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A SCIENTIFIC RETRODICTION OF OUR PAST*

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Our universe began with a blinding flash about 10 billion years ago — or rather a flash which would have been blinding had there been any possibility of eyes to see it. As radiation streamed out in all the directions that there are, the temperature fell to a point where energy could materialize as particles; matter rapidly passed through the ephemeral particulate forms which we now recreate in high energy accelerator laboratories. Before long most of the matter had ended up as atoms of hydrogen or helium. As the temperature kept on falling, masses of gas about the size of our galaxy began to separate from each other; these galaxies have been streaming apart ever since. Within these extended regions of gas, gravitational forces began separating out blobs containing as much mass as a star. Slowly at first, and then faster, the atoms within these regions fell towards the centers of the clouds. As the frequency of collisions between the falling atoms rose, so did the temperature, until the first thermonuclear fires were lit and the stars started shining with a steady light. Many of these original stars still light our night sky.

Any description of natural phenomena which attempts to be scientific always contains uncertainties and anomalies which can lead at a later stage to minor revision or radical reconstruction of the theory. For several years there was a rival theoretical description of the universe which ascribed the streaming apart of the galaxies to a continuous creation of matter rather than to an origin in time. This theory has recently been conclusively disproved and has been abandoned by its original proponents, leaving the field to the "big bang" theory sketched above; the latter theory has itself received quite dramatic support from new observations. It is significant that, outside of the subtle effects which did allow a choice to be made between the rival theories, both descriptions were in essential agreement about the course of events in our own galaxy

for the last nine billion years or so. Rather than interrupt this narrative with qualifications like the above, the reader is asked to treat the following statements as probable, but in varying degrees.

The more massive stars burned their hydrogen to helium and then their helium to iron at a much more rapid rate than the smaller stars which are still shining. For the massive stars the process could not stop at iron but led in the end to the production of a sudden burst of neutrinos which shot out of the core of the star, suddenly cooling it. This sudden loss of heat pressure allowed a rapid collapse of the outer layers of the star into the center yielding enormous transient compressions which produced many neutrons and the elements heavier than iron such as gold, lead, and uranium; the material which had fallen in then rebounded outward in a catastrophic explosion which now would be called a supernova. Within a billion years or so after the original massive stars where formed the regions between the smaller stars came to be sprinkled with the traces of elements which had been synthesized before and during the explosions of supernovae and then spewed out into space; this material was incorporated into the new stars which kept on being formed. Usually the newly formed elements and debris ended up as two or more stars, but for about one gas cloud in twenty most of the material condensed into a single central star with the little that was left compacted into smaller bodies circling the star — planets too small to light thermonuclear fires in their own centers. By four and one half billion years ago these planetary systems were quite common throughout the galaxy; one of them was our own. When the sun began to shine, it drove much of the residual gas and dust out of the system, but was not hot enough to disrupt the earth or the other planets. On the surface of the earth water began to collect into lakes and ponds, while the nitrogenous atmosphere

was rent with lightning and bathed in ultraviolet light from the sun. As a result amino acids, purines, pyrimidines, chlorophyll, and many of the simpler molecules we now find in living things were formed.

In ponds, clay banks, and other moist spots there were interesting nooks and crannies of just the right size and shape so that amino acids could nestle there and hook together; other hollows suited the joining of purines and pyrimidines into nucleic acid chains. Once formed, these chains themselves could serve as moulds to link up other organic molecules in chains and spirals. In some ponds inorganic crystals of magnetite contaminated with sulfur converted the energy of ultraviolet light from the sun into chemical energy, and when the right amino acids became attached, served as active sites for synthesis. Nucleic acid single spirals could be formed on these moulds, and could themselves reform amino acid chains. Droplets of these organic molecules enclosing energy converters and protected by selectively absorbing surfaces began to collect available molecules of similar structure. Within these droplets complicated sequences of chemical reactions become possible. Any reaction which increased the likelihood that the sequence in which it occurred would be repeated began to happen more and more often inside these organized structures. These structures in turn spread gradually over the surface of the earth as their materials were dispersed and recombined in suitable locations. Eventually the three essential parts of the interlocking system — surface, energy converter, and the double helix of nucleic acid carrying the essential information needed to replicate both itself and the structures which served that replication — were so adjusted that both reproduction and survival became reasonable reliable. Once these microscopic living things had appeared there was no turning back. The remaining free-living molecules suitable for ingestion disappeared

as life spread through the waters of the earth; less organized structures could not survive its onslaught. The first irreversible evolutionary change had taken place.

Primitive systems for energy conversion and for storing up this energy in organic materials were gradually replaced by more efficient means; chlorophyll came into its own as the primary energy converter, starting reaction chains which transform carbon dioxide, water, and trace elements into energy rich organic molecules. Oxygen produced by photosynthesis began to accumulate; living systems replying on its presence in the waters of the earth became possible, pushing the more primitive anerobic systems which had lived without oxygen into environments where they alone could survive. Three and a half billion years ago both blue-green algae and anerobic bacteria must have been plentiful on the earth. Larger single-celled structures, in which the nucleic acid was concentrated in a nuclear region and surrounded by more complicated machinery for the synthesis of proteins, took advantage of more abundant supplies of food and oxygen to build a new superstructure going farther than the older chemical reaction chains. The incorporation of simpler chlorophyll-containing plastids into these larger and more elaborate nucleated cells led to still higher levels of efficiency in energy and oxygen production. The next overall increase in complexity resulted in single-celled animals and plants of types still found today. But these developments presupposed the earlier forms, and interlocked the old and the new into a system of ecological interdependence that was to grow ever more complex as life evolved. Oxygen became more and more plentiful as a result of the photosynthetic activity of the plants, eventually producing an ozone layer in the upper atmosphere shielding out ultraviolet rays from the sun and protecting the surface of the earth. New styles of life and new

chemical reaction chains which could not have worked under the conditions of the primitive earth became part of the system for all but the most archaic organisms; again the change was irreversible.

Both interaction between individuals of the same species and the interlocking of different species into ecological systems is as old as cellular life. Some time during the last three and a half billion years, the greater flexibility for adaptation resulting from the grouping of cells into colonies began to be exploited. Even bacteria, grown under uniform conditions, produce colonies of characteristic shape, differing between different species; cells on the surface are subtly affected by some chemical communication from within the colony as a whole. Building on this or some other integrating effect, differentiated cell colonies, and then differentiated organs within colonies were evolved. For any multicelled organism, death of the organism is distinct from the death of the individual cells. Among the specialized organs were those for the interchange of genetic material between individuals, although the older option of self-reproduction was and is retained as an alternative in many species. The use of sexual reproduction insures that individuals will differ from both of their parents, while organism-death insures differential selection of these various individuals, leading to a closer adjustment between the species and the environment as a whole. Thus sex and death enormously speeded up the rate of evolutionary change, and the accuracy with which it could meet environmental challenges.

The increasingly oxygen-rich environment favored species making use of rapid chemical reactions and high mobility; for some animals, evolution of the central nervous system gave coordinated direction to that mobility. This may have occurred as long as a billion years ago; it must certainly have been

part of the scene more than half a billion years ago when the hard parts of animals began to be found in the fossil record. Long before that time the growing iron-nickel core of the earth may have produced a convective pattern in the mantle leading to differentiation between the oceans and one or more continents. The new environments again encouraged progressive change as plants, then invertebrates, then vertebrates invaded the land. Amphibians, the first vertebrate land dwellers, are still tied to water for the starting phases of their lives. The development of copulation, and the hard-shelled egg, broke this connection for reptiles and gave them freedom to explore and exploit the land. Somewhere along about this time the steadily growing core of the earth forced a new circulation pattern in the mantle splitting the older continents; these convection currents are still forcing the continents apart, broadening the Atlantic ocean, and keeping volcanic and earthquake zones active around the edges of the Pacific. Increased control over the internal chemical activity of some living things was achieved by the invention of warm blood in birds and mammals. Particularly among mammals, live birth followed by a long period of parental and social nurture provided leverage for social control and increasing flexibility in the patterns of group response to environmental challenge.

From perhaps 225 million years ago until about 65 million years ago, reptilian forms dominated the land, culminating in the dinosaurs or terrible lizards. Birds and mammals came into being during this period and found ways to live which did not conflict with the dominant forms. But when the dinosaurs disappeared about 65 million years ago, for reasons that are still unclear, many new ecological niches became available. The result was an explosive radiation of mammalian forms into many new types fitted for these new ways of life. For some, life in the trees led to the development of the grasping hand with opposed

thumb, stereoscopic color vision, and skillful hand-eye coordination mediated by a highly structured brain. When climatic changes reduced the forest area available, those species least successful in clinging to the original environment were forced to develop means of crossing the open spaces, and eventually to a gathering and hunting life on the open savannah. In competition with the baboons for this environment, our ancestors found an answer in erect posture and the ability to run for long distances, and a new form of social organization which facilitated the cooperation of adult males for hunting and the females and immature individuals of both sexes for gathering; these cooperative institutions incorporating sexual division of labor led to the invention of tools several million years ago.

Along with these developments went a reduction in tooth size and a diversification of tooth structure which has enabled us ever since to make effective use of a wide variety of plant and animal foods. There was also an increase in the length of the period of immaturity and nurture, allowing for the effective and continuing communication of the elaborate social organizations and cooperative traditions which had led to human adaptive success. By the start of the first ice age, man the maker had all these characteristics, and we find his bones intermingled with his tools and the animals hunted by means of those tools. Because of our cooperative institutions and material artifacts, we were able to meet the challenge of the severe climatic changes which started more than two million years ago. Our success contrasts markedly with the disappearance of nine out of ten of the species in existence before the "ice age". Then humans stood only about four and one half feet tall and had only half the body weight and brain size of modern men. During the next million to million and a half years, height, weight, and brain size gradually increased, while pebble

tools evolved into crude hand axes at a comparably slow pace. Remains found in Java from what might be three-quarters of a million years ago, and from Pekin of perhaps 350,000 years in age, both reveal men and women of modern height but smaller brains. Associated with the remains from Pekin is clear evidence for the use of fire.

Social organization proved its reliability as a method of adaptive response for many species besides our own under the severe conditions produced by the advance and retreat of the glaciers, and the corresponding climatic swings in tropical regions. In the environments which were rich enough in disposable energy to support elaborate organization, poorly integrated or less flexible species were replaced. This consolidated a new level of irreversible complexity at the level of adaptive social organization. But on this planet further advances of such qualitative significance as to prove irreversible have been confined to our own species. Perhaps the most significant of these occurred some time prior to the latest glacial advance; it was well established by the time our Neanderthal ancestors started ceremonially burying their dead more than 70,000 years ago. Burial implies a use of symbolic thought, and is correlated archeologically with an enormous increase in the rate of social invention. By 35,000 years ago, paleolithic hunters were carrying lunar calendars which allowed them to keep track of the $29\frac{1}{2}$ day period between full moons, the rhythm which determines so much of the life pattern in a hunting society. The previous million years had left behind only one main style of hand ax, whose style changed as slowly as the bones of its makers. In contrast, from the time we started burying our dead, the passing years show increasing diversity and novelty in the styles of flintworking, with many regional and local traditions. Tools were invented to make tools; bone needles show that clothing had come into use. Harpoons, fish-hooks, and a host of other inventions appeared.

These new inventions, particularly the hafted projectile point launched by bow or spear thrower, transformed man from a food gatherer into a skillful hunter. In the altered conditions of glacial Europe, they provided Cro-Magnons with the means to live abundantly off of the herds of large mammals such as mammoths or woolly rhinoceri. On this base they erected a rich artistic culture, whose surviving paintings and sculpture can still move us today. But paleolithic hunters went beyond the killing of individual animals to the slaughter of herds by driving them over cliffs, perhaps using fire in the process. It has been speculated that grasslands we now find in temperate regions may have been originally created by these prehistoric fires. The techniques may well have been too successful, and been the cause, direct or indirect, of the extinction of many species. At any rate, the path of man into the new world coincides in space and time with the extermination of food animals weighing over 100 pounds along that route. Whether or not this hunting economy perished of its own contradictions, Cro-Magnon and other paleolithic cultures could not survive the radically changed climatic conditions following the retreat of the glaciers; new ways of living were developed in both hemispheres.

The paleolithic social inventions established us as the dominant species in all regions of the world. Yet our numbers, like those of any other predator or food gatherer, were strictly limited by the interlocking system of plants and animals at that stage of evolution. This connection was broken about 10,000 years ago in several parts of the world when we began to manipulate our sources of food, and became food producers rather than hunters and gatherers. The social inventions marking this transition and its techniques differ widely, showing that they were independent expressions of a common human potentiality. On the Iranian plateau, the hunting of wild herds by men and the gathering of

edible seeds by women changed to the protection of herds by men and the planting of seeds by women. We know when the transition occurred because hunting cultures usually eat mature animals, while food producers often eat young animals; the bones remain for us to study. Wild grasses drop their ripe seeds, while crop plants keep the grain in the ear until it is harvested and threshed. Since crop plants have difficulty reseeding themselves, the mutation they represent from the wild variety must have succeeded because of selection by men. Thus archeologists can trace cattle and wheat, and other domestic species of the Mediterranean area, back to a transition from wild species on the Iranian plateau, and data the origin of food production there. The ancestral stock of maize (Indian corn) also dropped its kernels, while domestic varieties keep the kernels in the husk. Meso-americans began to select out and raise domestic corn as early as the varieties leading to wheat were selected in Iran. In 1969, it was discovered that the complex of food plants on which later civilizations of the Far East were based, were already being raised in Northern Thailand about 9,000 years ago.

Primitive methods for raising food plants exhaust the soil in a few years, so early neolithic villages had to keep moving on. Wherever a successful complex of inventions leading to food production was achieved or imported, the culture using it had to spread out across the whole area of soil and climate where these techniques could work. In the process, population rose to several times the level which could be supported by hunting and gathering. Once food producing societies had come to occupy large areas, reversion to hunting could not occur without mass starvation. Some major commitment to concentrating and storing protein in plants or animals has inevitably and irreversibly become necessary for every sizeable human population group ever since the neolithic age.

As the land filled up, the need for new social invention became ever greater, and the pace of change again quickened. In the Danube Basin this process has been traced archeologically from the period when the virgin land was occupied by unfortified villages, moving on every few years, to the time when there are permanent centers fortified against human enemies. In the latter villages, the earlier rough equality between households has disappeared, and the palace of the war chief is easily distinguishable from the huts of the peasantry. Weapons of war appear in the graves along side earlier hunting tools, and the grave of the chief is richly endowed. The same story can be documented, valley by valley, in Peru. Food production and the concentration of food reserves, together with population pressure, were precursors of organized warfare and the state. Nomadic peoples store their food in the moveable form of herds, and also as the land fills up must contest either other tribes or the settled agriculturalists for the necessities of their way of life.

In the valleys of the Tigris-Euphrates, the Nile, the Indus, and the Yellow River, annual floods brought down fresh soil each year and deposited it in alluvial plains. The rivers also supplied a steady source of water and a ready means to remove the human wastes which so readily breed pestilence when humans crowd together. So these favored areas came to possess higher population densities than the surrounding lands. Urban life accentuates still further the division of labor and the elaboration of social structure. For instance, in the alluvial valleys land had to be redistributed after each flood, which required firm social control; much was gained from communal irrigation works and flood control dykes and canals that no village had the surplus labor or insight to build on its own initiative. So heirarchical governing structures gained control over the village headmen, while the social cohesion of local tradition

was reinforced by a more elaborate religious system centralized in temples and governed by a trained priesthood, Priestly administrators were also trained to serve the more secular concerns of government. Administration on this scale requires permanent records, and these were developed in both hemispheres. More than 6000 years ago, some elements of written history had appeared, and copies of ancient documents made a thousand or so years later can still be read by contemporaries of ours who have teased out the meaning of wedge-shaped marks on clay. However, defense of these urban areas against the much sparser barbarian populations surrounding them took some of the social surplus to support a warrior class. Then as now, the existence of armies provided the government with temptation to military adventure, and the borders of the ancient empires were extended by conquest. Bronze weapons made by alloying copper with the rare metal tin gave the city armies a great advantage over the stone and copper equipped opposition; but this military technology could be copied in the barbarian areas, increasing still further the gap between the war leader, his henchmen, and the rest of the people. Thus new hierarchical aristocracies and monarchies grew up on the borders of ancient empires.

The few written records of these early periods we possess tend to distort our perspective and focus it too narrowly, even when they are supplemental and reinterpreted by archeological study. Both methods may place the first known instance of various social inventions in space and time, but cannot show that this was either when or where that invention first occurred. Much was going on in the rest of the world outside the regions called "civilized", as a few tantalizing clues reveal. African warriors with zebra-skinned shields serve as far from home as the halls of Minos in Crete; Egypt must have learned much from the

recruitment of population, slave or otherwise, from the Sudan. Judging by the subsequent political sophistication of African political institutions farther south, for instance the invention of taxation, it is a fair guess that much of the social invention which went into the service of the Pharaoh came from black administrators; indeed, it is now claimed that at least one of the greatest Egyptian dynasties was black. The high level of brass and iron technology in later African cultures has yet to be put in proper historical perspective. Whatever writing materials were used in the Indus Valley have not survived, but there is evidence from cylinder seals that there was contact between the Indus and Summeria, and who knows who gained the most. Contact probably also extended to the high civilization of China, and little is known of that was going along on the routes that maintained these contacts. For instance, it was first learned in 1968 that northern Thailand had a sophisticated bronze working technology a thousand years before there is any evidence for bronze along the Yellow River.

Somewhat less than 4000 years ago a practical method for working iron was developed on the Anatolian plateau, probably after being imported there from Africa. Since iron is the end product of stellar burning, it is very common on planets such as ours which have been compacted out of stellar ash. Thus iron offered cheap metal for both weapons and tools, breaking the aristocratic metal monopoly of earlier times. Once the Dorians had equipped their common soldiers with iron weapons, they were more than a match for the bronze-armed aristocrats of the Minoan and Mycenaean kingdoms, and they swept across Greece and the Aegean. Iron tools first cleared and then denuded the rocky valleys and slopes of Hellas as the growing population turned to shipbuilding, piracy and commerce. Out of the resulting social diversity came novel institutions such as democracy (for the slave-holding citizens), and novel systems of ideas, of

which the most far-reaching were rational science and deductive mathematics. But neither ideas nor institutions could solve the problem of internecine warfare between the Greek city-states. The warring cities were brought into line by the new imperialism of Macedon, which in turn succumbed to Rome. Imperial wars fed the slave markets of the classical world, debasing the role of manual labor in the community, and reducing the social incentive for coupling mechanical inventiveness to technological processes and labor-saving machinery. This was one of the reasons why Greek science and mathematics, Hellenistic gadgeteering, and Roman engineering failed to combine to produce an industrial civilization of the modern type.

Rome was but one of the many contemporary civilizations in different parts of the world. Incan, Mayan, African, Islamic, Indian, Chinese, Polynesian ... societies were already, or soon to become, fully comparable in their achievements to the Golden Age. Often they were more advanced in developments parochial Westerners identify as unique to our own traditions. Greek mathematics never developed the concept of zero as a number, invented by Hindu mathematicians, or the verbal algebra of Islamic scholars. The classical world was not as advanced mathematically or in astronomy as the contemporary Mayan civilization, which had invented place value notation, and adopted a calendar more accurate than the one in use today. The fall of Rome is in sharp contrast to the political and cultural stability of China, where changes of political leadership, even by conquest, could not change the basic patterns of Chinese society. And it was in China that paper, printing, the compass, and gunpowder — which were later to have such enormous impact in Europe — were invented. The fall of Rome left Europe a very backward part of the world for many centuries; during the time appropriately called the Dark Ages in Europe, major

change occurred elsewhere. New political and cultural inventions and institutions grew up in Africa, Islam became the dominant civilization in many parts of the world. Melanesia, Micronesia, and Polynesia were explored and developed. The feudal political institutions of Medieval Europe were in part a response to an invention made on the steppes of Asia — the stirrup. Charles Martel realized that he could not meet the shock cavalry of Saracens equipped with this new device without an adequate military force, similarly equipped. He expropriated church land, and distributed the land to those who would use it to raise horses rather than crops and undertake to supply mounted troops in return for their feudal position.

Yet this formerly backward area of Western Europe has for the moment brought the whole world under its hegemony, or the hegemony of states which it has spawned, creating a burgeoning technology which threatens our species, and perhaps all life on this planet, with extinction. Why this development occurred first in Western Europe is not obvious. Western technology had parallels in other cultures and civilizations which did not lead to revolutionary consequences. African and Chinese metal working techniques were initially in advance of those in Europe, and the Chinese had developed much complicated machinery. Many other cultures and civilizations have had as vigorous commercial development and as lively towns with as much or more specialization and division of labor as was found in Renaissance Europe. Other civilizations had military and naval institutions which could have developed their potential for conquest to the level actually achieved by Europeans. So why was Europe first?

It is possible that the sudden eruption of Europeans across the face of the globe can be explained in terms of energy conservation and its social correlates in their particular historical setting. Like other scientific and historical points

mentioned in this narrative, the explanation is controversial; yet it is compelling.

For societies drawing their energy primarily from animal and plant materials (all terrestrial societies prior to the eighteenth century), the energy surplus available after the requirements of food production are met is usually less than 20%, 80% or more of all human bodily motions which occur in such societies are directly connected with food production. Much of the remaining "surplus" is also not available, since it must go to maintain the social structure. This meagre energy base for traditional societies has profound consequences. Any form of social deviance which takes energy away from food production directly threatens the lives of members of the communities; traditions are rigid, and repression is harsh when those traditions are flouted. In such societies any marginal change can have enormous consequences out of all proportion to the amount of energy involved. For instance, the flowing river can carry bulk goods downstream at an energetic profit if they are exchanged for war or luxury goods to be transported back upstream. Thus a militant aristocracy can be supported in the hinterland to keep the peasants working and provide an expanded food base for cities at river mouths; this surplus in turn can support specialized division of labor in those cities. The concentration of wealth the river makes possible stabilizes the social structure against change, unless there is economic collapse, or foreign conquest.

The world-ranging sailing ship in European hands broke the stability of ancient hierarchical societies. The sailing ship delivers as motion several thousand times the energy stored in the food needed for the crew. The ship in turn opens up the economic gains which can be made by exploiting the division of labor among different climates and resources. Particularly when the ship

was armed with cannon (another application of inorganic energy), the expedition could combine military with commercial power to increase the profits gleaned from the concentrated wealth of ancient seaports. Such profits are of little consequence if they are distributed as booty among the crew. European institutions had long favored an alliance between merchants and monarchs which insured the return of the profits to the merchants who had financed the voyage. The concentration of the capital provided by sea power provided a continuing base for expanding conquest. Once launched on this imperial course, European nationals found a new world ripe for the plucking, including vast temperate regions which had few local agricultural traditions. Europeans took over these lands by conquering or murdering the indigenous inhabitants. Enslavement of the conquered peoples and importation of slaves from Africa provided a labor base for exploiting the land. The efficient agricultural techniques for temperate climates invented in manorial Europe could thus be brought to bear on virgin soil. The expanding food base led to a population explosion for peoples of European origin in both hemispheres, and further increased their power.

The power created by this explosive economic development became more and more concentrated in the hands of the mercantile bourgeoisie. By consolidating their common cause with the national monarchs, they broke the international power of the feudal system in the name of nationalism, and the financial power of the Roman church in the name of Protestantism. Although the resulting anarchy was checked when exhaustion set in after a century of religious warfare, the divisive doctrines that there is no higher good than the national will, and that the individual conscience is the ultimate moral authority, are still with us. They still have great potential for tearing international and internal order to shreds.

It was in this burgeoning commercial and imperialistic civilization that the new Scientific tradition was born. The Scientific Revolution coupled the rational mathematics and astronomy of the Greeks and Arabs to medieval mechanical theories, drawing strength from the study of non-literate technologies. Among these technologies, the mechanics and metallurgy of shipbuilding and weaponry play a prominent part. The method Galileo chose to bring in these aspects of folk knowledge as examples to illustrate his new mechanical laws is clever, and revealing; he set the stage for his dialogues concerning two new sciences in the arsenal of the Venetian Republic, and called in illustrations from the work going on around the protagonists. He, and the others who built the new experimental sciences, did not hesitate to build equipment with their own hands, or to pursue the knowledge laboriously gathered by rude craftsmen. The new "scientists" preferred evidence so gained to ancient error hallowed by literary traditions, and took their case directly to educated laymen, ignoring the established academics. Renaissance scientists were convinced that they had discovered new truth in a mathematical unity between the earth and the heavens. They boldly asserted that the planets are made of the same stuff as the earth, and obey the same laws. They advanced their claims as the creators of new knowledge with much the same fervor that Protestants were claiming for the authority of individual conscience, and national monarchs for the supremacy of national interest over international order. As with the other developments, the claim of moral neutrality for science is having unexpected consequences in our own time.

Mercantile capitalism, for all its dramatic achievements in European hands, did not change the basic energetic restrictions of an economy based on plants and animals and human labor. But the concentrated wealth and markets it opened up allowed the introduction of water power and steam into the

production process. Industrial capitalism, relying increasingly on fossil fuels for its energy, expanded the supply of material goods available in the world out of all proportion to what can be achieved by division of labor. Early factories drew on the rich mechanical tradition of the European craftsmen, and the engineering ingenuity of practical entrepreneurs like Newcomben and Watt, with little input from the new sciences. By the middle of the nineteenth century, however, study of the steam engine by scientists had led to an understanding of both heat efficiency and energy conservation. This understanding was rapidly extended to underpin powerful theories of chemistry, electricity, and magnetism. Electrical and chemical knowledge brought the scientific traditions and the practical technologies into an alliance that has grown ever closer; this synthesis has enormously strengthened the economic and military potential of industrialized nations.

The relationship between these economic upheavals and shifts in political and social power also came under scrutiny. Marx saw the revolutionary role played by the bourgeoisie: first destroying or replacing the aristocracy by alliance with the national monarchs, and then destroying monarchy by alliance with the people, while insuring that the resulting electoral forms remained in firm control of their own class. He attributed their power to their unique relation to the new means of production, but also saw that these relations of production were in contradiction with the communal means of production created by industrialism. Since capitalist competition necessarily concentrates wealth and power into a smaller and smaller number of hands, he predicted that eventually the producing class would become both numerous enough and class conscious enough to expropriate the expropriators, and start building the inevitable communist society.

Although Marx's analysis provided a rational explanation of how the bourgeoisie came to power, and of the inevitability of ultimate proletarian victory, it could not provide a detailed revolutionary strategy for achieving that victory. This problem was more complicated than Marx had envisaged. In particular, the enormous increase in material wealth made possible by the use of fossil fuels allowed the bourgeoisie to give up some of their increasing wealth to the producing classes without creating any real threat to their own economic power. This development was hardly altruistic, and did not take place until proletarians had organized and developed the strike and boycott into effective means for enforcing economic demands.

The wealth and power of Western and Central Europe was greatly enhanced by the exploitation of surplus labor in less developed countries. Those areas which had managed to escape the full impact of mercantile capitalism were soon brought under colonial administrations or economic control. The dynamic thrust of this imperialistic period of capitalism brought the advanced countries into collision over how the world should be divided. Thanks to the increasing wealth of the preceding half century, and the grudging distribution of some of it to the upper strata of their working classes, the ruling institutions retained the national loyalty of most of their workers, and led them blindly into the holocaust of World War I.

The burden of turning the energy and ore stored in the crust of the planet into goods for the advanced countries, food for their populations, and increasingly powerful weapons for their military forces, fell most heavily on the workers and peasants in less developed regions. Lenin saw that in his own country this consequence of imperialism could be turned to revolutionary advantage, and used the Communist Party to lead the nascent proletariat and

poor peasants to victory over the bourgeois state. But the state apparatus which they siezed consisted primarily of technicians and bureaucrats drawn from the bourgeoisie, and did not prove to be an effective instrument for constructing a communist society. Subsequent conflict within working class movements over when to support the socialist state in Russia, and when to work for world revolution, weakened opposition to the rise of fascism.

Capitalist, fascist, and communist powers were unable to achieve agreement on how to divide the spoils of the planet; their conflicts developed into world-wide war. In China Mao used anti-imperialist nationalism as the basis of a coalition to defeat Japan, and the Chinese Nationalists backed by the United States. By relying on the poor peasants in the villages, China was able to move out of feudalism directly to the task of building a communist society. A second Chinese revolution was needed to prevent the development of a Soviet-style bureaucracy; struggle continues. This struggle, evident in the increasing resistance to oppression by blacks, browns, and poor people in many lands, gives hope to balance fears of thermonuclear threats, resource exhaustion, and environmental deterioration.

Homo Sapiens is the dominant intelligent species on a planet which has existed for 4.5 billion years. We have been a cooperative, tool-using species for several million years, a symbol-using species for over 100,000 years, and a food-producing species for about 10,000 years. Until the last century we ran our societies on power which could be regularly replaced from the energy of sunlight stored by plants. The switch to fossil fuels must be transitory as they and the high grade ores used yesterday and today will soon be exhausted. Conversion to nuclear power could break our link with the organic world. We have succeeded in leaving the surface of our planet and visiting our nearest

neighbor in space, but have created such an unstable situation on the surface of earth that our continued existence is problematical. Could we obtain information about other intelligent species on other planets circling other suns who have gone through a similar transition from organic and inorganic energy, we might guess our future. Our place in nature depends on whether our creative ingenuity can meet the unique current crisis. Can each of us rise to that challenge?