MEN, MACHINES AND HISTORY

A SHORT HISTORY OF TOOLS AND MACHINES IN RELATION TO SOCIAL PROGRESS

BY

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PREFACE

I HAVE aimed to write this book in such a way that it can be read by young people in their last years at school and at Universities, Technical Colleges, Continuation Schools, etc. But, as I felt that the subject is of interest to people who in the course of time have become more knowledgeable, I have not hesitated to include here and there a sentence or a paragraph specially for their benefit.

Since my aim was to consider the history of tools and machines in relation to all aspects of life, I have necessarily included many references to social conditions at various epochs. I was able to make these brief, because this book is part of a series, other volumes of which will fill in the background at greater length and correct any distortions that may arise from my brevity.

I have chosen to interpret the word 'machine' somewhat widely. In particular, I include in its scope the many electronic devices (radio, sound films, photo-electric cells in the control of machinery, etc.) which have been so prominent in this century—for I feel that, though these are not 'mechanical' in the strict sense of the word, their development does represent the modern form of that trend towards greater control over nature which was earlier expressed in strictly mechanical form.

The work had to be done almost entirely in spare time while carrying on a war job, and though a final revision was made during the first year of peace, there was not time for as full an investigation of sources as might be desired. These circumstances, coupled with the breadth of the field, compelled me to rely to a considerable extent on secondary sources. However, I have cross-checked my information wherever possible, and though some factual errors may remain, these are not likely to be ones of major importance. Responsibility on matters of interpretation is, of course, entirely my own.

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Cambridge, August 1946. S. L.

CHAPTER I

THE FIRST INDUSTRIAL REVOLUTION
(TILL 3000 B.C.)

THE earliest men we know of made and used tools. In fact, man as we know him probably could not have survived without tools—he is too weak and puny a creature to fight nature with only his hands and his teeth. The first men were of a species very different from our own. Perhaps they could have managed to live without tools. But only with the aid of the tools that these more primitive species learnt to use was it possible for the man of today to evolve, losing much in bodily strength and speed, but more than compensating for this loss by developing a brain and hands and eyes that enabled him to call to his aid his many tools and machines that made him master of the world.

For the earliest tool-using men we have no space here. We begin with men of the late Palæolithic Age, men now of our own species, living by hunting and food-gathering. Already at this stage men had acquired a vast variety of tools. They had axes, knives, saws, spokeshaves, and scrapers of chipped stone, mallets, awls and piercing tools, needles of ivory, spears and harpoons. They had even tools for making tools. They used two very important machines: the bow and the spear-thrower. The former is the first machine which stores energy; the bowman puts his energy gradually into the bow as he draws it, storing it up ready to be released in concentrated form at the moment of shooting. And the spear-thrower is an application of the lever as an extension of a man's arm, giving the spear a greater range.

The transitional mesolithic societies that followed the Old Stone Age advanced yet further, developing in particular fishing tackle, a fine range of carpenter's tools, including the adze, gouge and chisel, and learning to make and use the sledge and the dugout canoe with its paddles.

But it is with the introduction of agriculture and the whole series of techniques associated with it that this history must really begin. This was the first great Industrial Revolution in man's history, the neolithic revolution, which took place not much more than 7,000 years ago. Formerly man gathered the food that nature unaided provided. Now he learnt to make nature provide what he wanted. All his previous advances seem insignificant beside this leap forward. The story of this first Industrial Revolution has already been told in Volume I of this series; here we shall only re-emphasize those aspects that have direct bearing on the subsequent history of tools and machines.

For agricultural purposes, men had to invent special tools: the wooden hoe to till the ground, the sickle of wood set with flint to reap the corn (Figure 1), the flail to thresh it, the quern to grind it.[1] But a full change from hunting and food-gathering to agriculture as the basis of life could not take place without a whole series of auxiliary changes. The wooden hoe and sickle required tools to shape them; sometimes plots had to be cleared before sowing. For these and other purposes neolithic man developed further the carpenter's tools that had appeared in the Neolithic Age, using ground and polished stone instead of the cruder

Fig. 1. Flint sickle from Fayum in Egypt.

[1] A primitive form of sickle, the straight reaping knife, appeared a little before the development of agriculture, for cutting down edible grasses not sown by man. Similarly the hoe has an ancestor in the digging-stick of mesolithic times; while pestles and mortars, which had been used for other purposes by palæolithic man, were used as well as the quern for early corn-grinding.

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chipped stone of his predecessors. He also added the bow-drill, in which the drill is rapidly driven by a string wrapped round it, attached at each end to a sort of bow which is moved back and forth. Cereals required storage and new ways of cooking. The game caught by the hunter can be roasted on a spit before an open fire, but cereals need slow, gentle cooking in some sort of vessel. Neolithic man solved this problem with pottery.

The skins of hunted animals provided the few clothes of palæolithic man. The agriculturalist had to find a substitute and he found it in textiles. But to master textiles he required two new machines: a spinning machine and a loom. The early spinning machine was very simple—a short stick with a hook or notch on one end to which the thread was attached and a flywheel (whorl) of stone or pottery at the other to ensure continuous spinning motion; and a distaff or forked stick to hold the unspun fibres. The spindle is given a twist and hangs spinning in the air while the operator feeds fibres from the distaff on to the end of the thread, where they are twisted into yet more thread. It is a simple mechanism by modern standards, yet a tremendous complication compared to any previous machine. And no fundamental improvement took place in the process of spinning till the Middle Ages.

The loom, even in its simplest form of a frame on which the warp is stretched while the weaver's fingers push the woof alternately over and under the warp threads, is a complicated piece of apparatus. And it did not stay long at that simple stage, but was soon improved with the heddle for separating the alternate warp threads, and other devices.[1]

Thus, almost from the beginning of the Neolithic Age, man had vastly increased the number of tools and machines that he used. But a very rapid advance was to follow. The

[1] Textile machinery is difficult to describe and its early history is often obscure. We shall therefore deal with it only in very general terms till medieval times.

change in man's way of life was propitious to invention. He had more security than ever before. The periods of leisure that intersperse agricultural activity gave time for invention. The comparatively permanent life that agriculture (at least in its more advanced stages) made possible allowed him to construct, accumulate and use equipment that the hunter would usually see only as an encumbrance. And lastly, man had learnt that nature could be controlled for his own benefit and had therefore acquired a degree of self-confidence that encouraged him to try new methods of increasing that control.

Conditions were particularly favourable in Mesopotamia and the valleys of the Nile and the Indus, where the periodically flooding rivers, soon to be controlled by irrigation, watered the crops and spread a new layer of mud each year which prevented the exhaustion of the soil. In these countries we find a great spate of invention in the couple of millennia before 3000 B.C. In this period man learned to smelt and use metals, to harness animals; he invented the plough and the wheeled cart and the sailing ship. These, and many similar inventions, laid the basis for great social changes which we shall mention later.

Copper and iron sometimes occur naturally as metals, and men at an early stage learned to make some use of them. But they used them as a superior sort of 'stone'—a 'stone' which was much less brittle than those commonly used for tools and which could be hammered into shape, instead of requiring chipping or grinding like the common stones. The great step forward came when men made two great discoveries. First, that heating certain types of stone with charcoal produced copper—the process of smelting. Second, that copper could be melted in a suitable furnace, run into a mould where it would solidify to reproduce the shape of the mould—the process of casting. These discoveries were probably made in or near Mesopotamia about 4000 B.C. Smelting was an important step, because the supplies of natural metals in the world are so tiny that their use could have no important effect on men's lives. And without casting, the most valuable and important properties of copper would be left unused.

Though there were in some places 'factories' for making them, in general the stone tools could be made by the man who used them, as and when he needed them. Not so with metal; it required a highly organized system of production. Quarrying (and later, underground mining) required a host of techniques for dealing with hard rocks, such as cracking them by lighting fires against them and throwing water on the hot surface, or splitting them by inserting wooden wedges in cracks and then soaking them in water so that they expand and prise the rocks apart.

Then the ore must be smelted. That required furnaces capable of giving temperatures so high as to need some sort of blast. The best way to produce the blast would be by bellows, but these were not discovered till about 3000 B.C., so that the earlier workers had to use blowpipes or tunnels arranged to catch the prevailing wind.

Then the smith had to turn the crude lump of copper into useful tools or weapons. The first process was casting, which like smelting requires a high-temperature furnace, as well as crucibles in which to melt the metal. There must be moulds of sand, clay or pottery to run it into, and means of shaping these moulds as required. For anything but the simplest product the mould must be made in two or more pieces which can fit together to receive the molten metal. After casting, the tool must be finished in various ways, by hammering, smoothing with files, grinding to a sharp edge on a stone, and so on.

So it will be seen that the use of copper required many auxiliary inventions to make it practicable, and many specialized craftsmen to do the work—specialists who would not be producing food but must be fed by the community.

How men discovered the smelting of metal we do not know. It has been suggested that perhaps somebody accidentally dropped some malachite (a copper-bearing mineral commonly used to paint the eyes, partly as a cosmetic, partly as a protection against certain fly-borne infections) into a charcoal brazier, and observed a few beads of copper running out at the bottom. Perhaps the discovery was made many times, and many times forgotten as useless. For we must remember that the usefulness of an invention depends on the structure of society. The use of copper, as we have seen, requires specialist miners and smiths, who shall devote their whole time to that work and therefore must be fed, clothed and housed from a surplus produced by other members of the community. Until the technical level was high enough to provide this surplus, it would be impossible to keep these specialists, and therefore impossible to use metals. Thus, even if the smelting of copper was discovered accidentally in some early neolithic society, it would have been brushed aside as useless and soon forgotten. But eventually with the gradual advance of neolithic technique the time arrived when the community could afford to keep specialists who produced no food—and then any further accidental discovery of copper smelting would soon be developed as a useful asset.

The miners and smiths were not by any means the only specialists required to make metals socially usable. Copper ore was not found in the lands occupied by the advanced neolithic farmers, who could support the smiths and use their products. The ore or the copper had to be transported over long distances. This required traders and transport workers. Early neolithic communities had been more or less self-supporting, trade being confined to a few luxuries, ornaments and charms. But as the societies became capable of producing a surplus over their immediate needs, they tended more and more to exchange this surplus for products obtainable only from a distance, the most important of which were copper and its ores. At the same time the villages tended to grow into towns containing craftsmen like smiths and carpenters, and later entirely unproductive classes like priests, kings, nobles. All these had to be supported by food and other basic necessities carried in from the surrounding countryside. Thus the transport industry grew, and as it grew it developed better methods of transportation.

The sledge, we have seen, was invented in mesolithic times. The agricultural peoples enormously extended its use. Then, perhaps through first using rollers to ease the work, they invented the wheeled cart—next to agriculture and metallurgy, perhaps the most important invention ever made. Wheeled vehicles were in use in Sumeria as early as 3500 B.C., in North Syria perhaps earlier. By 3000 B.C. they were in general use in Mesopotamia, Elam and Syria; they reached the Indus by 2500 B.C. But in Egypt they were unknown till very much later.

The wheeled cart would not have been nearly so great an advance, were it not combined with another invention—the harnessing of animals (Figure 4). This invention is connected partly with the expansion of transport that we are discussing, and partly with another great invention of this period: the plough—a tremendous improvement over the hoe which had earlier been used to till the ground. Animals were soon widely used both for ploughing and for drawing vehicles.

The harnessing of animals was the first instance of men using some force other than human muscles to do their work for them. At about the same time they also first learned to use an inorganic force—the wind, to drive sailing ships (Figure 2). Sailing ships were in use in Egypt soon after 3500 B.C., and by 3000 B.C. they were freely navigating the eastern Mediterranean, and probably also the Arabian Sea. Today the comparative comfort and safety in which we can live is based largely on our use of non-animal power—wind, water, coal and oil. Here in the East, before the dawn of civilization, we see the first step being taken towards our modern age of power.

To describe all the inventions of these thousand or two fruitful years before 3000 B.C. would take too much space. Here we shall mention only one more, the potter's wheel, which not only made possible the production of much better pottery at the cost of much less labour, but also made pottery the first mechanized production industry, the first step on the way to the mass production factory of today.

Finally, let us note how closely these inventions were interconnected. Metals, for example, could not have been used without improvements in transport to carry the ore or metal from mine to user, nor without the agricultural improvements which gave sufficient yields to allow the supporting of specialists withdrawn from primary production. And conversely the wheeled cart, the plough, the sailing ship, or the potter's wheel, requiring, as they do, quite advanced carpentry, probably could not have been used on any extensive scale without metal tools to make them.

CHAPTER II

THE FIRST CIVILIZATIONS
(3000–1100 B.C.)

ALONG with the advances in the field of tools and machines that we described in the last chapter, there occurred equally important advances in other techniques. For example, in the river valleys of Mesopotamia, Egypt and the Indus systems of controlled irrigation were evolved, which enormously increased the productivity of the land. In all spheres of activity men were able to produce much more than before, because they had better tools and better methods. The savage hunter, or the early neolithic farmer, could make ends meet in good seasons—and in bad, part of the tribe died from under-nourishment. Now it was possible to produce an assured sufficiency for all, and beyond that a

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small surplus, available to increase the comfort and luxury of life. But social progress did not take place along the simple lines of a continually improving standard of living for the whole population; the technical developments themselves decreed a different form of development.

The tools and machines we have described could only be made at the cost of a considerable amount of labour. Only the few men or families who had been more than usually successful with their crops could spare the time to make them, or alternatively barter a part of their surplus crop with a specialist in exchange for an advanced tool. But once acquired, the new tool gave its possessor a great advantage. With a plough his crops would be yet better, and he would in future have a further surplus available to barter for yet more specialized tools. This was especially true of copper. It provided more serviceable tools than stone; it could be cast into forms which could not be produced from stone; copper tools lasted much longer than stone tools; when the edge was dulled, it could more easily be resharpened. But more than that, if copper is superior to stone for tools, it is much more so for weapons. If a chisel breaks, it means only a delay to make a new one. If a dagger breaks in battle, it means death or captivity. So the owner of copper weapons had a tremendous advantage in warfare. Again, copper is a much more costly commodity than stone. In the period we are speaking of, only a few could possess it. For centuries the tools of the peasant remained of stone and wood.[1]

There resulted a tendency to the accumulation of wealth in the hands of the few. He who was already moderately well-to-do could obtain copper implements or other advanced tools. Using these, he (or his family, or later his slaves or serfs) could work more efficiently than others and gather yet more wealth, which gave him a further advantage over his neighbours—and so on, in snowball fashion. Or,

[1]This is especially true of Egypt; in Mesopotamia sickles were often made of bronze after 2500 B.C.

if he wished to gain wealth by force of arms, or to make others work for him, his advantages with copper weapons were even greater.

From this (and many other factors tending in the same direction) there resulted a complete social revolution. The hunters and food-gatherers of the Palæolithic Age had lived in an equalitarian society of the type called 'primitive communism'.[1] Their wealth was the property of the whole tribe and the welfare of every member of the tribe was the responsibility of all. Some might accumulate more personal possessions (ornaments, for example) than others, but differences in wealth were usually small. Government was by the meeting of the whole tribe, with possibly an elected chief in times of stress. The tribe was held together in this communistic society by the necessity of presenting an unbroken front in the hard struggle against nature; internal rivalry meant failure in the struggle, and death. The change-over from hunting to agriculture weakened the basis of this type of society; for the family, tilling its own fields, was capable of becoming a self-sufficient unit, and therefore the tribe as a unit became less important. The neolithic societies remained essentially equalitarian, in that land was communally owned and the fields redistributed from year to year among the different families. Nevertheless, it became possible for one family by greater skill or greater luck to prosper more than another. At first these differences would not be great, nor would they have any strong tendency to grow.

But with the use of copper and the other inventions described towards the end of the last chapter, the situation (as we have seen) became such that any person who had

[1] We have no direct knowledge of the structure of any society before about 3000 B.C., but these descriptions, based on reconstruction from the houses, tools, etc., left behind by these peoples and on the structure of apparently similar societies existing in modern times in backward parts, must be somewhere near the truth. They are, however, much over-simplified and schematized, as are the descriptions of the changes which followed.

accumulated a small surplus had a great advantage in accumulating more. Differences in wealth and power between different members of the community increased apace. Men used the advantage given them by copper weapons to force others to pay them tribute or rent for the land or to become their serfs. Having dominated local communities in this way, they built armies from them and went on to conquer surrounding districts—till great empires were built up.

The process was probably a gradual one in which the inequalities grew slowly, but by 3000 B.C. it had produced a decisive change in the structure of society. The simple communities of more or less equal farmers had been replaced by states in which the vast majority of the inhabitants lived at subsistence level, often as slaves or serfs, while all the surplus product of their labours was used to provide a luxurious existence for a small class of kings, nobles and priests, as well as supporting the civil services and armies which formed the mechanism for extracting from the masses the products of their work. Class-divisions had become the basis of social structure.

From the point of view of the oppressed peasant, serf or slave, this change would seem an unqualified catastrophe. But from the point of view of the human race as a whole, and especially from the point of view of people living today on the verge of another transformation of equal magnitude, it was a necessary step forward. Though factors arising from the new social structure sometimes held back advance for centuries, nevertheless the technical developments that had to come, in order to carry forward the progress described in the last chapter, would have been impossible without the form of organization that class-divisions produced. This arose, for example, from the mere costliness of producing copper tools. If the surplus above subsistence level that neolithic society produced had remained equally divided among all the members of the village, then only rarely would a family have sufficient surplus to exchange with a smith for even one tool. But the increasing concentration of wealth in the hands of a few at the expense of the many enabled these few to barter their surplus food (or other necessities) for the smith's tools, and thus provided the basis for the existence of the smith (or the miner, or any other specialized craftsman). And some of the technical advances that we shall describe in the rest of this book required much larger numbers of craftsmen, or the organization of large labour forces, withdrawn from the direct production of necessities, and consequently they were only possible because a few individuals possessed sufficient wealth (or, what it really amounts to, sufficient power to make others work for them) to be able to support these large numbers of specialists.

Thus the many technical advances of the millennia before 3000 B.C., not only caused the social changes, but probably also depended on the gradual increase of class-divisions to provide the concentrations of wealth necessary for their use. And the full establishment of the great class-divided states in Egypt, Mesopotamia and the Indus valley shortly before 3000 B.C. was followed by several centuries of a great flowering of the various techniques. This was not such a period of radical innovation as that which we described in the last chapter; rather it was one in which men built on these innovations, refining the skill with which they were used and increasing enormously the scale on which they were applied.

But there were several important inventions. About 3000 B.C., or within a century or so after, several important developments in metal-working took place in and around Mesopotamia. Tweezers were enlarged into tongs (not hinged, however, but depending on the spring of the metal) with which the smith could efficiently handle the smaller pieces of hot metal. But large objects and crucibles containing metal had to be lifted between two stones or between green twigs. The introduction of bellows improved metallurgical processes. The extremely ingenious *cire perdu* process of casting was developed. In this a wax model of the shape required is made. This is then coated with clay and placed in a furnace, where the wax melts and runs away, while the clay is baked hard to form a mould. Molten metal is then run into the mould and, after cooling, the clay is broken away. Most important of all metallurgical advances of this period was the introduction of bronze, an alloy of copper and tin, which was a radical improvement on copper. It gave harder and more durable tools, and it made possible really fine casting, which is impossible with unalloyed copper. None of these new techniques spread to Egypt till over a thousand years later.

Already the craftsmen of Egypt and Mesopotamia produced a wide variety of articles of high quality. The coppersmith of about 3000 B.C. made axes, adzes, chisels, gouges, drills, knives, saws, nails, clamps, needles, razors, tweezers, and so on. The carpenter made boats, chariots, furniture, harps and lyres; by about 2800 B.C. he was using plywood of six layers.

The Egyptian pyramids constitute the supreme example of the enormous scale on which the rulers of this time could organize labour and the high degree of accuracy that could be achieved. The Great Pyramid of Cheops was built of about 2,300,000 blocks of stone, totalling some 5,750,000 tons in weight, while the larger blocks weighed up to 350 tons. Merely to reach the site, they had to be dragged up 100 feet. According to a tradition reported by Herodotus, 100,000 men were engaged in moving blocks three months of each year for ten years. With a base of 775¾ feet square, the error in any side was less than one inch in length or level. As a contribution to the progress of mankind, the pyramids are of negligible value, but the techniques evolved for building them to such size and accuracy must have had a profound effect on all subsequent building. Only soft rocks could be cut with bronze tools. Hard rocks were pounded with balls of dolerite (a hard resilient stone). The craftsman could do this in such a way as to detach a block as required from the mass in the quarry—a task of no mean skill, since either too hard or too soft a blow will fail. Metal wedges or wooden wedges expanded by wetting them were also used to detach blocks. These were modifications of the techniques of the copper miners. The block was pounded into shape with dolerite balls or pointed hammers, then dragged into position on a sledge (the wheel was still unknown in Egypt). There the shaping was continued with picks and lastly, at the fine stage, with tubular drills, probably bow-driven, using some abrasive. The implements used in building the pyramids were the lever, the sled, ropes, rollers and sleepers (the pulley was a much later invention), measuring rods and cords, the plumb line and water for levelling. The method of levelling was to run a watercourse round the work, banking it up with mud, and to measure down from it at many points to the level required.

Our first reaction is amazement that such magnificent results should be achieved with such meagre technical equipment. Yet meagre as the equipment seems to us, it was the final product of a great advance in the mason's technique, and not for many centuries was it improved upon. The increased scale of application showed itself in other fields. Ships, for example, had reached 170 feet in length by 2700 B.C.

Yet before 2500 B.C., what can be termed the first industrial revolution of human history had come to an end. It was a revolution that began with the invention of agriculture and the techniques that came with it, continued through that great period of invention in the couple of millennia before 3000 B.C., and then, with advances in skill and scale rather than fundamental innovations, till about 2500 B.C. But after that date stagnation set in, and for many centuries only slight advances took place. Not only did fundamental advances cease for a long period, but even in many techniques where the basic ideas had been evolved earlier, but remained

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