(1) HISTORY of the WORLD, from 4.6 billion BC to 600 BC

Before beginning the history of science, it is useful to know in what larger historical context we must embed it. The following remarks are a short summary of what can be found in many books (including history books!). You will come away with a feeling for how insignificant and transitory our present earth-based culture really is.

(a) Brief History of Prehistoric Earth

We now know that roughly 14.5 billion years ago, an event took place whose very earliest stages still lie beyond our present laws of physics. This was the '*Big Bang*'. Whether the 'universe' that emerged from this is unique, and what happened 'before' the Big Bang (if this phrase means anything) is not known. Some 300,000 years after the Big Bang, the universe had cooled sufficiently so that it became transparent to radiation- this allows us to look back to this time. Roughly a billion years later, matter started to condense into gravitationally bound entities- stars, gas clouds, and galaxies. All the while the universe was expanding, in such a way that the farther away two regions happened to be from each other, the faster they were moving apart.

Some 5 billion years ago, a large cloud of gas and dust contracted under its own gravity to form the solar system and the sun. This happened in one of the spiral arms of our galaxy, the 'Milky Way', at a distance of roughly 25,000 light years from the central core (ie., roughly half way out); our galaxy had already been in existence for a few billion years before this happened. There was nothing original about all this - galaxy formation and the birth of stars was already well developed only 800 million years after the Big Bang. There are now some 100 billion galaxies within range of our telescopes, each containing on average some 50 billion stars- and the majority of these have extensive planetary systems, many much larger than our own solar system. The total number of planetary systems in the visible universe is thus of order $10^{22} - 10^{23}$, a number so colossal it is almost impossible to explain. Suppose we tried to count all the grains of sand on a small beach (including digging down to bedrock, to unearth *all* the sand grains!)). Clearly the number would be overwhelmingly large- you can quickly convince yourself that even if you spent your whole life counting sand grains, you would hardly be able to count the grains in a patch only a square metre in size (remember, you have to count the ones underneath as well!). Now take all the grains of sand from all the beaches in all the world- perhaps a hundred thousand km of beach front. An incredible number of sand grains, for sure- but would this give us a number as big as 10^{23}? No - in fact nowhere near. You would have to repeat the process for over 10,000 worlds before you arrived at this huge number.

We thus see that there is nothing really special about our solar system. In fact the sun is a very ordinary star, a yellow dwarf, hardly noticeable outside the local solar neighbourhood. In our own galaxy, sun-like stars and earth-like worlds will be repeated many times - along with an incredible variety of other worlds, some bizarre in the extreme. Of course they will all have their own stories to tell, and there will be a huge variety of these - the visible universe is characterised by extraordinary variety and complexity. It is also marked by unimaginable violence - many worlds have vanished, and will continue to do so, in catastrophic events like supernovae, which we will look at later in the course. Thus there is a fragility to the history of any particular part of the universe - it can be disrupted at any time, and these disruptions should be though of as the rule rather than the exception.

The earth was formed roughly 4.6 billion years ago. Initially very hot (a huge amount of gravitational energy was released by the accretion of the earth, and in the first 300-500 million years of its life it continued to accrete passing material, in a massive bombardment), the earth gradually cooled and the oceans formed. The initial evolution of archaic life forms, and the conversion of the atmospheric chemistry to an oxygen-nitrogen atmosphere, is a long story whose earlier stages are still not well understood. We still do not know how the jump was made from simple molecules - easily formed anywhere in the universe - to complex self-replicating molecules possessing elaborate control machinery. Thus the genesis of life on earth, one of the great questions of our time, is still not understood. It is however becoming increasingly clear that in a universe which is held very far from thermodynamic equilibrium by intense energy sources, the evolution of very complex structures in certain regions of that universe is more or less inevitable. Quite how this works, in general, is not yet understood- this is another question of great interest.

Much less well understood still is what might have happened elsewhere, on the stupefyingly large number of other planets in the visible universe- or in the vast but not empty spaces between them. There is an argument due to Fermi, according to which life in the universe must be rather rare, otherwise it would have already visited us. This argument makes a number of assumptions not worth going through here, but its major flaw is one rather typical in the history of such speculations- it assumes that 'life' from elsewhere would even be recognisable as such to us. My own opinion is that the scope for evolution of complex systems is so enormous that we can hardly imagine what might have been created, or how- and that if 'life' from another part of the universe were advanced enough to be able to visit us, we probably would not even notice it, or know what it was. It is likely that our present understanding of 'life' is unable

to embrace even a tiny fraction of the possibilities open to a universe governed by quantum mechanics and relativity.

Higher life forms appeared on earth in profusion some 600 million yrs ago, at the beginning of the Cambrian era. In a fascinating series of evolutionary steps and mis-steps, life evolved from the sea to land-dwelling species with lungs, roughly 300 million yrs ago. Gradual diversification from early plants, amphibians and crustaceans gave the earth insects, trees, reptiles, etc; on many occasions massive waves of extinction occurred because of climatic changes or because of massive meteorite strikes (for example, the Triassic period was ushered in 220 million years ago by an asteroid strike, which wiped out 98% of all species on earth). Flowering plants appeared 120 million yrs ago, during the Mesozoic era (the time of the dinosaurs); and so did the early mammals. Roughly 65.3 million yrs ago, the dinosaurs were wiped out, and mammals and birds (which had evolved from dinosaurs or their precursors) gradually became the dominant higher species (except in some parts of the world - for example, mammals did not evolve in New Zealand, which was cut off from other land masses 200 million yrs ago). The end of the dinosaurs was partially caused by an asteroid, which hit the Earth near what is now the Yucatan peninsula, leaving a crater 300 km in diameter- widespread climatic and geologic changes also occurred around this time, and helped in the demise of most extant species.

The last 65 million years- the Cenozoic era- have seen enormous changes on the earth (including the retreat of the sea that formerly divided North America in two - what are now the prairie regions were then under water). Just a look at the last few hundred thousand years - hardly a moment compared to the duration of the Cenozoic era, and yet utterly vast compared to human history - is enough to convince us how little we know of the earth's whole story. Large fluctuations in surface temperature have occurred on earth in the last 400,000 years, with ice ages coming and going, and species coming into being and disappearing - life on earth only 50,000 ago was dominated by animals that no longer exist.

The evolution and extinction of different species and families of organisms proceeds even as we speak. This process is presently being accelerated by human interference with planetary ecology - and we ourselves are just as susceptible to evolutionary pressures as any other species, and in all likelihood we will disappear along with the millions of other life forms that have come and gone. The most successful of all animals on earth, measured by longevity, is the shark - it has existed in various forms for 400 million years. Its success has not come from huge brain power or from frenetic activity - indeed we do not really know why it has lasted so long. The end for many species has often come suddenly, in ways that were hardly predictable - despite great progress in evolutionary biology, and in population biology, our models still give only a fairly primitive understanding of such processes. Humans are perhaps the first species on earth to have imagined their own demise, but there is no real reason, certainly at present, to suppose that this will ultimately save them.

We thus arrive at a remarkable picture of the earth - a tiny oasis embedded in a hostile universe, beset from time to time by titanic forces, and utterly unremarkable or apparently unusual on a cosmic scale. It has lasted for a long time, and during this time many interesting life forms and other structures have emerged - often to be annihilated once again, but with others emerging in their place, always driven by the incoming energy of the sun. Our present situation is the result of an enormously long series of accidents - there is nothing inevitable about any of it. When we come to study the rise of civilisation and of science, this hit-and-miss picture will be repeated again and again - a microscopic simulacrum of the larger picture, in which a series of chance events is connected causally across eons of time, under the ever-shifting influence of huge and capricious forces.

This enormously long tapestry of events, in the history of the earth, is very difficult for humans to fully grasp. But these time scales are insignificant compared to the *length scales* we must contemplate when looking out onto the universe. The distance to even the nearest star, apart from the sun, is over 40 trillion kilometers. This is so vast that it is hard to explain. A car traveling at 100 km per hour would take 50 million years to make the journey. Even the fastest rockets sent from the earth would take several hundred thousand years. Light only takes 4.3 years but it travels at incredible speed- at 300,000 km every second. And yet this scale, of 4 light years, is still utterly negligible compared to the scale of galaxies and clusters of galaxies. Our Milky Way galaxy is a huge spiral-armed disc some 100,000 light years across, with an oval central nucleus some 10,000 light years across. The Milky Way contains some 200 billion stars, which themselves make up only a small fraction of its total mass- the rest is made up from 'dark matter', whose nature we currently do not understand at all (this is another one of the 'big questions' presently being asked by physicists!).

Only in the 20th century has it been possible to imagine objects at such a colossal scale- and yet as we saw at the beginning of this short survey, this scale is still minuscule compared to what we can now see. Vast distances lie between even neighbouring galaxies, and yet modern telescopes now have 100 billion of them within range, looking out some 13.5 billion light years from the earth. If past experience is anything to go by, this is hardly likely to be the end of our expanding horizons. However it is almost as far as we will be able to see, at least according to our present understanding. The reason is that in an important sense, the *size* of our visible universe is roughly the same as its *age*. In looking out 13.5 billion light years from earth, we are looking back 13.5 billion years in time, to only 1 billion

years after the Big Bang. The ratio between our distance measure and our time measure is the velocity of light- for every light year we look out from the earth, we look back 1 year in the past. It is only because light travels so fast (by human standards) that the universe's size seems so much more impressive than its age. In any case, we cannot at present look farther back than the Big Bang - and so the size of the visible universe is limited to an expanding sphere around us, whose radius right now is 14.5 billion light years.

There is a great temptation to imagine that somehow we are at a very special time in the history of the earth, privileged to be the first to contemplate the universe for what it really is. Many have yielded to this temptation (both now, and at many previous periods in human history!). Just how special we really are is another question that some consider important- we shall revisit it, along with the other questions noted above, near the end of this course.

(b) Remarks on Ancient Human History

To deal with the history of science in manageable chunks, it is necessary to gloss over most of the really interesting periods in human history, as they came to pass in different parts of the world. As a mild antidote to this, the following gives a very quick survey of some of the main things that happened up before the time of the Ancient Greeks.

(i) **Prehistoric Man**

Humans evolved from Apes- the finer details of this evolution are not yet known but DNA decoding is likely to clear much of this story up in the next few decades. At the present time it looks as though the crucial evolutionary steps occurred in Africa. The fascinating story of how evolution proceeded from *Australopithecus* to *Homo Sapiens sapiens* will only be sketched here. It is perhaps worthwhile emphasizing just how much we still don't know. Little is yet known about which genetic and developmental changes led to early Man. We have some information on how, eg., *Homo Erectus* lived, but the answers to even quite basic questions remain mysterious (eg., when did speech evolve, and what physiological changes did it incorporate?). These are also big questions of our time- there is a reasonable possibility they will be answered int he next 20-30 years.

Australopithecus appeared some 4.5 mllion yrs ago, and continued for over 2 million yrs in one form or another- remains have been found in Ethiopia, Kenya, and the Transvaal. Already one sees the divergence between the Apes and the early hominids, and several physiological features distinguishing this species - as well as the oppositional thumb and binocular vision, one has the ability to walk upright (this latter was clearly of use in open savannah, which was then appearing in Africa along with climatic changes). Already *Australopithecus* had a bigger brain than the apes.

Roughly 2 millon yrs ago one sees the first signs of *Homo Habilis*, which showed the first signs of using tools of stone, and of creating some sort of artificial construction (a windbreak or wall found in the Olduvai gorge (Tanzania), dating from 1.9 million yrs ago, and behind which meat was eaten). This species spread rapidly across Africa, Asia, and Europe.

Roughly 1.5 million yrs ago one sees the beginnings of *Homo Erectus*, which reached its peak perhaps 250,000 yrs ago. This species already had a brain the size of modern man's, and was distinguished by its use of the stone 'hand axe', which was probably not an axe, and was used to cut things ranging from food to skins. Important physiological and behavioural changes accompanied the increase in brain size. Woman had larger hips to allow the passage of larger heads during birth- and there was no more oestral cycle, ie., women were by then sexually active at all times (man being the only mammal to have made this evolutionary change). Children are by this time less well developed at birth, and there was clearly a longer child-rearing period - this eventually became a learning period in which physical and mental development was accomplished, and the beginnings of collective culture were transmitted. One finds the earliest traces of wooden huts up to 15 metres long, and objects like spears, bowls, etc; one also sees the construction of shapes like circles, ellipses, and triangles. Two other significant developments occurred - the use of fire (although probably not the ability to make it), and hunting. This meant the development of new food supplies, cooperative behaviour which must have played some role in the development of language, and also the possibility of living in less hospitable climates (in caves); and of cooking.

During this time there were large climate swings on earth, with a long Ice Age from roughly 200,000-100,000 BC, and extensive ice ages from 50,000-10,000 BC (with the worst period from 20,000-10,000 BC). Massive ice sheets spread down over Europe, Asia, and North America, down to the US-Canada border, southern France, and northern China. The records in these regions are of course seriously disturbed by these changes. One distinguishes the stone-

using cultures by the Lower Paleolithic (from c. 2 million yrs ago to 50,000 yrs ago) and the Upper Paleolithic (to 10,000 yrs ago).

Roughly 250,000 yrs ago *Homo Sapiens Neanderthalis* appeared (this is Neanderthal Man, named after the place in Germany where remains were first found). The most complete records of this species exist in Europe, but it spread over Asia and Africa as well. It survived the Ice Ages in Europe, but roughly 23,000 years ago, during the last great Ice Age, the competition between *Homo Sapiens sapiens* (modern man) and Neanderthal Man finished with the extinction of Neanderthal Man. None of this is simple- many of these species names are labels which will be revised as more remains are discovered, and DNA analysis reveals a more complete picture. Note also that there was clearly inter-breeding between Neanderthal Man and *Homo Sapiens*, and we know really very little about how these 2 groups interacted with each other. In any case Neanderthal man was able to use fire, and had clothes, and remarkably, a form of ritualized burial. This included the construction of grave sites, where plant and flower remains have been found. There also appears to have been a form of warfare, involving cannibalism, possibly between tribes.

Some 100,000 yrs ago *Homo Sapiens sapiens* appeared, first in Africa; roughly 40,000 yrs ago it had reached Europe and North America (the latter by a land bridge across the Bering sea, caused by the withdrawal of the Oceans, with water taken up by the Ice caps). One now finds extensive tools, made from stone, bone, and flint (which also allowed the control of fire). These include bone needles, knives, bows and arrows, spear throwers, and harpoons, in various parts of the world. Most striking of all is the appearance of the first early art. The first traces of this now known are from some 35,000 yrs ago in Europe (Cave painting is also found in Africa from 27,000 yrs ago, and in Australia from 20,000 yrs ago). There are stone, bone, and clay figurines, and most famously, the extraordinary cave paintings of SW France and Spain. The best known is at Lascaux, in the Dordogne region, found by some boys in 1940. These paintings begin some 25,000 yrs ago, and abruptly disappear about 11,000 yrs ago, just before the end of the last Ice Age- the most important period was from roughly 23-18,000 yrs ago. They are very detailed, with themes mostly centred on animals- they often seem to tell stories, but the animals in some cases also seem to have a primitive religious significance. From very extensive archeological evidence we have acquired a detailed picture of how man lived in this period- a picture which has animated many movies and books in recent years. There is little doubt that research in the next few decades will do much to fill out the picture we now have, of the development of prehistoric man- it will in all likelihood change it a great deal as well.

(ii) Civilisation- from 8,000 BC- 600 BC

The end of the last ice age, 10,000 yrs ago, apparently heralded a new way of life for modern Man. The sea level rose again (the English channel, for example, made its reappearance around 7000 BC). This is the beginning of the Neolithic period.

There are very many books which give a detailed picture of the rise of different civilisations around the world in the time since then. Our purpose is not to go into this- it would take many pages even to summarize it. What is of more interest here is the fact that the remarkable edifice of modern civilisation, and by implication of modern science, is actually the result of a small number of crucial advances, made in certain places at certain times. It is then worth noting just a few details of the rise of civilisation, with the following 2 questions in mind:

Why did these crucial advances only happen under very special circumstances- and what were these circumstances?

Given the extreme fragility of many civilisations, and of the intellectual advances made by them, how inevitable was the development of modern science?

We will return briefly to these questions at the end of the course- they are difficult, and their very nature means that no firm answers can be given. It is clearly not worth even trying until we have seen how science did develop.

In the following I just give a brief digest of the history of the important civilisations, up to the first one of crucial interest to us (the Ancient Greek civilisation).

10,000-4,000 BC

10,000 BC: Process of formation of 5 Great Lakes is largely complete- melting ice will continue to enlarge them and change their boundaries for several more thousands of years. Many primitive artifacts found in Southern Ontario from this period.
8500 BC: Jericho- first walled town
7500 BC: 1st Cemeteries in North America
7000 BC: Çatal Hüyük (Anatolia, Turkey); farming, cattle herding
6500 BC: Greece, Aegean region- farming
Middle East- first metallurgy

6000 BC: Thailand- rice cultivation
5200 BC: Nile valley- barley and grass seed cultivation
5000 BC: Mesopotamia- Copper used for first time
China- Yanshao pottery
Mexico- Maize cultivation begins
Peru- Chumash indians build wooden plank fishing canoes
English Channel begins to reform as ice melting continues to raise the global sea level.

4000-3000 BC

4000 BC: Plough invented (Mesopotamia)
Britain- first farming in Britain
Sahara region- domesticated animals

3500 BC: Sumerian civilisation begins in earnest in Mesopotamia- cuneiform script, food stores, etc.
Clay tokens used for money; Copper alloys, smelting of Gold, Silver
Crete- early civilsations already using oarships
Mesopotamia- wheel invented
3200 BC: Beginning of civilisation at Ur
3050 BC: Egyptian provinces unified

3000- 2000 BC

Asia

3000 BC: China- first use of plough
2900 BC: China- beginning of period of 'Sage Kings'
Pakistan- Indus valley civilisation (Harrapan culture) begins
2700 BC: China- Bronze age, and beginning of silk weaving
2697 BC: China- reign of 'Yellow Emperor' begins

2200 BC: Japan- Middle Jōman period
Hieroglyphic writing appears in Far East

Middle East, Mediterranean, Africa

3000 BC: Egypt, Mesopotamia- Unified weights and Measures, surveying methods
Mesopotamia- invention of wheeled chariot
Palestine- Bronze age begins. Molded Copper axes and knives
Crete- bronze age begins
2700 BC: Mesopotamia- huge irrigation networks
2686 BC: Egypt- Old Kingdom begins (runs from 2686-2160 BC)
2650 BC: Egypt- Building of great pyramids begins (Djoser pyramid)
2500 BC: Egypt- wooden boats, manufacture of oil by pressing, perfumes
Mesopotamia- fine metalwork

2300 BC: Mesopotamia- Sargon unites Sumerian civilisations
2040 BC: Egypt- Middle Kingdom begins (runs from 2040-1674 BC)

Europe

3000 BC: beginning of Megalithic culture in W. Europe.
England- first stages of building Stonehenge
2500 BC: English Channel- invasions of Britain across Channel
Scottish Neolithic culture
2200 BC: Ireland- beginning of Bronze age
England- 2nd stage of building of Stonehenge

Americas, Australasia

3000 BC: Ecuador, Columbia- pottery begins
2800 BC: Brazil- first Amazonian villages

2000- 1000 BC

Asia

2000 BC: Siberian Neolithic culture begins
1766 BC: China- Shang dynasty begins; bronze age culture. First urban civilisations, bronze casting
1500 BC: India- European Aryans invade India
China- existence of Pythagorean triangles and mathematical permutations noted
1450 BC: India- Brahma worship begins
1100 BC: China- beginning of first Chinese dictionary (compiled 1100-900 BC, with 40,000 characters)
1045 BC: China- Zhou dynasty starts

Middle East, Mediterranean, Africa

2000 BC: Crete- Minoan civilisation begins (pottery)
Egypt- locks become commonly used
Aegean Sea- first sailing ships
1894 BC: Babylon (Mesopotamia)- first dynasty begins (runs from 1894-1595 BC)
1800 BC: Egypt- existence of Pythagorean triangles noted
1792 BC: Babylon- reign of Hammurapi begins. Elaborate astronomical observations, time-keeping.
1620 BC: Anatolia (Turkey)- Hittites (Indo-European culture) establish themselves. Cuneiform script soon after.
1558 BC: Egypt- New Kingdom begins (runs from 1558-1085 BC)
1550 BC: Syria- Hittites capture Aleppo
1500 BC: Eruption of Thira (Santorini), Collapse of Minoan civilisation
1450 BC: Greece- Rise of Mycenean civilisation
Iron weapons become common in Middle East
Egypt- beginning of bondage for Hebrews (1500-1250 BC). Double ruddered sailing vessels used
1400 BC: Alphabet devised by Phoenicians
Greece- Beginning of construction of Acropolis in Athens (from 1400-1100 BC)
1240 BC: Moses gives 10 Commandments to the Israelites
1200 BC: Mesopotamia- Gilgamesh epic recorded
1300 BC: Egypt- construction of Abu Simbel rock temples
1193 BC: Turkey- Alliance of Myceneans and other city states sacks and destroys Troy
1182 BC: Egypt- Reign of Rameses III begins (from 1182-1151 BC)
1140 BC: Utica (Africa)- first Phoenician colonisation
1120 BC: Mycenae destroyed- Greek 'dark age' begins

Europe

1700 BC: England- 3rd phase of building of Stonehenge begins

Americas, Australasia

2000 BC: Peru- settlements in Andes, with ceremonial centres; first metalwork, cotton growing
New Guinea- first settlers
1800 BC: Micronesia- first settlers
1500 BC: Mexico- Olmec culture- gravel platforms
1400 BC: Honduras- village life
1300 BC: Fiji, Samoa, etc- first Polynesian settlers

1000-500 BC

Asia

900 BC: China- mathematics includes arithmetic, geometry, equations with 2 unknown quantities.
800 BC: China- Planetary motions analysed
650 BC: China- beginning of Iron-based technology
605 BC: China- Lao-Tzu, founder of taoism, is born (lives 605-520 BC)
563 BC: Nepal- Siddhartha Gautama, the future Buddha, is born (lives 563-483 BC)
551 BC: China- birth of Confucius (551-479 BC)
526 BC: China- first codes of law issued
500 BC: India- caste system established. Susrata (surgeon) performs cataract operations. Rice cultivation begins

Middle East, Mediterranean, Africa

1000 BC: Israel- Hebrew alphabet developed
922 BC: Israel- splits into Israel and Judea
900 BC: Egypt- kingdom of Kush becomes independent of Egypt
814 BC: Tunisia- Phoenicians found city state of Carthage
800 BC: Greece- Homer writes the "*Odyssey*"
Israel- subterranean sewage and water supply system functioning
776 BC: Greece- first Olympic games in Athens
753 BC: Italy- Rome founded
604 BC: Babylon- Nebuchadnezzar claims throne
581 BC: Israel- Nebuchadnezzar II burns Jerusalem
558 BC: Persia- beginning of Persian empire- reign of Cyrus the Great (558-529 BC). Zoroaster begins to found his religion
539 BC: Mesopotamia- Persians conquer Babylon
536 BC: Greece- beginning of construction of Apollo's temple at Delphi
517 BC: Egypt- canal constructed from Nile to the Red Sea
509 BC: Italy- Roman Republic founded, Tarquin deposed

Europe

1000 BC: E Europe- Teutonic tribes move west as far as Rhine

Americas, Australasia

600 BC: Mexico- Mayan civilisation

The general impression that one gains from the above digest is of slow progress, and of the rise and fall of many civilisations. What is less obvious is that the history of many of these civilisations remains almost totally unknown to us. It is only those periods for which archaeological remains are reasonably detailed that we have any real understanding of what happened. The change in our knowledge during even the last 50 years makes it clear that there are huge gaps in what we know, and filling these may well give us a very different view of how things have evolved.

At this point, apparently quite arbitrary in the calendar of human history, we stop, in order to focus on a key period in the development of science- the 'Golden Age' of Ancient Greece.