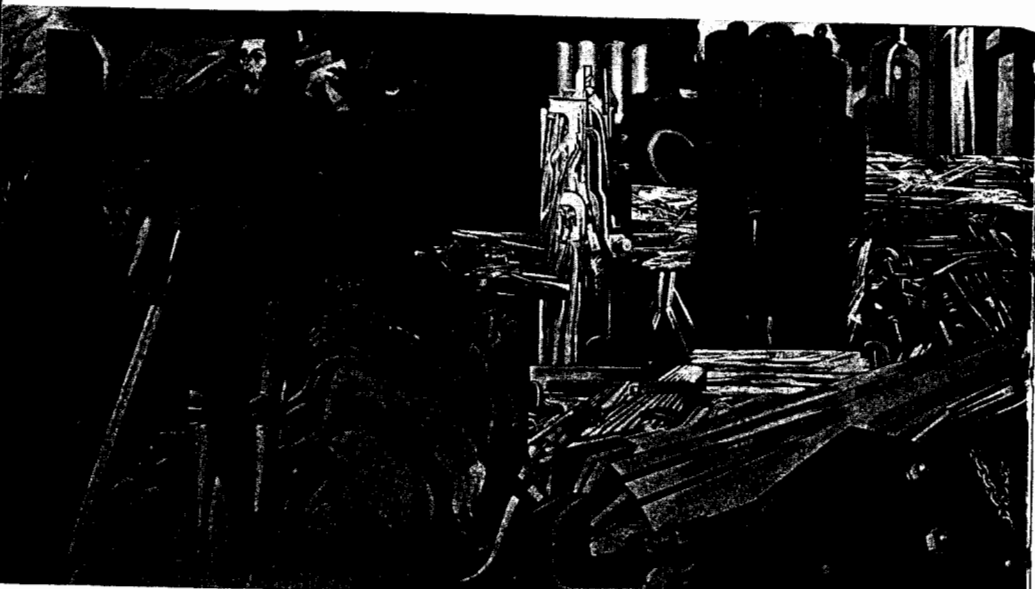


TECHNICS AND CIVILIZATION

BY LEWIS MUMFORD



I. THE GENESIS OF THE MACHINE

HARCOURT, BRACE AND COMPANY

NEW YORK

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Third printing, June, 1934

*The first draft of this book was written in 1930 and the second was completed in 1931. Up to 1932 my purpose was to deal with the machine, the city, the region, the group, and the personality within a single volume. In working out the section on technics it was necessary to increase the scale of the whole project: so the present book covers only a limited area of the first draft. While *Technics and Civilization* is a unit, certain aspects of the machine, such as its relation to architecture, and certain aspects of civilization that may ultimately bear upon the course of technics remain to be treated at another time.* L. M.

Typography by Robert Josephy

PRINTED IN THE UNITED STATES OF AMERICA
BY QUINN & BODEN COMPANY, INC., RAHWAY, N. J.

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OBJECTIVES

During the last thousand years the material basis and the cultural forms of Western Civilization have been profoundly modified by the development of the machine. How did this come about? Where did it take place? What were the chief motives that encouraged this radical transformation of the environment and the routine of life: what were the ends in view: what were the means and methods: what unexpected values have arisen in the process? These are some of the questions that the present study seeks to answer.

While people often call our period the "Machine Age," very few have any perspective on modern technics or any clear notion as to its origins. Popular historians usually date the great transformation in modern industry from Watt's supposed invention of the steam engine; and in the conventional economics textbook the application of automatic machinery to spinning and weaving is often treated as an equally critical turning point. But the fact is that in Western Europe the machine had been developing steadily for at least seven centuries before the dramatic changes that accompanied the "industrial revolution" took place. Men had become mechanical before they perfected complicated machines to express their new bent and interest; and the will-to-order had appeared once more in the monastery and the army and the counting-house before it finally manifested itself in the factory. Behind all the great material inventions of the last century and a half was not merely a long internal development of technics: there was also a change of mind. Before the new industrial processes could take hold on a great scale, a reorientation of wishes, habits, ideas, goals was necessary.

To understand the dominating rôle played by technics in modern civilization, one must explore in detail the preliminary period of ideological and social preparation. Not merely must one explain the existence of the new mechanical instruments: one must explain the culture that was ready to use them and profit by them so extensively. For note this: mechanization and regimentation are not new phenomena in history: what is new is the fact that these functions have been projected and embodied in organized forms which dominate every aspect of our existence. Other civilizations reached a high degree of technical proficiency without, apparently, being profoundly influenced by the methods and aims of technics. All the critical instruments of modern technology—the clock, the printing press, the water-mill, the magnetic compass, the loom, the lathe, gunpowder, paper, to say nothing of mathematics and chemistry and mechanics—existed in other cultures. The Chinese, the Arabs, the Greeks, long before the Northern European, had taken most of the first steps toward the machine. And although the great engineering works of the Cretans, the Egyptians, and the Romans were carried out mainly on an empirical basis, these peoples plainly had an abundance of technical skill at their command. They had machines; but they did not develop “the machine.” It remained for the peoples of Western Europe to carry the physical sciences and the exact arts to a point no other culture had reached, and to adapt the whole mode of life to the pace and the capacities of the machine. How did this happen? How in fact could the machine take possession of European society until that society had, by an inner accommodation, surrendered to the machine?

Plainly, what is usually called *the* industrial revolution, the series of industrial changes that began in the eighteenth century, was a transformation that took place in the course of a much longer march.

The machine has swept over our civilization in three successive waves. The first wave, which was set in motion around the tenth century, gathered strength and momentum as other institutions in civilization were weakening and dispersing: this early triumph of the machine was an effort to achieve order and power by purely external means, and its success was partly due to the fact that it

evaded many of the real issues of life and turned away from the momentous moral and social difficulties that it had neither confronted nor solved. The second wave heaved upward in the eighteenth century after a long steady roll through the Middle Ages, with its improvements in mining and iron-working: accepting all the ideological premises of the first effort to create the machine, the disciples of Watt and Arkwright sought to universalize them and take advantage of the practical consequences. In the course of this effort, various moral and social and political problems which had been set to one side by the exclusive development of the machine, now returned with doubled urgency: the very efficiency of the machine was drastically curtailed by the failure to achieve in society a set of harmonious and integrated purposes. External regimentation and internal resistance and disintegration went hand in hand: those fortunate members of society who were in complete harmony with the machine achieved that state only by closing up various important avenues of life. Finally, we begin in our own day to observe the swelling energies of a third wave: behind this wave, both in technics and in civilization, are forces which were suppressed or perverted by the earlier development of the machine, forces which now manifest themselves in every department of activity, and which tend toward a new synthesis in thought and a fresh synergy in action. As the result of this third movement, the machine ceases to be a substitute for God or for an orderly society; and instead of its success being measured by the mechanization of life, its worth becomes more and more measurable in terms of its own approach to the organic and the living. The receding waves of the first two phases of the machine diminish a little the force of the third wave: but the image remains accurate to the extent that it suggests that the wave with which we are now being carried forward is moving in a direction opposite to those of the past.

By now, it is plain, a new world has come into existence; but it exists only in fragments. New forms of living have for long been in process; but so far they have likewise been divided and unfocussed: indeed, our vast gains in energy and in the production of goods have manifested themselves in part in a loss of form and an impoverishment of life. What has limited the beneficence of the machine? Under

what conditions may the machine be directed toward a fuller use and accomplishment? To these questions, too, the present study seeks an answer. Technics and civilization as a whole are the result of human choices and aptitudes and strivings, deliberate as well as unconscious, often irrational when apparently they are most objective and scientific: but even when they are uncontrollable they are not external. Choice manifests itself in society in small increments and moment-to-moment decisions as well as in loud dramatic struggles; and he who does not see choice in the development of the machine merely betrays his incapacity to observe cumulative effects until they are bunched together so closely that they seem completely external and impersonal. No matter how completely technics relies upon the objective procedures of the sciences, it does not form an independent system, like the universe: it exists as an element in human culture and it promises well or ill as the social groups that exploit it promise well or ill. The machine itself makes no demands and holds out no promises: it is the human spirit that makes demands and keeps promises. In order to reconquer the machine and subdue it to human purposes, one must first understand it and assimilate it. So far, we have embraced the machine without fully understanding it, or, like the weaker romantics, we have rejected the machine without first seeing how much of it we could intelligently assimilate.

The machine itself, however, is a product of human ingenuity and effort: hence to understand the machine is not merely a first step toward re-orienting our civilization: it is also a means toward understanding society and toward knowing ourselves. The world of technics is not isolated and self-contained: it reacts to forces and impulses that come from apparently remote parts of the environment. That fact makes peculiarly hopeful the development that has been going on within the domain of technics itself since around 1870: for the organic has become visible again even within the mechanical complex: some of our most characteristic mechanical instruments—the telephone, the phonograph, the motion picture—have grown out of our interest in the human voice and the human eye and our knowledge of their physiology and anatomy. Can one detect, perhaps, the characteristic properties of this emergent order—its pattern, its

planes, its angle of polarization, its color? Can one, in the process of crystallization, remove the turbid residues left behind by our earlier forms of technology? Can one distinguish and define the specific properties of a technics directed toward the service of life: properties that distinguish it morally, socially, politically, esthetically from the cruder forms that preceded it? Let us make the attempt. The study of the rise and development of modern technics is a basis for understanding and strengthening this contemporary transvaluation: and the transvaluation of the machine is the next move, perhaps, toward its mastery.

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 me-

chanical or sensory capacities of the human body, or for reducing to a measurable 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

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

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

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

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 clock-work” 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 Renaissance 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 over-estimated: 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

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 Renaissance: 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 Renaissance 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 Bianco, 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

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,

13: Summary and Prospect

We have studied the origins, the advances, the triumphs, the lapses, and the further promises of modern technics. We have observed the limitations the Western European imposed upon himself in order to create the machine and project it as a body outside his personal will: we have noted the limitations that the machine has imposed upon men through the historic accidents that accompanied its development. We have seen the machine arise out of the denial of the organic and the living, and we have in turn marked the reaction of the organic and the living upon the machine. This reaction has two forms. One of them, the use of mechanical means to return to the primitive, means a throwback to lower levels of thought and emotion which will ultimately lead to the destruction of the machine itself and the higher types of life that have gone into its conception. The other involves the rebuilding of the individual personality and the collective group, and the re-orientation of all forms of thought and social activity toward life: this second reaction promises to transform the

nature and function of our mechanical environment and to lay wider and firmer and safer foundations for human society at large. The issue is not decided: the results are not certain: and where in the present chapter I have used the prophetic form I have not been blind to the fact that while all the tendencies and movements I have pointed to are real, they are still far from being supreme: so when I have said "it will" I have meant "we must."

In discussing the modern technics, we have advanced as far as seems possible in considering mechanical civilization as an isolated system: the next step toward re-orienting our technics consists in bringing it more completely into harmony with the new cultural and regional and societal and personal patterns we have co-ordinately begun to develop. It would be a gross mistake to seek wholly within the field of technics for an answer to all the problems that have been raised by technics. For the instrument only in part determines the character of the symphony or the response of the audience: the composer and the musicians and the audience have also to be considered.

What shall we say of the music that has so far been produced? Looking backward on the history of modern technics, one notes that from the tenth century onward the instruments have been scraping and tuning. One by one, before the lights were up, new members had joined the orchestra, and were straining to read the score. By the seventeenth century the fiddles and the wood-wind had assembled, and they played in their shrill high notes the prelude to the great opera of mechanical science and invention. In the eighteenth century the brasses joined the orchestra, and the opening chorus, with the metals predominating over the wood, rang through every hall and gallery of the Western World. Finally, in the nineteenth century, the human voice itself, hitherto subdued and silent, was timidly sounded through the systematic dissonances of the score, at the very moment that imposing instruments of percussion were being introduced. Have we heard the complete work? Far from it. All that has happened up to now has been little more than a rehearsal, and at last, having recognized the importance of the singers and the chorus, we will have to score the music differently, subduing the insistent brasses and the kettle-drums and giving more prominence to the violins and the

voices. But if this turns out to be so, our task is even more difficult: for we will have to re-write the music in the act of playing it, and change the leader and re-group the orchestra at the very moment that we are re-casting the most important passages. Impossible? No: for however far modern science and technics have fallen short of their inherent possibilities, they have taught mankind at least one lesson: Nothing is impossible.

INVENTIONS

1: Introduction

This list of inventions makes no pretence to being exhaustive. It is meant merely to provide an historical framework of technical facts for the social interpretations of the preceding pages. While I have attempted to choose the more important inventions and processes, I have doubtless left out many that have equal claim to appear. The most comprehensive guide to this subject are the compilations by Darmstaedter and by Feldhaus; but I have drawn from a variety of sources. The dates and attributions of many inventions, as every technician knows, must remain somewhat arbitrary. Unlike a human baby, one often cannot say at what date an invention is born: frequently, indeed, what was apparently a still birth may be resuscitated a few years after its first unhappy appearance. And again, with inventions the family lineage often is hard to establish; for, as W. F. Ogburn and Dorothy S. Thomas have demonstrated, inventions are often practically simultaneous: the result of a common heritage and a common need. While I have endeavored to be both accurate and impartial in giving the date of the invention and the name of the putative inventor, the reader should keep in mind that these data are offered only for his convenience in looking further. Instead of a single date one finds usually a series of dates which mark progress from the state of pure fantasy to concrete realization in the form that has been most acceptable to the capitalist *mores*—that of a commercial success. As a result of these *mores* far too much stress has usually been laid upon the individual who put the title of private ownership upon this social process by taking out patent rights on “his” invention. But observe: inventions are often patented long before they can be practicably used, and, on the other hand, they are often ready for use long before industrial enterprisers are willing to take advantage of them. Since modern science and technology are part of the common stock of Western Civilization, I have refused to attribute inventions to one country or another and I have done my best to avoid an unconscious bias in weighting the list in behalf of my own country—trusting by my good example to shame the scholars who permit their most childish impulses to flaunt themselves in this field. If any bias or misinformation still exists, I will welcome corrections.

2: List of Inventions

Summary of the existing technics before the tenth century. Fire: its application in furnaces, ovens, kilns. The simple machines: inclined plane, screw, etc. Thread, cord, rope. Spinning and weaving. Advanced agriculture, including irrigation, terrace-cultivation, and soil regeneration (lapsed in Northern Europe). Cattle breeding and the use of the horse for transport. Glass-making, pottery-making, basket-making. Mining, metallurgy and smithing, including the working of iron. Power machines: water-mills, boats with sails, probably windmills. Machine-tools: bow-drills and lathes. Handicraft tools with tempered metal cutting edges. Paper. Water-clocks. Astronomy, mathematics, physics, and the tradition of science. In Northern Europe a scattered and somewhat decayed technological tradition based on Rome; but South and East, from Spain to China, an advanced and still active technology, whose ideas were filtering into the West and North through traders, scholars, and soldiers.

TENTH CENTURY

Use of water-clocks and water-mills.

The iron horse-shoe and an effective harness for horses. Multiple yoke for oxen. Possible invention of the mechanical clock.

999: Painted glass windows in England

ELEVENTH CENTURY

1041-49: Movable type (Pi Sheng)

1050: First real lenses (Alhazen)

1065: Oliver of Malmesbury attempts flight

1080: Decimal system (Azachel)

TWELFTH CENTURY

Military use of gunpowder in China.

The magnetic compass, known to the Chinese 1160 B.C., comes into Europe, via the Arabs.

1105: First recorded windmill in Europe (France)

1100: Bologna University

1118: Cannon used by Moors

1144: Paper (Spain)

1147: Use of wood cuts for Capital letters. (Benedictine monastery at Engelberg)

1180: Fixed steering rudder

1188: Bridge at Avignon. 18 stone arches—3,000 ft. long

1190: Paper mill (at Hérault, France)

1195: Magnetic compass in Europe (English Citation)

THIRTEENTH CENTURY

Mechanical clocks invented.

1232: Hot-air balloons (in China)

1247: Cannon used in defence of Seville

1269: Pivoted magnetic compass (Petrus Peregrinus)

1270: Treatise on lenses (Vitellio)

Compound lenses (Roger Bacon)

1272: Silk reeling machine (Bologna)

1280: Opus Ruralium Commodorum—Compendium of Agricultural Practice (Petrus de Crescentis)

1285-1299: Spectacles

1289: Block printing (Ravenna)

1290: Paper mill (Ravensburg)

1298: Spinning wheel

FOURTEENTH CENTURY

Mechanical clock becomes common.

Water-power used to create draft for blast furnace: makes cast iron possible. Treadle loom (inventor unknown). Invention of rudder and beginning of canalization. Improved glass-making.

1300: Wooden type (Turkestan)

INVENTIONS

1315: Beginnings of Scientific Anatomy through dissection of human body (Raimondo de Luzzi of Bologna)

1320: Water-driven iron works, near Döbrilugk

1322: Sawmill at Augsburg

1324: Cannon [Gunpowder: 846 A.D. (Magnus Graecus)]

1330: Crane at Lüneburg

1345: Division of hours and minutes into sixties

1338: Guns

1350: Wire-pulling machine (Rudolph of Nürnberg)

1370: Perfected mechanical clock (von Wyck)

1382: Giant cannon—4.86 metres long

1390: Metal types (Korea)

1390: Paper mill

FIFTEENTH CENTURY

Use of wind-mill for land drainage. Invention of turret windmill. Introduction of knitting. Iron drill for boring cannon. Trip-hammer. Two-masted and three-masted ship.

1402: Oil painting (Bros. van Eyck)

1405: Diving suit (Konrad Kyeser von Eichstadt)

1405: Infernal machine (Konrad Kyeser von Eichstadt)

1409: First book in movable type (Korea)

1410: Paddle-wheel boat designed

1418: Authentic wood engraving

1420: Observatory at Samarkand

1420: Sawmill at Madeira

1420: Velocipede (Fontana)

1420: War-wagon (Fontana)

1423: First European woodcut

1430: Turret windmill

1436: Scientific cartography (Banco)

1438: Wind-turbine (Mariano)

1440: Laws of perspective (Alberti)

1446: Copperplate engraving

1440-1460: Modern printing (Gutenberg and Schoeffer)

1457: Rediscovery of wagon on springs referred to by Homer

1470: Foundations of trigonometry (J. Müller Regiomontanus)

1471: Iron cannon balls

1472: Observatory at Nürnberg by Bernard Walther

1472-1519: Leonardo da Vinci made the following inventions:

Centrifugal pump

Dredge for canal-building

Polygonal fortress with outworks

Breech-loading cannon

Rifled firearms

Antifriction roller bearing

Universal joint

Conical screw

Rope-and-belt drive

Link chains

Submarine-boat

Bevel gears

Spiral gears

Proportional and paraboloid

Compasses

Silk doubling and winding apparatus

Spindle and flyer

Parachute

Lamp-chimney

Ship's log

Standardized mass-production house

1481: Canal lock (Dionisio and Petro Domenico)

1483: Copper etching (Wenceslaus von Olmutz)

1492: First globe (Martin Behaim)

SIXTEENTH CENTURY

Tinning for preservation of iron. Windmills of 10 H.P. become common. Much technical progress and mechanization in mining industries, spread of blast-furnaces and iron-moulding. Introduction of domestic clock.

1500: First portable watch with iron main-spring (Peter Henlein)

1500: Mechanical farming drill (Cavallina)

1500-1650: Intricate cathedral clocks reach height of development

1508: Multicolored woodcut

- 1511: Pneumatic beds (Vegetius)
 1518: Fire-engine (Platner)
 1524: Fodder-cutting machine
 1528: Re-invention of taxi meter for coaches
 1530: Foot-driven spinning wheel (Jürgens)
 1534: Paddle-wheel boat (Blasco de Garay)
 1535: Diving bell (Francesco del Marchi)
 1539: First astronomical map (Alessandro Piccolomini)
 1544: *Cosmographia Universalis* (Sebastian Münster)
 1544: Elaboration of algebraic symbols (Stifel)
 1545: Modern surgery (Ambroise Paré)
 1546: Railway in German mines
 1548: Water supply by pumping works (Augsburg)
 1550: First known suspension bridge in Europe (Palladio)
 1552: Iron-rolling machine (Brulier)
 1558: Military tank
 1558: Camera with lens and stop for diaphragm (Daniello Barbaro)
 1560: *Accademia Secretorum Naturae* at Naples (first scientific society)
 1565: Lead pencil (Gesner)
 1569: Industrial exhibition at Rathaus, Nürnberg
 1575: Hero's Opera (translation)
 1578: Screw lathe (Jacques Besson)
 1579: Automatic ribbon loom at Dantzig
 1582: Gregorian calendar revision
 1582: Tide-mill pump for London (Morrice)
 1585: Decimal system (Simon Stevin)
 1589: Knitting frame (William Lee)
 1589: Man-propelled wagon (Gilles de Bom)
 1590: Compound microscope (Jansen)
 1594: Use of clock to determine longitude
 1595: Design for metal bridges—arch and chain (Veranzio)
- 1595: Wind-turbine (Veranzio)
 1597: Revolving theater stage
- SEVENTEENTH CENTURY
- Water wheels of 20 H.P. introduced: transmission by means of reciprocating rods over distance of one-quarter mile. Glass hothouse comes into use. Foundations of modern scientific method. Rapid developments in physics.*
- 1600: Dribbling of wheat to increase yield (Plat)
 1600: Treatise on terrestrial magnetism and electricity (Gilbert)
 1600: Pendulum (Galileo)
 1603: *Accademia dei Lincei* at Rome
 1608: Telescope (Lippersheim)
 1609: First law of motion (Galileo)
 1610: Discovery of gases (Van Helmont)
 1613: Gunpowder in mine blasting
 1614: Discovery of logarithms by John Napier
 1615: Use of triangulation system in surveying by Willebrord Snell van Roijen (1581-1626)
 1617: First logarithm table (Henry Briggs)
 1618: Machine for plowing, manuring and sowing (Ramsay and Wilgoose)
 1619: Use of coke instead of charcoal in blast furnace (Dudley)
 1619: Tile-making machine
 1620: Adding machine (Napier)
 1624: Submarine (Cornelius Drebbel). Went two miles in test between Westminster and Greenwich
 1624: First patent law protecting inventions (England)
 1628: Steam engine (described 1663 by Worcester)
 1630: Patent for steam engine (David Ramsay)
 1635: Discovery of minute organisms (Leeuwenhoek)
 1636: Infinitesimal calculus (Fermat)
 1636: Fountain pen (Schwenter)
 1636: Threshing machine (Van Berg)

- 1637: Periscope (Hevel, Danzig)
 1643: Barometer (Torricelli)
 1647: Calculation of focusses of all forms of lens
 1650: Calculating machine (Pascal)
 1650: Magic lantern (Kircher)
 1652: Air pump (v. Guericke)
 1654: Law of probability (Pascal)
 1657: Pendulum clock (Huygens)
 1658: Balance spring for clocks (Hooke)
 1658: Red corpuscles in blood (Schwammerdam)
 1660: Probability law applied to insurance (Jan de Witt)
 1665: Steam automobile model (Verbiest, S. J.)
 1666: Mirror telescope (Newton)
 1667: Cellular structure of plants (Hooke)
 1667: Paris Observatory
 1669: Seed drill (Worlidge)
 1671: Speaking tube (Morland)
 1673: New Type fortification (Vauban)
 1675: First determination of speed of light (Roemer)
 1675: Greenwich Observatory founded
 1677: Foundation of Ashmolean Museum
 1678: Power loom (De Gennes)
 1679-1681: First modern tunnel for transport, 515 feet long, in Languedoc Canal
 1680: First power dredge (Cornelius Meyer)
 1680: Differential calculus (Leibniz)
 1680: Gas engine using gunpowder (Huygens)
 1682: Law of gravitation (Newton)
 1682: 100 H.P. pumping works at Marly (Ranneguin)
 1683: Industrial Exhibition at Paris
 1684: Fodder-chopper run by water-power (Delabadie)
 1685: Foundation of scientific obstetrics (Van Deventer)
 1687: Newton's *Principia*
 1688: Distillation of gas from coal (Clayton)
- 1695: Atmospheric steam engine (Papin)
- EIGHTEENTH CENTURY
- Rapid improvements in mining and textile machinery. Foundation of modern chemistry.*
- 1700: Water power for mass-production (Polhem)
 1705: Atmospheric steam engine (Newcomen)
 1707: Physician's pulse watch with second hand (John Floger)
 1708: Wet sand iron casting (Darby)
 1709: Coke used in blast furnace (Darby)
 1710: First stereotype (Van der Mey and Müller)
 1711: Sewing machine (De Camus)
 1714: Mercury thermometer (Fahrenheit)
 1714: Typewriter (Henry Mill)
 1716: Wooden railways covered with iron
 1719: Three color printing from copper plate (Le Blond)
 1727: First exact measurement of blood pressure (Stephen Hales)
 1727: Invention of stereotype (Ged)
 1727: Light-images with silver nitrate (Schulze: see 1839)
 1730: Stereotyping process (Goldsmith)
 1733: Flying shuttle (Kay)
 1733: Roller spinning (Wyatt and Paul)
 1736: Accurate chronometer (Harrison)
 1736: Commercial manufacture of sulphuric acid (Ward)
 1738: Cast-iron rail tramway (at Whitehaven, England)
 1740: Cast steel (Huntsman)
 1745: First technical school divided from army engineering at Braunschweig
 1749: Scientific calculation of water resistance to ship (Euler)
 1755: Iron wheels for coal cars

- 1756: Cement manufacture (Smeaton)
 1763: Modern type chronometer (Le Roy)
 1761: Air cylinders; piston worked by water wheel. More than tripled production of blast furnace (Smeaton)
 1763: First exhibition of the industrial arts. Paris.
 1763: Slide rest (French encycl.)
 1765-1769: Improved steam pumping engine with separate condenser (Watt)
 1767: Cast iron rails at Coalbrookdale
 1767: Spinning jenny (Hargreaves)
 1769: Steam carriage (Cugnot)
 1770: Caterpillar tread (R. L. Edgeworth: see 1902)
 1772: Description of ball-bearing (Narho)
 1774: Boring machine (Wilkinson)
 1775: Reciprocative engine with wheel
 1776: Reverberatory furnace (Brothers Cranege)
 1778: Modern water closet (Bramah)
 1778: Talking automaton (von Kempelen)
 1779: Bridge cast-iron sections (Darby and Wilkinson)
 1781-1786: Steam engine as prime mover (Watt)
 1781: Steamboat (Jouffroy)
 1781: Drill plow (Proude: also used by Babylonians: 1700-1200 B.C.)
 1782: Balloon (J. M. and J. E. Montgolfier). Original invention Chinese
 1784: Puddling process—reverberatory furnace (Cort)
 1784: Spinning mule (Crompton)
 1785: Interchangeable parts for muskets (Le Blanc)
 1785: First steam spinning mill at Papplewick
 1785: Power loom (Cartwright)
 1785: Chlorine as bleaching agent (Berthollet)
 1785: Screw propeller (Bramah)
 1787: Iron boat (Wilkinson)
 1787: Screw propeller steamboat (Fitch)
 1788: Threshing machine (Meikle)
 1790: Manufacture of soda from NaCl (Le Blanc)
 1790: Sewing machine first patented (M. Saint—England)
 1791: Gas engine (Barker)
 1792: Gas for domestic lighting (Murdock)
 1793: Cotton gin (Whitney)
 1793: Signal telegraph (Claude Chappe)
 1794: Ecole Polytechnique founded
 1795-1809: Food-canning (Appert)
 1796: Lithography (Senefelder)
 1796: Natural cement (J. Parker)
 1796: Toy helicopter (Cayley)
 1796: Hydraulic press (Bramah)
 1797: Screw-cutting lathe (Maudslay). Improved slide-rest metal lathe (Maudslay)
 1799: Humphry Davy demonstrates anesthetic properties of nitrous oxide
 1799: Conservatoire Nationale des Arts et Métiers (Paris)
 1799: Manufactured bleaching powder (Tennant)

NINETEENTH CENTURY

Enormous gains in power conversion. Mass-production of textiles, iron, steel, machinery. Railway building era. Foundations of modern biology and sociology.

- 1800: Galvanic cell (Volta)
 1801: Public railroad with horsepower—Wandsworth to Croydon, England
 1801: Steamboat *Charlotte Dundas* (Symington)
 1801-1802: Steam carriage (Trevithick)
 1802: Machine dresser for cotton warps (necessary for power weaving)
 1802: Planing machine (Bramah)
 1803: Side-paddle steamboat (Fulton)
 1804: Jacquard loom for figured fabrics

- 1804: Oliver Evans amphibian steam carriage
 1805: Twin screw propeller (Stevens)
 1807: First patent for gas-driven automobile (Isaac de Rivaz)
 1807: Kymograph—moving cylinder for recording continuous movement (Young)
 1813: Power loom (Horrocks)
 1814: Grass tedder (Salmon)
 1814: Steam printing press (Koenig)
 1817: Push-cycle (Drais)
 1818: Milling machine (Whitney)
 1818: Stethoscope (Laennec)
 1820: Bentwood (Sargent)
 1820: Incandescent lamp (De la Rue)
 1820: Modern planes (George Rennie)
 1821: Iron steamboat (A. Manby)
 1822: First Scientific Congress at Leipzig
 1822: Steel alloys (Faraday)
 1823: Principle of motor (Faraday)
 1823-1843: Calculating machines (Babbage)
 1824: Portland cement (Aspdin)
 1825: Electro-magnet (William Sturgeon)
 1825: Stockton and Darlington Railway
 1825-1843: Thames tunnel (Marc I. Brunel)
 1826: Reaping machine (Bell). First used in Rome and described by Pliny
 1827: Steam automobile (Hancock)
 1827: High pressure steam boiler—1,400 lbs. (Jacob Perkins)
 1827: Chromo-lithography (Zahn)
 1828: Hot blast in iron production (J. B. Nielson)
 1828: Machine-made steel pen (Gillot)
 1829: Blind print (Braille)
 1829: Filtration plant for water (Chelsea Water Works, London)
 1829: Liverpool and Manchester Railway
 1829: Sewing machine (Thimonnier)
 1829: Paper matrix stereotype (Genoux)
 1830: Compressed air for sinking shafts and tunnels under water (Thomas Cochrane)
 1830: Elevators (used in factories)
 1831: Reaping machine (McCormick)
 1831: Dynamo (Faraday)
 1831: Chloroform
 1832: Water turbine (Fournreyron)
 1833: Magnetic telegraph (Gauss and Weber)
 1833: Laws of Electrolysis (Faraday)
 1834: Electric battery in power boat (M. H. Jacobi)
 1834: Anilin dye in coal tar (Runge)
 1834: Workable liquid refrigerating machine (Jacob Perkins)
 1835: Application of statistical method to social phenomena (Quetelet)
 1835: Commutator for dynamo
 1835: Electric telegraph
 1835: Electric automobile (Davenport)
 1836: First application of electric telegraph to railroads (Robert Stephenson)
 1837: Electric motor (Davenport)
 1837: Needle telegraph (Wheatstone)
 1838: Electro-magnetic telegraph (Morse)
 1838: Single wire circuit with ground (Steinheil)
 1838: Steam drop hammer (Nasmyth)
 1838: Two-cycle double-acting gas engine (Barnett)
 1838: Propeller steamship (Ericsson: see 1805)
 1838: Boat driven by electric motor (Jacobi)
 1839: Manganese steel (Heath)
 1839: Electrotype (Jacobi)
 1839: Callotype (Talbot)
 1839: Daguerreotype (Niépce and Daguerre)
 1839: Hot vulcanization of rubber (Goodyear)
 1840: Grove's incandescent lamp
 1840: Corrugated iron roof—East Counties Railroad Station
 1840: Micro-photography (Donne)
 1840: First steel cable suspension bridge, Pittsburgh (Roebing)
 1841: Paper positives in photography (Talbot)

- 1841: Conservation of energy (von Mayer)
 1842: Electric engine (Davidson)
 1842: Conservation of energy (J. R. von Mayer)
 1843: Aerostat (Henson)
 1843: Typewriter (Thurber)
 1843: Spectrum analysis (Miller)
 1843: Gutta percha (Montgomery)
 1844: Carbon arc lamp (Poucault)
 1844: Nitrous oxide application (Dr. Horace Wells): see 1799
 1844: Practical wood-pulp paper (Keller)
 1844: Cork-and-rubber linoleum (Galloway)
 1845: Electric arc patented (Wright)
 1845: Modern high speed sewing machine (Elias Howe)
 1845: Pneumatic tire (Thomson)
 1845: Mechanical boiler-stoker
 1846: Rotating cylinder press (Hoe)
 1846: Ether (Warren and Morton)
 1846: Nitroglycerine (Sobrero)
 1846: Gun-cotton (C. F. Schönbein)
 1847: Chloroform-anaesthetics (J. Y. Simpson)
 1847: Electric locomotive (M. G. Farmer)
 1847: Iron building (Bogardus)
 1848: Modern safety match (R. C. Bottger)
 1848: Rotary fan (Lloyd)
 1849: Electric locomotive (Page)
 1850: Rotary ventilator (Fabry)
 1850: Ophthalmoscope
 1851: Crystal Palace. First International Exhibition of Machines and the Industrial Arts (Joseph Paxton)
 1851: Electric motor car (Page)
 1851: Electro-magnetic clock (Shepherd)
 1851: Reaper (McCormick)
 1853: Science Museum (London)
 1853: Great Eastern steamship—680 feet long—watertight compartments
 1853: Mechanical ship's log (William Semens)
- 1853: Mass-production watches (Denison, Howard and Curtis)
 1853: Multiple telegraph on single wire (Gintl)
 1854: Automatic telegraph message recorder (Hughes)
 1855: Commercial production of aluminum (Deville)
 1855: 800 H.P. water turbine at Paris
 1855: Television (Caselle)
 1855: Iron-plated gunboats
 1855: Safety lock (Yale)
 1856: Open hearth furnace (Siemens)
 1856: Bessemer converter (Bessemer)
 1856: Color photography (Zenker)
 1858: Phonograph. Voice vibrations recorded on revolving cylinder (Scott)
 1859: Oil mining by digging and drilling (Drake)
 1859: Storage cell (Planté)
 1860: Ammonia refrigeration (Carre)
 1860: Asphalt paving
 1860-1863: London "Underground"
 1861-1864: Dynamo motor (Pacinnotti)
 1861: Machine gun (Gatling)
 1862: *Monitor* (Ericsson)
 1863: Gas engine (Lenoir)
 1863: Ammonia soda process (Solvay)
 1864: Theory of light and electricity (Clerk-Maxwell)
 1864: Motion picture (Ducos)
 1864 and 1875: Gasoline engine motor car (S. Marcus)
 1865: Pasteurization of wine (L. Pasteur)
 1866: Practical dynamo (Siemens)
 1867: Dynamite (Nobel)
 1867: Re-enforced concrete (Monier)
 1867: Typewriter (Sholes)
 1867: Gas engine (Otto and Langen)
 1867: Two-wheeled bicycle (Michaux)
 1868: Tungsten steel (Mushet)
 1869: Periodic table (Mendelejev and Lothar Meyer)
 1870: Electric steel furnace (Siemens)
 1870: Celluloid (J. W. and I. S. Hyatt)
 1870: Application of hypnotism in psychopathology (Charcot)
 1870: Artificial madder dye (Perkin)

- 1871: Aniline dye for bacteria staining (Weigert)
 1872: Model airplane (A. Penaud)
 1872: Automatic airbrake (Westinghouse)
 1873: Ammonia compression refrigerator—Carle Linde (München)
 1874: Stream-lined locomotive
 1875: Electric car (Siemens)
 1875: Standard time (American railroads)
 1876: Bon Marché at Paris (Boileau and G. Eiffel)
 1876: Discovery of toxins
 1876: Four-cycle gas engine (Otto)
 1876: Electric telephone (Bell)
 1877: Microphone (Edison)
 1877: Bactericidal properties of light established (Downes & Blunt)
 1877: Compressed air refrigerator (J. J. Coleman)
 1877: Phonograph (Edison)
 1877: Model flying machine (Kress)
 1878: Centrifugal cream separator (De Laval)
 1879: Carbon glow lamp (Edison)
 1879: Electric railroad
 1880: Cup and cone ball-bearing in bicycle
 1880: Electric elevator (Siemens)
 1882: First central power station (Edison)
 1882: Motion picture camera (Marly)
 1882: Steam turbine (De Laval)
 1883: Dirigible balloon (Brothers Tissandier)
 1883: High speed gasoline engine (Daimler)
 1884: Steel-frame skyscraper (Chicago)
 1884: Cocaine (Singer)
 1884: Linotype (Mergenthaler)
 1884: Turbine for High Falls (Pelton)
 1884: Smokeless powder (Duttenhofer)
 1884: Steam turbine (Parsons)
 1885: International standard time
 1886: Aluminum by electrolytic process (Hall)
 1886: Hand camera (Eastman)
 1886: Aseptic surgery (Bergmann)
 1886: Glass-blowing machine
 1887: Polyphase alternator (Tesla)
- 1887: Automatic telephone
 1887: Electro-magnetic waves (Hertz)
 1887: Monotype (Leviston)
 1888: Recording adding machine (Burroughs)
 1889: Artificial silk of cotton refuse (Chardonnet)
 1889: Hard rubber phonograph records
 1889: Eiffel Tower
 1889: Modern motion picture camera (Edison)
 1890: Detector (Branly)
 1890: Pneumatic tires on bicycles
 1892: Calcium carbide (Willson and Moissan)
 1893-1898: Diesel motor
 1892: Artificial silk of wood pulp (Cross, Bevan and Beadle)
 1893: Moving picture (Edison)
 1893: By-product coke oven (Hoffman)
 1894: Jenkin's "Phantoscope"—first moving picture of modern type
 1895: Motion picture projector (Edison)
 1895: X-ray (Roentgen)
 1896: Steam-driven aerodrome flight—one half mile without passenger (Langley)
 1896: Radio-telegraph (Marconi)
 1896: Radio activity (Becquerel)
 1898: Osmium lamp (Welsbach)
 1898: Radium (Curie)
 1898: Garden City (Howard)
 1899: Loading coil for long distance telegraphy and telephony (Pupin)
- TWENTIETH CENTURY
General introduction of scientific and technical research laboratories.
 1900: High speed tool steel (Taylor & White)
 1900: Nernst lamp
 1900: Quantum theory (Planck)
 1901: National Bureau of Standards—United States
 1902: Caterpillar tread improved. [See 1770]
 1902: Radial type airplane engine (Charles Manly)