment and benefit of man's life." And Descartes, in his Discourse on Method, observes: "For by them [general restrictions respecting physics] I perceived it to be possible to arrive at knowledge highly useful in life; and in lieu of the speculative philosophy usually taught in the schools to discover a practical, by means of which, knowing the force and action of fire, water, air, the stars, the heavens, and all the other bodies that surround us, as distinctly as we know the various crafts of our artisans, we might also apply them in the same way to all the uses to which they are adapted, and thus render ourselves the lords and possessors of nature. And this is a result to be desired, not only in order to the invention of an infinity of arts, by which we might be able to enjoy without any trouble the fruits of the earth, and all its comforts, but also especially for the preservation of health, which is without doubt of all blessings of this life the first and fundamental one; for the mind is so intimately dependent upon the condition and relation of the organs of the body that if any means can ever be found to render men wiser and more ingenious than hitherto, I believe that it is in medicine they must be sought for."

Who is rewarded in the perfect commonwealth devised by Bacon in The New Atlantis? In Salomon's House the philosopher and the artist and the teacher were left out of account, even though Bacon, like the prudent Descartes, clung very ceremoniously to the rites of the Christian church. For the "ordinances and rites" of Salomon's House there are two galleries. In one of these "we place patterns and samples of all manner of the more rare and excellent inventions: in the other we place the statues of all principal Inventors. There we have the statue of your Columbus, that discovered the West Indies: also the Inventor of Ships: your monk that was the Inventor of Ordnance and Gunpowder: the Inventor of Music: the Inventor of Letters: the Inventor of Printing: the Inventor of observations by astronomy: the Inventor of Works in Metal: the Inventor of Glass: the Inventor of Silk of the Worm: the Inventor of Wine: the Inventor of Corn and Bread: the Inventor of Sugars. . . . For upon every invention of value, we erect a statue to the Inventor and give him a liberal and honorable reward." This Salomon's House, as Bacon fancied it, was a combination of the Rockefeller Institute

and the Deutsches Museum: there, if anywhere, was the means towards the relief of man's estate.

Observe this: there is little that is vague or fanciful in all these conjectures about the new rôle to be played by science and the machine. The general staff of science had worked out the strategy of the campaign long before the commanders in the field had developed a tactics capable of carrying out the attack in detail. Indeed, Usher notes that in the seventeenth century invention was relatively feeble, and the power of the technical imagination had far outstripped the actual capacities of workmen and engineers. Leonardo, Andreae, Campanella, Bacon, Hooke in his Micrographia and Glanvill in his Scepsis Scientifica, wrote down in outline the specifications for the new order: the use of science for the advancement of technics, and the direction of technics toward the conquest of nature were the burden of the whole effort. Bacon's Salomon's House, though formulated after the actual founding of the Accademia Lynxei in Italy, was the actual starting point of the Philosophical College that first met in 1646 at the Bullhead Tavern in Cheapside, and in 1662 was duly incorporated as the Royal Society of London for Improving Natural Knowledge. This society had eight standing committees, the first of which was to "consider and improve all mechanical inventions." The laboratories and technical museums of the twentieth century existed first as a thought in the mind of this philosophical courtier: nothing that we do or practice today would have surprised him.

So confident in the results of the new approach was Hooke that he wrote: "There is nothing that lies within the power of human wit (or which is far more effectual) of human industry which we might not compass; we might not only hope for inventions to equalize those of Copernicus, Galileo, Gilbert, Harvey, and others, whose names are almost lost, that were the inventors of Gunpowder, the Seaman's Compass, Printing, Etching, Graving, Microscopes, Etc., but multitudes that may far exceed them: for even those discovered seem to have been the product of some such methods though but imperfect; what may not be therefore expected from it if thoroughly prosecuted? Talking and contention of Arguments would soon be turned into labors; all the fine dreams and opinions and universal metaphysical nature, which the luxury of subtil brains has devised, would quickly vanish and give place to solid histories, experiments, and works."

The leading utopias of the time, Christianopolis, the City of the Sun, to say nothing of Bacon's fragment or Cyrano de Bergerac's minor works, all brood upon the possibility of utilizing the machine to make the world more perfect: the machine was the substitute for Plato's justice, temperance, and courage, even as it was likewise for the Christian ideals of grace and redemption. The machine came forth as the new demiurge that was to create a new heaven and a new earth: at the least, as a new Moses that was to lead a barbarous humanity into the promised land.

There had been premonitions of all this in the centuries before. "I will now mention," said Roger Bacon, "some of the wonderful works of art and nature in which there is nothing of magic and which magic could not perform. Instruments may be made by which the largest ships, with only one man guiding them, will be carried with greater velocity than if they were full of sailors. Chariots may be constructed that will move with incredible rapidity without the help of animals. Instruments of flying may be formed in which a man, sitting at his ease and meditating in any subject, may beat the air with his artificial wings after the manner of birds . . . as also machines which will enable men to walk at the bottom of seas or rivers without ships." And Leonardo de Vinci left behind him a list of inventions and contrivances that reads like a synopsis of the present industrial world.

But by the seventeenth century the note of confidence had increased, and the practical impulse had become more universal and urgent. The works of Porta, Cardan, Besson, Ramelli, and other ingenious inventors, engineers, and mathematicians are a witness both to increasing skill and to growing enthusiasm over technics itself. Schwenter in his Délassements Physico-Mathématiques (1636) pointed out how two individuals could communicate with each other by means of magnetic needles. "To them that come after us," said Glanvill, "it may be as ordinary to buy a pair of wings to fly to remotest regions, as now a pair of boots to ride a journey; and

to confer at the distance of the Indies by sympathetic conveyances may be as usual in future times as by literary correspondence." Cyrano de Bergerac conceived the phonograph. Hooke observed that it is "not impossible to hear a whisper a furlong's distance, it having been already done; and perhaps the nature of things would not make it more impossible, although that furlong be ten times multiplied." Indeed, he even forecast the invention of artificial silk. And Glanvill said again: "I doubt not posterity will find many things that are now but rumors verified into practical realities. It may be that, some ages hence, a voyage to the Southern tracts, yea, possibly to the moon, will not be more strange than one to America. . . . The restoration of grey hairs to juvenility and the renewing the exhausted marrow may at length be effected without a miracle; and the turning of the now comparatively desert world into a paradise may not improbably be effected from late agriculture." (1661)

Whatever was lacking in the outlook of the seventeenth century it was not lack of faith in the imminent presence, the speedy development, and the profound importance of the machine. Clock-making: time-keeping: space-exploration: monastic regularity: bourgeois order: technical devices: protestant inhibitions: magical explorations: finally the magistral order, accuracy, and clarity of the physical sciences themselves—all these separate activities, inconsiderable perhaps in themselves, had at last formed a complex social and ideological network, capable of supporting the vast weight of the machine and extending its operations still further. By the middle of the eighteenth century the initial preparations were over and the key inventions had been made. An army of natural philosophers, rationalists, experimenters, mechanics, ingenious people, had assembled who were clear as to their goal and confident as to their victory. Before more than a streak of grey had appeared at the horizon's rim, they proclaimed the dawn and announced how wonderful it was: how marvelous the new day would be. Actually, they were to announce a shift in the seasons, perhaps a long cyclical change in the climate itself.

self. Schwenter in his Délassements Physico-Mathématiques (1636)
a long cyclical change in the climate