A Brief History of Science
Part-1: The Advent of Agriculture

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Introduction

In my class I often ask my students "What was the first major scientific invention of mankind?" Some say "fire", some say "wheel". None of these is actually true. Fire was tamed long before the species Homo Sapiens appeared on the face of the Earth. It was achieved by some pre-human ancestor species. In fact, it was the use of fire and the consequent shift in diet from raw meat to roasted meat that caused the change in the shape of the mouth. This, in turn, enabled the development of articulated speech—a prime characteristics of the human species. Hence taming of fire cannot be said to be a "human" invention. The invention of the wheel, in contrast, happened much later—when the requirement for bulk transport arose in the society following the development of agriculture.

The invention of agriculture is, in fact, the first major scientific invention that caused a great change in the structure of the society. In the following pages we shall delve into the details of that scientific revolution.

The structure of society before the advent of agriculture

Scientists believe that the "anatomically modern" man evolved around 2,00,000 years ago and the "behaviourally modern" man (capable of articulated speech and tool-making) evolved towards the end of the last ice age, around 40,000 years ago. Since then, until the advent of agriculture some 10,000 years ago—that is, for the most part of human history—the main means of subsistence were hunting and gathering. What was the society like, in those times?

Firstly, the resources in the forests were limited. When the food sources in one area got depleted, people had to move to another in search of food. So, the people in those times had to be constantly on move, leading a nomadic life. There was no "settled" life (houses, villages, towns) in those times.

Secondly, the food items they hunted and gathered are all perishable. If you don't eat it now, it will rot. So there was no question of storing food. Consequently, there was no question of somebody amassing wealth depriving the others. True, the savages fought with each other for food. But once the issue is settled—somebody having a bigger chunk of food and somebody smaller—there was no difference between one individual and another. Nobody could keep the food for eating later. They were all equal. There were no haves and have-nots. There were no kings and queens. There was no upper class and lower class.[1]

A peculiar characteristics of a society without class division is that there is no private property. Whatever meagre resources

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[1]A detailed account of this period is found in "Man makes himself" by V. Gordon Childe [1].

they had: the bow, the arrow, the spear—belonged to everybody. This is a feature noticed by the famous anthropologist Morgan in the 19th century while studying the aborigine groups who were still in the "hunting-gathering" stage. In our country the writings of the famous Bengali litterateur Bibhuti Bhusan bear testimony to this fact when he describes the life of the tribals in Chhotanagpur (now in Jharkhand). When these tribals passed by somebody's house, if some article like a spade or a stool was found lying outside, they would simply take it. People thought they are habitual thieves. But Bibhuti Bhusan shows that these tribals did not have the idea of something "belonging to" somebody. If something useful is found lying somewhere, they found it natural to use it. They did not the sense of private property. This is the second important character of a society in hunting-gathering stage.

The life in this hunting-gathering stage was largely dependent on the vagaries of nature. A stone falls from a hill and kills somebody. So they tried to please the stone so that it does not kill anymore. Fierce storms killed people; so they tried to please the wind. The sun gave light; and so they tried to please the sun. The way of pleasing was to dance, to chant, and to offer things that they perceived as pleasant. In this stage there was no idea of god. What they tried to please were all natural forces. In that primitive state of knowledge they had no idea how to tame these natural forces. So they performed rituals to please these natural forces. In anthropological literature, this is called the "magic" phase in the development of culture[2]. This is the third important feature of the savage society.

In the hunting-gathering stage, their tools and implements were all made of stone. From the angle of material use, this period is called the "paleolithic" or the old stone age.

As the human population increased, the available resources in the forests proved to be insufficient to sustain the society. The society faced a crisis. The escape from the crisis was provided by the advent of agriculture.

The invention of agriculture

The exact circumstances of the invention of agriculture and the who-did-it are not known. But one can easily realise the course of events unfolding as the society faced the shortage of food. People must have noticed that seeds fall on the ground, germinate, grow into plants, and then bear fruit. So if you put many seeds of a fruit-bearing plant in a convenient place they will produce fruits after some time. Some grassy plants produce small and hard grains. These are particularly convenient as food because these can be stored for use later. For us, the logic behind agriculture seems to be obvious. But for the people 20,000 years ago, this small step involved a lot of trial-and-error, wrong and right guesses, and pangs of hunger. "Somewhere in the Mediterranean region, wheat grew wild" wrote H. G. Wells, "and man may have learned to pound and then grind up its seeds for food long before he learned to sow. He reaped before he sowed." [3]

Thus started the cultivation of food-grains like wheat and barley in the forest clearings and open grasslands. It was still the stone age (the stone age after the invention of agriculture is called the neolithic or the new stone age), and so the cultivation with stone implements was very primitive. It was a small beginning, but it ushered a sea-change in the society.

[2] For details, read "The Golden Bough" by Sir James Frazer [2].

Socio-cultural changes brought in by agriculture

Firstly, wherever agriculture was practised, people had to stay rooted there at least until the harvest time. Mostly agriculture demanded a settled life in one place. So settlements developed. People started building houses fit for long periods of accupation. Slowly these started taking the shape of villages and towns. The human race moved away from nomadic life and took step towards settled life. Such settlements began to grow in Nile valley, in Mesopotemia, in the Tigris-Euphrates plains.

Secondly, for the first time a condition was created where the product of agriculture—the foodgrains—could be stored for later use. In those early days agriculture was not very productive, and so there was scarcity of food. But people could not move away in search of food, because agriculture demanded that they have to remain there. The the dearth of the stored items to fulfil the needs of the whole clan caused fights within the clans over the meagre amount of food available. But unlike the hunting-gathering times, the ones who won and could forcibly occupy the foodgrains, could keep it. Thus, by sheer muscle power, some people could own the foodgrains, depriving the others. This was not possible in the hunting-gathering time.

After the start of agriculture, the available cultivable land was very small, because forests cannot be cleared with stone implements. For the first time occupation of this meagre land was of value. By the same process of intra-clan fights, some people occupied the available land, depriving the others. These people slowly became the rulers of clans. Some of these clans, and the land they dominated, increased when they fought with and defeated other clans. Thus, kings and kingdoms appeared (for a detailed account, see [1]).

In the hunting-gathering society also, skirmishes and fights between tribes and clans were common. Since food was in short supply, the victor clan did not want to increase the number of hungry mouths, and the vanquished clan was simply killed off. But when agriculture started, it became advantagous to keep the prisoners alive, to force them to work in the fields of the victor clan. Thus started slavery—a phase of society where some people owned the land, and the slaves worked on the land.

Another important change was taking place in the cultural picture. As we have seen, culturally the hunting-gathering society was in the “magic” phase—where the music, the dance, and other cultural aspects were aimed towards pleasing the natural forces. Now, with the advent of agriculture, and the consequent creation of the rulers and the ruled, people saw that some men were bestowed with power and privilege. In logical extension, they pictured the natural forces also to have similar powers. Thus started a cultural phase in which gods appeared [2].

Note that as yet there was no concept of an omnipotent god. The gods (plural) of that time essentially represented the natural forces, but imagined in the character of powerful humans. Each god was specialized in a particular aspect—a god for rain, a god for sun, a god for wind, a god for love, etc.—and each had very human character. They could get angry, they could be pleased with offerings, they had family relations with other gods. The Greek gods, for example, reflect the nature of this period. But this character is found in the culture of all the societies of that time, in different parts of the globe.

Slowly the clan chiefs and local kings increased their power and the land they control, and around 5000 years ago, large empires began to develop—in Assyria, Sumeria, Egypt and other places in the middle East—mainly centred around the fertile Tigris-Euphratis and Nile river basins. Around 2750 BC, a large kingdom developed in Sumeria in the land spanning from the Persian Gulf to the Mediterranean sea, with Sargon as the king. The first Babylonian empire was consolidated by the king Hammurabi around 2100 BC. Around the same time there was a semitic invasion of Egypt which set up the rule of the Pharaohs. Thus the condition was created for another development in the cultural landscape.

The advent of large empires brought some order and stability in the society, with laws and rules created by the powerful emperors that everybody had to obey. People saw that there is a similar order and stability in nature too: the sun rises in the East and sets in the West everyday, the seasons change from winter to summer and back, high and low tides come in clock-like regularity. From analogy, they argued that, the way the harmony and stability in society is created by the existence of a powerful king at the helm, guiding and creating the rules for the society, in a similar manner the harmony and order in nature is created by an all-powerful Lord, who guides the universe and creates the laws that nature follows. Thus was born the idea of an omnipotent God. From written records it seems that this idea first appeared in the literature of the Jewish people—the Hebrew Bible—which was later adopted by the Christian and Islam religions [3].

In the hunting-gathering society there was practically no exchange between the clans. Every clan had to hunt, gather, and thereby arrange the food independently. When agriculture developed, this was no longer possible, because every area is not suitable for the production of all types of food. So exchanges became necessary. Initially the exchanges were in the form of barter: some amount of one product being exchanged with some amount of another. But the problem was that the two types of produce may not be available at the same time. So the need arose of some kind of guarantee that if one gives up some amount of rice he produced, at a later time he can get an equivalent amount of meat. When kings and empires emerged, they began to play the role of intermediary by producing objects bearing the seal of the king (in the form of terracotta disks and, later, coins)—which acted as this guarantee. Thus, money appeared in the society as the means of exchange.

In the hunting-gathering society, everybody had to do everything; the whole clan had to participate in hunting. There was very little specialization of activities. As agriculture developed, people had to perform specific tasks: some producing implements needed for agriculture, some tilling the land, some exchanging the produce, etc. Thus, specialization of activities developed, specific people devoting time and energy to specific type of work.

It was in the backdrop of these social and cultural developments that we have to understand the scientific developments resulting from the development of agriculture.

The developments in science resulting from the advent of agriculture

The advent of agriculture was a scientific development, and we have seen that it caused a tumultuous change in the structure of society and its cultural edifice. These societal changes, in turn, created the conditions for further developments in science.

Wheel: Large volume of exchange over relatively large distances demanded modes of transport other than being carried physically by the slaves. This societal necessity prompted the next major technological breakthrough: the invention of the wheel. There is evidence of the use of wheel in Sumeria around 3500 BC. The Indus Valley civilization had the use of wheel around 3000 BC. Slowly its use spread to other societies, and carts on wheels, carried by oxen or horses became the prime mode of transport.

Pottery: In the hunting-gethering society, people ate fruits and roasted meat. But when agriculture developed, the diet shifted towards foodgrains—which had to be cooked. Moreover, wheat and barley are reaped once a year, and had to be consumed all round the year. Thus storage became necessary. Earthen pottery developed in almost all neolithic societies as the means of storing and cooking food.

Pottery involves a number of complex processes: choice of the right kind of clay, application of water in the right measure, use of a rotating wheel in which the soft and moist clay is given shape, and the use of a kiln in which the dried pot is burnt to make it hard. Thus, this development demanded some knowledge of the motion of a rotating body, and the controlled production of heat by burning of a fuel like charcoal, etc. In the opinion of Gordon Childe, "pottery involved an appreciation of a number of distinct processes, the application of a whole constellation of discoveries." Various societies developed distinctive techniques of shaping and burning clay. This enables the archeologists of today to identify ancient people and their period when they find characteristic pieces of pottery at the excavation sites.

Metallurgy: Agricultural implements made of stone were not very effective in ploughing the land, and so the agriculture in the neolothic age was primitive. As the demand grew, there was need to improve agricultural production. This drove the development in metallurgy.

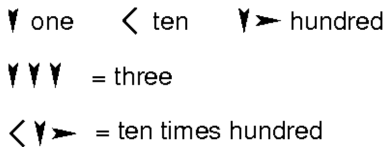
Metallic copper is often found in nature, and so the initial use came from collecting the metal and beating it into various shapes. But as the demand grew other sources were found. The pottery furnaces used fire-wood and charcoal, which are reducing agents. If the clay from which the pottery was being made contained the minerals of copper and tin, some part of it would have reacted with the carbon to produce metallic copper, or more probably, a mixture of copper, tin, and other metals. Probably some people accidentally found this alloy, bronze, in the hearths, and found it useful. Slowly the knowledge spread through trade routes, ushering the "Bronze Age".

For this, people had to develop methods of producing a reducing atmosphere by restricting the flow of air. Even though the reduction of the ore can be achieved at 800°C, melting of metallic copper requires a temperature of 1085°C, for which blowers had to be developed. Fashioning useful objects out of bronze required die-casting. Archeological evidence in Egypt and Mesopotemia shows that all this had been achieved by about 3000 BC.

Thus, bronze came into use for making agricultural implements, weapons, and coins. A group of metal-workers developed in every society. When some clan developed particular useful ways of fashioning bronze, it spread quickly to the other societies related by commodity exchange. The "bronze age" lasted for a long time, about two millennia, before the production and use of iron was mastered around 1200 BC.

The course of events in the discovery was probably similar: Some community may have accidentally reduced iron ore when they tried to use it as clay for making pottery or the furnace itself. Some confusion, groping in the dark, wrong and right

Box-1:
Cuneiform numbers of Babylon



Thousands of burnt clay disks with cuneiform script have been discovered in the library of the Babylonian king Ashurbanipal. These are now kept in the British Museum. These show that the babylonians had three arrowhead-shaped symbols for one, ten, and hundred, as shown above, and they could write the big numbers using these. In those terracotta tablets there is mention of numbers like 14 being square numbers. This confused the archaeologists for a long time. The problem was cracked when they realized that the Babylonians wrote numbers to the base of 60 (which means 14 is $1 \times 60 + 4 = 64$, a perfect square). This base-60 number system has found its way into modern times in various ways—60 minutes in an hour, 360 degrees in a circle, etc.

guesses, and trial and error must have gone in before they could figure out where this black hard substance came from. There is evidence that iron-extraction first started in the iron-ore rich areas of Asia Minor. Slowly the technique was developed, and the knowledge quickly spread along the trade routes.

Numbers: In the hunting-gathering society, numbers were required only for counting animals and fruits, and so people had use for only whole numbers of small denominations. Most clans of that time knew how to count up to 3, and anything more than 3 were "many". Society had not placed any greater demand on human intellect.

But when agriculture developed, people needed to count bigger numbers. For this purpose the "positional system" was developed. In the modern "decimal" system when we write 354, we actually construct the number as

$$3 \times 10^2 + 5 \times 10^1 + 4 \times 10^0.$$

Here 10 is the radix. But similar number systems could be constructed with other numbers as radix. The Maya civilization of South America used 20 as radix, in Babylon people wrote numbers with 60 as radix (see Box-1). The Arabs used 10 as radix. But these systems would be rather restricted without the use of the number zero. This was discovered in India in the early Buddhist period. Thus started the decimal number system in the modern form.

After the onset of private property, when people started to "own" land, the dimensions of the land had to be measured. It is easy to see that land does not always come in "whole number" dimensions, like 2 miles by 3 miles. Moreover, the quantity of foodgrain had to be measured (especially when trade was involved), and this also does not come in whole number units. So, the practical necessities made it imperative to conceive fractional numbers. Soon the method of writing fractions was invented.

Writing: With the advent of private property, keeping a record of the possession became a necessity. The heads of cattle and the baskets of foodgrain had to be counted, and for that purpose the number systems evolved, as shown above. Initially the numbers were recorded by cuts in sticks, knots in ropes, and by strokes in terracotta tablets. But slowly symbols for the numbers evolved, and these were written down in clay which were burnt for preservation.

The logical extension followed, where not only the numbers, but also the objects and actions started to be represented by symbols. The cuneiform of Mesopotemia and the hieroglyphics of Egypt are scripts of that time. The development of true alphabets—where the symbols represent sounds and not whole words—developed much later, after the onset of the iron age. It is noteworthy that writing actually developed out of accountancy.

Astronomy: Soon after agriculture was initiated, people noticed that each type of foodgrain has to be sown at a particular time, and has to be reaped at another particular time. Thus, the need arose to develop a method of timekeeping. This can be done using any event that occurs in equal intervals of time. Initially nature provided the clue: the appearance of certain birds and insects indicate the arrival of specific seasons. But in many cases it was necessary to prepare before the arrival of an event (for example, the annual flood of the Nile basin). So more accurate indicators were necessary. People noticed that the motion of the sun and the moon follows such periodic cycles. Thus, in order to develop a calendar, people started keeping record of the apparent motion of the sun and the moon. Thus started the first phase of astronomy.

Arithmatic: Trade and exchange demanded one to perform the basic arithmatic operations of addition, subtraction, multiplication, and division. Actually addition and subtraction started even before people started to write the number-symbols. But when the signs were invented to represent numbers, it became possible to do these operations in an abstract way, by manipulating the numbers, without counting the actual objects.

The demand of repeated addition and subtraction (multiplication and division) also came from trade, but more so from land measurement and building (you have to calculate how many stones you need in order to build a pyramid).

Geometry: The measurement of land demanded the ability to measure the area of rectangles, triangles, polygons and circles. The Egyptians developed the ability to calculate these (see Box-2).

The advent of agriculture also demanded that the quantity of foodgrains stored in granaries had to be measured. Now, it so happened that the Bablylonians made the granaries in the shape of pyramid without the pointed top, which was replaced by the roof. Thus mathematically the problem was to find the volume of a truncated pyramid. In the terracotta tablets we find verbal instructions to calculate it, which when translated to the language of algebra, looks like

$$\text{Volume} = h\left[\frac{(a+b)^2}{2} + \frac{(a-b)^2}{2}\right]$$

where a is the length of the side of the base, b is the length of the side of the top, and h is the height. This is reasonably good, but not accurate enough. The Egyptians improved upon it (because they had much to do with pyramids), which we find in a papyrus now kept in the Pushkin State Museum of Moscow (called the Moscow papyrus). In it we find the question and answer: "If you are told: a truncated pyramid of 6 for the vertical height by 4 on the base by 2 on the top: You are to square the 4; result 16. You are to double 4; result 8. You are to square this 2; result 4. You are to add the 16 and the 8 and the 4; result 28. You are to take 1/3 of 6; result 2. You are to take 28 twice; result 56. See, it is of 56. You will find [it] right" In modern language the prescription translates to the formula

$$\text{Volume} = \frac{h}{3}\left(a^2 + ab + b^2\right)$$

Box-2:
The Ahmes papyrus

A piece of papyrus was found by the Scottish explorer Alexander Henry Rhind (now kept in the British Museum) in 1858 which contains probably the best examples of Egyptian mathematics. It was written by a scribe named Ahmes (hence the name) around 1650 BC. It shows that the Egyptians had progressed considerably in geometry. For example, it poses the question "How to find the area of a circle of diameter 9 "khet"? It proceeds to answer as follows: "First subtract 1/9th of the diameter, that is 1, from 9. We get 8. Now find 8 times 8. We get 64. This is the area." In modern language the method translates to area=$(d - d/9)^2$. Now we know that the area is $\pi(d/2)^2$, which gives a value of 63.6164. This is not very far from what they got.

This turns out to be the correct formula for the volume of a truncated pyramid.

Thus we see that the practical requirements of the time drove a significant development in geometry, and paved the way for the fantastic growth of the subject in the later times.

Conclusion

The neolithic revolution that occurred with the advent of agriculture has all the characteristic features of a true scientific revolution. Firstly, the discovery itself was prompted by social necessity; secondly, the discovery resulted in far-reaching change in the structure of the society; and thirdly, the discovery and the resulting change in the society fuelled further development in science and technology.

But there are certain features in the nature of science of that time, which changed in the later phases of human history. One can notice that all the developments in this period started from some *observation*, which was followed by trial and error. Often, through many trials and many errors, and manipulation of the things at hand, one reached a desirable result. When that was achieved, it was propagated, practised, and improved upon—again by trial and error. At that stage technology preceded theory.

Another noticeable feature is that the ideas of that time were basically materialistic. People concerned themselves with the immediate necessities of the society. In that

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primitive stage of human knowledge, they did not have the answers to many questions that concerned them. In the absence of the right answers, they resorted to speculations. But the questions concerned the immediate problems of survival. Even the imagination of the gods of that time were reflection of their material necessities and the problems of survival.

It was in the later phase, in the first major iron age civilization that took root in Greece, when slavery was entrenched strongly to create a class who had enough free time to engage in thinking alone, that we find speculation taking flight away from physical reality. The flight of imagination resulted in theoretical developments, but brought in subjective thoughts and idealism—which were to block the advance of science in the subsequent periods. That great upheaval of human intellect, its positives, negatives, and achievements, will be the subject matter of the next part of this essay. □

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