UNIT I

HISTORY OF SCIENCE

Until recently, the history of science was a story of success. The triumphs of science represented a cumulative process of increasing knowledge and sequence of victories over ignorance and superstilition; and from science flowed a stream of inventions for the improvement of human life. The recent realization of deep moral problems within science, of external forces and constraints on its development, and of dangers in uncontrolled technological change has challenged historians to a critical reassessment of this earlier simple faith.

The historian soon recognize that the idea of science that he acquired during this deduction is only one of many and that it is a product of temporary circumstance. The latter include the presence of nearly autonomous centres of research in universities, large-scale application of scientific results by technologists; and religion. In the 19th century there was a blurring of these present distinctions between science, industry, and philosophy, and three or four centuries earlier; the historian finds that the study of nature was conducted within a framework of assumptions about the world that are now rejected as magical or supersition. Also, the deeper that historians penetrate to the roots of modern European science, the more difficult it is to separate the "scientific" attitudes, and the "factual" results; from those that appear to be their opposities. Earlier historians treated these mixtures as anomalies; they are now used as cludes to reveal conceptions of the natural world, and man's way of knowing it, that had vitality and meaning in their own time. Thus the history of science demands and fosters an enhanced imagination: the ability to see oneself and one's science as one phase in a continuing evolution. In a period when relevance is demanded of scholar studies, the history of science provides this just as much in its exploration of the distant and strange structures inquiry into the natural world as in its critical analysis of the immediate sources of contemporary conceptions and practices. This account will be organized around the natural science created by modern European civilization, for this is the form of science that this brought the world to its present condition and that, it seems, must be understood and controlled if mankind is to survive. The roots of this science lie deep in the human past and in many civilizations. Here, they can be mentioned only in passing, but at the outset it must be pointed out that the present way of comprehending the natural world is a very recent development. It was possible for great civilizations of the past to achieve highly developed technologies and religious and legal systems in the complete absence of a conception of science as it is now understood. Such were the civilizations of ancient Egypt, Mesopotamia, India, and the Western Hemisphere. Even the Hebrews, people whose religion forms a large part of the basis of European civilization, were indifferent to science. Although some two and a half milenia ago the Greeks created a system of thought that was similar to the scientific, in succeeding the creatures there was little progress beyond their achievement and little comprehension of it. In Europe, science has enjoyed continuous progress for some 500 years, even though for most of that period it was of minor interest among a cultural elite. The lives of ordinary people were affected only in the most indirect ways by the thoughts of scientists and the application of their results. The great power of science and its pervasive influence on all aspects of life are thus very recent developments. Although knowledge of the world is independent of the particular circumstances of its first discovery and can be transmitted between nations and cultures, the human endeavour where by that knowledge is achieved is a product of its ever-changing human environment.

SCIENCE IN ANCIENT AND MEDICAL WESTERN CIVILIZATION

Science in Greek civilization. The dawn of European science has traditionally been located among the philosophers of the Greek city-states on the coast and islands of the eastern

Mediterranean, in the later 6th and 5th centuries BC. Their work is known only through fragments, references, and brief quotations made by authors who came later, perhaps by hundreds of years. By selection of fragments they can be made to appear more rational and scientific than is justified. For example, the famous saying scientific than is justified. For example, the famous saying of the earliest known philosopher, Thales, "All is water, is in its fragment actually followed by " and the world is full of gods". It does not appear likely, however, that the early Greek philosophers were concerned with exampling the phenomena of the perceptual world rather than offering recipes for practice and that they did so by invoking causes rather than personal agents, even if these causes were themselves derived by analogy with handicraft experience and human behaviour (thus the cosmic principles of "love and strife" of Empedocles). In this break from the mythological explanations of their own culture and of the ancient civilizations from which they probably borrowed much of their detailed knowledge, the Greeks are precursors of the modern European scientific attitude. One very important tradition, that of the Pythagoreans, was explicitly religious. Their founder attempted to find the key to universal harmony, both natural and social, and the personality of numbers, which were seen as shaped arrays of dots, was an important due. Somewhat later appeared the Eleatics, Zeno and Pharmendies, using a sophisticated conceptual analysis to support the philosophical position that asserted the unchanging unity of existence. Zeno's paradoxes of aggregation and motion presented a challenge that is still alive.

Although by the later 5th century this inquiry became quite sophisticated, it was still speculative explanation of commonsense phenomena rather than highly technical argument about controlled artificial experiences; the later emerges only with Aristoltle. Also, although this philosophy flourished among the elite in the so-called golden age when Pericles rules Athens, the common sense of time was still mythical and magical, as can be seen from the list of crafts in

Aeschylus *Prometheus Bound.* In the troubled times of the later 5th century, the suspicion of irreligion among the philosophers became strong is implicit in the condemnation of Anaxagoras and in the attacks on Socrates in *The clouds*of Aristophanes.

The two learned arts in which there was an approach to maturity by this time were, first, medicine, the practice of which was at least attempting to apply disciplined method in observation and inference, and, second, geometry, which was accumulating a body of results about relations between particular constructed figures and was approaching the problems of logical structure.

Plato, early 4th century BC, is the earliest philosopher whose writings are extant. He was a powerful propagandist for mathematics. In the *Republic* he argued that geometry prepares the mind for the discourse of dialectic about the real ideas, of which perceptible things are but images, and thence to wisdom and illumination. His *Timaeus* was in earlier times a more influential work; in this he sketches a cosmogony along Pythagorean line, including a theory of music in terms of simple rations and a survey of accepted theories of physics and physiology. He befriended geometers, including Eudoxus, who probably founded the mathematical cartography of the spherical Earth and also gave a profound treatment of irrational quantities.

Aristotle, also in the 4th century BC, was one of the world's first, and greatest, scholars. His interest ranged over the entire natural and human world, including ethics and metaphysics. Through accurate observations and disciplined theorizing, he created a biological science and a taxonomy much like those in use today. Later scholars have identified mistakes in his descriptions, but there are classic cases where his apparently false reports were checked and confirmed (on rare, local species) less than a century ago. He also organized cooperative research for large-scale studies, as in the comparative study of the constitutions of the Greek city-states. He was a master of scholarly method; in each study he would

define the area and it problems, dialogue critically with his predecessors and it problems, dialogue critically with his predecessors (usually showing they were native in some important respect), and then proceed by experience and reason to develop his argument. To him are owned most of the basic divisions of learning and also the articulation of the principles of method and of the different sorts of knowledge attainable by the use of reason.

Aristotle started his career as a disciple of Plato but eventually came to disagree with him on fundamentals. In particular, he considered mathematics as an abstraction from natural reality, which for his was a complex, self-regulating living system. Indeed, all subsequent philosophy of nature is a dialogue between Plato and Aristotle, for whom the deepest philosophical problems were related to life. His biological studies culminated in the problem of generation, the transmission of form between separate bodies. He tried also to explain the workings of the first cause of all physical phenomena, through the realization of its purpose in the celestial cycles. He had little sympathy with enchantments; for him, dreams were a result of subconscious thought and bodily discomfort rather than messages from a spirit. His principles of explanation were in terms of perceptible qualities (e.g., hot or cold, wet or dry) and a series of causes (matter, agent, plan, and purpose, in ascending order) or the analogy of craftwork by the principle "art imitates nature".

For some years he was tutor to the prince who later became Alexander the Great, and, though later this to the Museum of Alexandra. His writings were the basis of natural philosophy wherever it was practiced up to the17th century, but he was inevitably misunderstood, and his writings were used for the framing of sterile dogmas. Aristotle was centuries ahead of his times and is still a source of insight and instruction today.

In the empire created by Alexander the Great (late 4th century BC) Greek culture flourished. The great cities competed for famous scholars and classical texts, and some of them established centres of learning such as the Museum at the planned city of Alexander. Independent of the religious temples, these had large libraries, provided employment for scientists scholars, and by preserving records and instruments lent continuity to research work. Although this Hellenistic Age (roughly 323 to 30 BC) did not reach the heights of genius of the earlier one, it produced some great mathematicians (Euclid, Archimedes, and Appolomus) and astronomers (Hipparchus). Studies in medicine and physiology also advanced, and, during this period the origins of European alchemy were developed by Egyptian chemists attempting to rationalize chemical change by Aristotelian theories.

Science in Rome: Toward the close of the pre-Christian period, the Roman Empire achieved dominance over the entire Mediteranean world. Rome presents a paradox to historians of science. This civilization, so sophisticated and apparently modern in its politics and personalities, very strong in the learned discipline of the law, very progressive in the state technologies of warfare and public hygiene, with direct access to the corpus of Greek science, nonetheless failed to produce a single scientist. Two very great scientists lived during the reign of Marcus Aurelius in the 2nd century AD, but they were both Greek: Galen of Pergamon, who synthesized and advanced the study of medicine, anatomy, and physiology; and Ptolemy of Alexandria, who brought mathematical astronomy near to a classic perfection and also tried to bring the mathematical, scientific approach to the earliest empirical social science, astrological prediction. The Romans themselves considered science as fit only for casual speculation, on the one hand, and practical techniques, on the other. Their encyclopedia literature is a cautionary tale of the corruptions of knowledge in the absence of critical standards. Scientific matters were discussed seriously among the Romans only in connection with basically ethnical philosophies. The two leading schools were the stoics and Epicureans, and the messages offered by them to the wise man were, respectively, dignified resignation and the pursuit of happine s. The letter school, however, produced a masterpiece

of speculative science, *De return natura (On the Nature of Things)*, by Lucretius (1st century BC). The message of his atomistic explanations of phenomena was that immaterial spirits are only fictions whose function is to instill fear and obedience among the superstitious masses.

To explain the Romans' utter failing in science, historians have speculated on whether slavery, by stifling the drive for industrial innovation, was the cause; but this seems too simple. Perhaps the social structure of Rome, combined with its long adherence to gross forms of magnic, left no place for an appreciation of that peculiar commitment to the hard and hazardous road to knowledge and wisdom that lies through disciplined inquiry into isolated aspects of the natural world. Indeed, when one considers how few have been the cultures in which science has flourished, one may reverse the question and consider Rome as the normal and classical, Greece as the surprising phenomenon to be explained.

Medieval Science: The Greco-Roman civilization went through its full cycle in about 1,000 years. The next half millennium in Europe, up to the year 1000, is often called in Dark Ages. Literate culture in western Europe, ruled by Rome, was barely kept alive in the monasteries, with occasional attempts at revival by great kings such Alfred and Charlemagne. By contrast, in the Eastern Empire ruled by Constantinople a civilized society continued, although in all its own 1,000 - year history Byzantium produced little new science of note. As a new, ruder form of society took shape in the West, there was great pioneering work in the clearing of forests and swamps for settlement, and some crucial inventions (horse collar, stirrup, heavy plow, windwheels, and waterwheels) were either invented or borrowed. In the early 11th century, most learned men knew and understood only a few tattered fragments of ancient science, but thereafter progress was rapid. The 12th century enjoyed a renaissance brought about partly by contact with the superior Islamic civilization in Spain and Palestine, partly by the development of towns with literate upper classes. From this period com : the first speculative treatises on natural philosophy. The 13th century saw the founding of the universities and the great age of scholastic learning. To this age belong the great theologian St. Thomas Aquinas and the experimentally minded Roger Bacon. In the 1350s, however, Europe was struck by economic and social disaster in the form of a general financial collapse and the Black Death (the bubonic plague). Although philosophical debate, including interesting mathematical speculation, still took place, scientifically this later period was sterile.

Opinions on medieval science have oscillated wildly. Earlier historians saw it as unrelieved dogmatism and superstition, while others have tried to show that many essentials facts and principles of modern science were discovered then. The problem becomes clearer when it is realized that learned men were not at all trying to do scientific research as it is understood now. Natural philosophy and particular facts were studied mainly in connection with problems relating to religion, either for the elucidation of biblical texts (literally and figuratively) or for debate with adherents of pagan philosophies (notably Aristotle as interpreted by the Muslim philosopher Averoes) or in the development of a mystical Neoplatonic cosmology in which light was studied as the clue to reality that can be grasped by the senses and described geometrically. The distinction between technique, theoretical magic, and folk magic was not at all clear to anyone. Hence in modern terms, even Roger Bacon was the gullible victim of superstition. Thus in Europe in a formative period of the present civilization, there is something that could be called science but that requires anthropological imagination to understand.

SCIENCE IN OTHER CIVILIZATIONS

Description of the scientific achievements of the other great civilizations of the world is brief in this article because of the considerably lesser contributions they made to science as it is presently understood.

Islam: Islamic culture is the most relevant to European science. Not only is the religion itself closely related to Judaism and Christianity, but there was active cultural contact between Arabic speaking lands and Latin Europe at crucial periods. Ironically, the great age of Islam coincide with the low point of culture in Western Europe. Conquests by the Prophet's followers began in the 7th century, and by the 10th, Arabic was the literate language of nations stretching from Persia to Spain. Arabic conquerors generally brought peace and prosperity to the countries they settled. For example, the library of Cordoba in Spain apparently had more than 500,000 books at a time when scarcely 5,000 survived north of the Pyrenees. Also, the Muslims were tolerant of the other monotheistic faiths, so that Jews rose to high position in Islamic lands at a time when they were scarcely permitted survival in Europe. Drawing on the traditions of Greek science through Christian scholars of Syria, the early Arabic rulers of Bagadad in the 9th century had the bulk of the corpus of Greek science translated, and, soon after, their own scholars advanced further, particularly in mathematics, astronomy, optics, chemistry, and medicine. The social base of science, however, was thin. In a theocratic society, medicine alone among the pagan sciences was considered acceptable. Hence no single center of scientific culture flourished for much more than a century, and, although materials were transmitted between them, the loss of continuity prevented a sustained development. Also, the style of scholarship was for a single man to try encompass the whole world of learning for the achievement of secular wisdom, perhaps as a way toward illumination. The very greatest men could make creative advances, but cooperative scholarship, necessary for making lesser men effective, was rare.

Contact between Islam and Latin Europe came mainly through Spain, where Christians and Jews could act as intermediaries and translators. The 12th century saw a heroic program of translation of works from Arabic to Latin, at first in astrology and magic, then in medicine, and finally in philosophy and science. A lesser route was through southern Italy, where commercial contacts existed with Tunisia. Ti is significant that the earliest medical school in Europe was at Salerno and that it was later rivaled by Montpellier, also close to Arabic and Jewish sources. Despite its leadership, however, even by the time of the translations, the Islamic civilization was under pressure from barbarians along its periphery, and it soon went into decline. In addition to its enormous service to Western civilization in preserving and then transmitting the Greek heritage, Arabic as also contributed to modern science a number of words, mainly of plants and foods, but also words as alcohol and algebra.

India: The Indian civilization is about the oldest still alive, and it achieved a high level of technology at an early stage. European contacts with it come mainly through Arabic sources, and historical research is not yet sufficiently advanced to distinguish priorities and lines of transmission. It does appear that Indian mathematics, with a high developed system of numeration and reckonling, influenced Arabic algebra, it also provided the principal Arabic numerals (*i.e*, the nine digits and zero in a place-value system). But the characteristic science of in a place -value system). But the characteristic science this civilization is that of the higher consciousness, and, in this, European thought has been so deficient that it becomes aware of its lack only occasionally. Hence the achievements of Europe and India cannot be compared strictly but must be recognized as being complementary.

China and Japan: China presents more of a challenge to the historian of European science. Its basic common sense is this-worldly, although it is based on interpersonal harmonies rather than abstract regularities. In spite of the distances between them and their totally different languages, there has been more or less continuous contact between Europe and China since classical Greek times. Usually the connection was indirect and restricted to trade in luxury goods, but even in classical times there were curious synchronisms in philosophical

movements in Europe and China, and in the 13th century; there was considerable personal contact, of which that of Macro Polo is but the most famous instance. Also, Chinese technology until the Renaissance was consistently more advanced than European and, in his monumental work, the British historian of science Joseph Needham has shown the patterns of transmission of a series of important inventions from China westward. Indeed, the three great inventions that 16th century writers and, later, Francis Bacon saw as crucial for the transformation of European society all came from China: the magnetic compass, gunpowder, and the printing press. Yet Europe never recognized its debt to China, while, more important, the Chinese never achieved the beak through to modern science of the European sort.

The ignorance of the debt of the West to China is easily explained. In the period when technical devices were imported or copied, they were of little concern to the learned, and so their ultimate origins were never questioned. When the Jesuit missionaries arrived in China in the late 16th century, brining the fruits of Western science and technology as proofs of the superiority of Christianity, it was at a time when these pursuits were at a low ebb in China, so that many native achievements had been forgotten. The failure of China to make the break through may be considered in relation to the two phases of the creation of European science discussed below. Chinese society was always stable, ruled by a nonhereditary civil service with a governing philosophy that was one of practical accommodation rather than of abstract principles. Merchants were a districted class, and technical innovation had to be accomplished within the bureaucracy. Thus, the features of European Renaissance society that implled the practical arts forward at a rapid pace were never present in China. Moreover, the Chinese philosophy of nature was also based on organic analogies and relations of harmony. It never could have accommodated the picture of dead matter moving in accordance with mathematical laws, on which Galilean science was based. Related tot his is the technical fact that only the

Greeks had produced an abstract, logical mathematics that could function as the language of science. Chinese mathematics consisted of reckoning rules, and, in spite of their great sophistication, these could be applied only to the detailed calculations for which they had been designed. Thus, China failed to become Europe. It is likely, however, that with the new appreciation in the West of the need for the establishment of a subtle harmony between the individual self and nature, scientific society may yet have something to learn from the ancient Chinese way.

Finally, there is the fascinating case of Japan. For centuries a cultural colony of China, it had a brief exposure to Western science and religion before its rulers decided early in the 17th century to close the door on such dangerous influences. In the latter part of the 19th century, the Japanese decide to assimilate with the rest of the world and then did so with a vengeance. Their own native religion was sufficiently vague to accommodate any assertions of Western science, and the Japanses scientists, technologists, and ordinary folk now manage to live partly in a hyper-modern world and partly still in one of ancient, rigid social tradition.

CREATION OF EUROPEAN SCIENCE

The "science" of which histories are written is European. Although other civilizations made essential contributions toward it, and though now all nations participate in research, natural science is a distinctive creation of European and its cultural colonies. Its roots in thought and society are the same as those of European technology and of its acquisitive spirit, hence science is an important part of the process that achieved domination for this small and, until recently, barbarous corner of the world. The creation of European science has two phases, one of technical development in the 16th century, the other of philosophical revolution in the 17th century. Out of these came the idea of science that is current to this day.

Rebirth of science in the Renaissance: The word science and its ancestors in Greek and Latin is an old one, with continuously changing meanings. In the period now being considered, it was restricted to the fields providing knowledge: theology and philosophy. For the rest, the term was art or technique. Some arts were called liberal and were taught in Latin at schools and universities. They were language, logic, rhetoric, mathematics, and the learned, or professional, arts of medicine and law. The other arts were mechanical and generally involved unpleasant work for low pay. The ruling conception of knowledge was still radically different from that of the present day. It was universally accepted that there had been a golden age when all things were known (in the Garden of Edeh and perhaps gain in some age of sages or in classical times). The rediscovery of these truths was not merely a matter of gathering facts for their first provision and subsequent loss had been events with religious significance. As the perceptible world was strongly influenced by divine, demonic, and magical agencies, so too the penetration of its secrets was more than a secular task. Since the modern conception of science has some of its roots in the conflict against this world view, it is difficult to imagine how a scientific point of view could have existed within it. Until the historian comes to terms with it, however, he remains imprisoned in his own temporary categories, unable to understand the larger world outside. A convenient starting date for the period of European expansion is 1413, the year of the first raid by Europeans on the African coast, just a half millennium before World War I began the breakup of the European empires. In the early 15th century the cultural scene in European was generally break: the universities were in decay, the church was disintegrating, and the economy still suffered from effects of the Black Death; he subjects now called science barely existed except when studied in connection with some practical art; even then, materials were scarce, competence low, and social organisation rudimentary.

The roots of the rebirth of science can be located in three main centres. The first and most famous root is something that can be called the discovery of man and nature, a product of the artistic Renaissance of 15^{th} – century Italy. The inspiration for this was the discovery of classical antiquity and the fact that the Humanist scholars edited and published Latin and Greek texts and translations in all field, including science. The visual arts, loosely grouped as architecture, were raised in social esteem and given a classical pedigree in a book by the Roman author Vitruvius. The great artists became men of wide interests and culture, whom the nobility sought to patronze; the career of Lenoardo da Vinci in the later 15^{th} century exemplifies this exalted position and many-sided activity.

At the same time, the mountainous region in southern Germany, with and points at Nuremberg and Cracow, enjoyed a rapid growth in mining, metallurgy, and trade. Practical mathematics and the theory and practice of metal working were developed there. The Rhine linked this region with the prosperous weaving centres of Flanders, and it was on this trade route that printing was invented by Gutenberg. This was a highly sophisticated and expensive venture in what might be called research and development, the problem being to find alloy metals of the correct properties for molds in which to cast replaceable bits of type. Once invented, the process spread rapidly. By the end of the century every major city had its press, and the availability of cheap books worked its transformation on learning and culture.

During the century, the Spanish and Protuguese began their explorations. The Portuguese worked down and around the coast of Africa, perhaps using Brazil for a landfall, looking for gold and for the legendary Prester John in Ethopia instead, they found the sea route to India, thus bypassing the Middle East route for spices (then defined as anything purchased from the technically superior Eastern nations, including flavourings, condiments, and drugs). Joining the search late, the Spanish financed Columbus, and their conquistadors then opened up

the New World. Transoceanic navigation created new demands is on astronomy and on mathematical techniques and instruments and the earliest research establishments were those of Spain and Portugal, specifically for hydrographic techniques. The New World introduced new plants, animals, disease, and civilizations to Europe; the excitement and unsetting effects of its discovery lasted for generations.

The printed books of the 16^{th} century provide (in their modern reproductions) a convenient source of evidence for the state of science. At the beginning of the century, knowledge was still rudimentary and largely dependent on confused digests of ancient and Arabic sources. By midcentury there appeared works that surpassed the best of their predecessors. In astronomy, there was the *De revolutionibus* (1943) of the Polish Nicolaus Copernicus, a technical masterpiece as well as a revolutionary treatise on cosmology. In anatomy, the Belgian Andreas Vesalius created a new approach to anatomical research and teaching in his *De fabrica* (1943). In mathematics, the Italian Gerolamo Cardano advanced algebra (providing the general solution of the cubic equation) in his *Arsmagna* (1545).

During this century the Protestant Reformation touched off a series of wars for which gentlemen officers needed certain new mathematical skills associated with fortification and gunnery, which also called for new classes of practitioners, such as military surgeons and engineers. Although some of the theoretical fields tended to be speculative, there was in general an enormous improvement in all these arts. By the end of the century, the applied mathematical arts were a standard part of the education of a gentleman on the Continent. The French mathematician philosopher Rene Descartes learned them at his Jesuit school and the Italian Galileo taught them at the University of Padua. In this way there came a temporary lowering of the barriers of class snobbery against such arts. This was crucial for the formation of the new philosophy and its acceptance by the liberally educated audience to which it was directed.

The new philosophy, however, was not a prerequisite for successful science. Around the turn of the century, and later, there appeared great works of science containing particular discoveries that are still accepted as facts to this day, but the scientists who achieved them were still working within the world view that was shortly to be rejected by the new philosophy. Thus William Gilbert (1600) in England explained the compass needle in terms of the Earth's being giant, very weak magnet, but he did this in the course of proving that the world soul is embodied in the magnet. In Prague, Johnnaes Kepler shortly afterward (1609) discovered the true orbits of the planets as ellipes around the sun, and he never eased his search for the harmonies of the cosmos. Later (1628), William Harvey in England established the circulation of the blood, but him it was more a microcosmic image of the circulations of the world than it was purely mechanical system. The strangest mixture, by modern standards, is to be found in the chemistry of Paracelsus and his followers of the 16th centuries. They combined elements of metallurgical crafts, folk medicine, alchemy, mystical religion, and social and reform, and yet they were successful as chemists.

Revolution in natural philosophy. In the 17th century, there occurred a radical recasting of the objects, methods, and functions of natural knowledge. The new objects were regular. phenomena a in a world devoid of human and spiritual properties; the methods were of disciplined, co-operative research; and the functions were the combination of scholarly knowledge and industrial power. Although this is frequently called the scientific revolution, it was a revolution about science rather than in it. In most fields of inquiry, progress was continuous through both centries, nor did the external social environment of science change drastically. For a leading cause of the inception and rapid diffusion of this philosophy, the radical change in educated common sense about the world must be examined; briefly stated, the change was from the notion of a living cosmos of earlier times to that of a dead universe.

The main target of attack by the revolutionaries was the traditional higher education that was called Scholastic. Scholasticism assumed a living world, created and guided by God quite simply for man's benefit, and its study was largely accomplished by citing authorities, either philosophical or scriptural. The function of this knowledge was rationalize sense experience in harmony with revealed religion. By contrast, the ancient and honourable sciences of astrology and alchemy, and their relations, were usually dismissed by the new philosophers with a passing sneer because, in their common sense, these were so ridiculous as to require no refutation. Thus, in 1600 an educated man knew that the earth was in the center of the cosmos, the seat of change, decay, and Christian redemption, while above it circled the planets and starts, themselves pure and unchanging but moved by some sort of intelligent or divine spirits and also signaling and influencing human events by their locations and aspects. One hundred years later his equally Christian descendant knew (unless he lived in the church-controlled Catholic country) that the Earth was but one of the planets moving through unimaginable distances in empty space and that God could still operate. Similarly, the earlier man, as a reasonable person, would accept the overwhelming evidence for the working of enchantments and the prevalence of witches; while the later one, with equal certainty, would dismiss all those stories as the effects of charlatanry, in the one case, and torture, in the other.

The prophets of this 17th century revolution were Francis Bacon in England, born 1561 René Descartes in France, born 1596, and Galileo Galilei in Italy, born 1564. Each of them was committed to a great mission, over and above particular facts and theories, and each in his way tasted tragic detect. Bacon, professionally in the law and politics, borrowed thems for earlier pietistic philosophers and saw himself as inaugurating a reform of knowledge, so that the material redemption of mankind could go with spiritual salvation in preparation for the millennium. He hoped to effect this program through royal patronage and was shattered when his public career came to and end suddenly in an unjust disgrace. Descartes believed that he had rescued truth and religion from the corrosive criticism of the skeptics, by a method based on the example of geometry. By its means he would be the new Aristole, constructing a complete philosophy, starting with mechanics and reaching medicine. Thus, he would inaugurate a new epoch of longevity and wisdom, realizing the program of the Rosicrucian mystical fraternity with whose ideals he had become identified. But his work became bogged down in complexities of every sort, and by the end of his short life, he knew that he was only a great metaphysician and mathematician. Galileo was less exalted in his ideals and more thorough in practice. He only wanted to destroy the scholastic conception of philosophy and substitute his own, one of free exploration of an impersonal mathematical universe. For him, the Copernican system was a very beautiful fact in its own right and also a weapon against the professorial simpletons. He was insufficiently sensitive to the religious and ideological consequences of what he thought was his little revolution in its time and place, and so he blundered disastrously into a conflict with his former friend and protector Pope Urban VIII. Although under house arrest, ill, and going blind, he maintained an invigorating hate for his enemies and, at the age of 74, published his masterpiece on mechanics, the *Two New Sciences.* Bacon's contribution to science was nil, but he provided an inspiring ideal and also shred judgments on the social activity of science. Descartes created a new metaphysics, a radically improved algebra and geometry, and some viable results in physics (explanation of the rainbow). Galileo's vast labours for Copemicus had only an indirect effect, and that a mixed one; but by his mechanics he brought relative clarity to the science of motion and laid firm foundations for future work.

In spite of their differences in style and contribution, these three prophets shared a common commitment about the natural world and its study. Nature itself was seen by them ad devoid of spiritual and human properties. There could be no

dialegue with it, whether using mystical illumination or inspired authority. Rather, it had to be investigated soberly and impersonally, using sense experience and reason. Strange and prodigious pheonemena, such as earthquakes, wonder cures, and monstrous births, which had been important subjects of speculation over the ages, were seen to be of less significance than regular, repeatable observations. Care and self-discipline were necessary in observation as well as theorizing, and cooperative work was important for the steadly accumulation and testing of results.

The goals of inquiry still retained an influence from magic in that the traditional philosopher's ideal of contemplative wisdom was replaced by that of domination over nature of human benefit. But the loss of belief in magical powers entailed changes in methods and also in responsibilities. In the absence of potent enchantments and elixirs, knowledge of nature was either beneficial when applied to marginal improvements of industry and medicine or was innocent. The moral optimism of modern European science was thus built into its foundations and became unequestioned common sense, until the labour when atomic bombs were dropped on the civilians of Hiroshima and Nagasaki.

The establishment of scientific societies was direct result of the new conception of natural knowledge and the methods of its pursuit. From the outset it was recognized that such societies, and their journals, must achieve a harmony between the needs of the community for rapid diffusion of results and the needs of scientists for the protection of their private property in their hard-won results. The Royal Society in London, proclaiming its adherence to the ideals of Francis Bacon and suppressing its connections with reformers on the parliamentary side, was chartered in 1662 by the newly restored king, Charles II. The French followed suit in a few years' time, and somewhat later other continued monarch did the same. National styles asserted themselves even this early. The Royal Society, for example, was a private club with little more than moral support from the crown, while the continental academics were established by the state and the members gained a income though they lost their independence.

As regards the constitution and workings of the natural world, the new philosophers (with the exception of Bacon) assumed that all visible phenomena are the result of interactions of invisibly small particles of matter. These have neither intelligence nor purposes, and thus the paradigm reaction is the collision of balls. Hence the perceptionble qualities of things (on which Aristotelian science was based) are only secondary, mere effects in our minds. The primary qualities are those capable of mathematical description. Although this view had many dispute variations (Newton in particular adding force as a real agent), there was an unusually sharp demarcation between its adherents and those of its rival views, Aristotelianism and alchemy.

In some fields the new philosophy was appropriate for progress at the stage, and the fields were transformed. Such were cosmology, mechanics, and pneumatics. Elsewhere in science its distinctive achievements were modest. Optics had received its modern start from Kepler and electricity and magnetism from Gilebrt. Chemical theory was not significantly advanced; the corpuscular explanations of Robert Boyle in England (middle 17th century) only rationalized existing ideas. In biology and medicine, although there was a premature attempt at reduction to a physical model, this did not show results for another two centuries. The direct impact on technology was restricted to the rationalization of simple machines and the development of vacuum techniques. Thus the new philosophy was not a generalization from the success of a new science. Rather, it was a prior metaphysical commitment that, eventually, over later generations, proved its fruitfulness in all fields.

Under these circumstances, it is not surprising that many scientists, particularly those in chemistry and medicine, rejected the corpuscular philosophy as useless revival of an ancient atheistic system, since, if the corpuscles had no intelligence or purpose, their collisions were random,

accidental, and the whole universe was without purpose. Chemistry was not yet a study of controlled process involving pure reagents but was still tied to craft-industrial practice and to Paracesian medicine. In England during the Civil War, there occurred a debate on the nature and social functions of science and education, in which the mathematically oriented scholars found themselves on the conservative side. The issue, raised in (1654 by a chemist, John Webster, was whether or not the universities should replace their antiquated, sterile curriculum by studies of honest, hardworking, practical crafts based on Parecelsian chemistry. The defenders of the status quo (including the future founders of the Royal society) argued that genuine scientific teaching was available to those who wanted it; but at last they had to admit that they accepted the universities role as finishing schools for the elite and for that reason would not trouble the students with compulsory new subjects.

The career of Sir Isaac Newton at the end of the 17th century illustrates the complexities that persisted even when the revolution had been successful. One of the greatest scientists and mathematicians of all time, he brought the heavens and Earth together in one impersonal law of attraction, the law of gravity, and also brought a new rigour to methods of quantitative experimental investigation. Although he advocated the utmost caution in theorizing, he still believed it possible and proper to induced from the phenomena of nature to a discussion of the deity. When he came to the foundations of his physics and discussed space time, gravity and force, he found theology of direct relevance. He also used astronomical methods for an improvement of ancient and biblical chronology and firmly believed that a study of the Old Testament prophecies would produce a true interpretation, thus providing guidance in the politico-religious affairs of the time. His masterpiece, the *Principia* (1687), was in many ways the culmination of the scientific revolution. By the time it appeared, however, the impetus had slackened, and no new recruits of the same caliber were coming forward. Indeed, by the end of the 17th century, interest in natural philosophy had ebbed so much that the Royal Society was early defunct, it was revived by Newton himself from 1704, to become a club for gentlemen who enjoyed hearing about experiments and collections. Nevertheless, the main work of the revolution in philosophy had been accomplished, and European literate culture, including science, was firmly set on the path to complete secularization.

The image of Newton dominated science in the 18th century, just as that of his friend John Locke dominated philosophy. The early 18th century was a complacent age. Europe was recovering from two centuries of turmoil, outside the sphere of the Enlightenment, there were no great philosophical struggle and the science that was practiced was mainly consolidation. A handful of great mathematicians (the Bernoulli family and Lenohard Euler, all of Switzerland) developed the differential and integral calculus invented by the German philosopher Gottfried Leibniz to the form in which it is now taught. Natural history developed steadily, receiving social or Natural history developed steadily, receiving social organization and an intellectual synthesis from the Swedish botanist Carolus Linnaeus. "Experimental philosophy" was cultivated by gentlemen, and a successful theory of static electricity was established by the American scientists and diplomat Benjamin Franklin. Although these achievements did not comprise a great advance, they firmly established a certain style of science – that advocated by the prophets of the new philosophy, although, of course, without their revolutionary inspiration.

Nature of European Science: The special character of European science can be explained by the circumstances in which scientists in these two successive phases worked on their inherited materials. These included the basic principle of knowing the natural world through demonstrative argument, a principle first achieved in Greek culture, then picked up by Islamic civilization but not by any other. Although, all the beginning of the Renaissance, European science and

technology were derived from older traditions and were generally interior, certain features of European society of the time enabled it to make exceptionally rapid progress. Even though society was still largely agrarian, undemocratic, and stratified by inherited social position, there were several areas in which the style of social life was more fluid and individualistic than anywhere else. There was a freedom to invent and to exploit one's inventions for private gain unhindered by state suppression. In other civilizations (the Far East and medieval European), technical innovation was monitored and suppressed if it threatened political or social stability. In the relatively fluid society of Europe, individuals had a motive for innovation in that they could advance themselves thereby. Also, the barriers between different fields of activity appropriate to different classes were relaxed, permitting the educated man to dabble in invention, using his knowledge and literate skills. Invention could be in devices or in knowledge; men could move freely from one to another and back again. The context in which this destabilizing activity was fostered was one of aggressive commercial and political expansion, of states pitted against each other, and of Europe against the world. This society has been called early capitalism, and, although its political structures tended to the principle of the absolute state, even these were liberal in comparison with the totalitarian societies of earlier and more recent times. And it was in the focal points of commercial and manufacturing development (Italy, south Germany) that the technical arts first made their most rapid progress.

Although, by the end of the 16th century, European science surpassed that of its sources and rivals, its products were still not qualitatively different from theirs . then there came the revolution in philosophy that transformed European science into something unique. There had been earlier periods when an atomistic philosophy of matter had been advocated, but it had always been a philosophical speculation. This time it was injected into a flourishing scientific endeavour. Slowly at first, but at an accelerating pace, the synthesis created a new sort of science. Most important was the new style of the social activity of research, in which the secrecy and ruthless competition characteristics of private inventors were tempered and disciplined by the commitment to cooperative work for the common good. The roots of this lie partly in the loss of belief in magical powers, so that none could hope to unlock the secrets of the universe by solitary endeavour. Also, the idealism of the prophets of the new philosophy called for a new cooperative ethic of reach, and, even as this inspiration waned, its effects were maintained by an adaptation of the code of honour of gentlemen scholars. Thus, the mutual stimulus of theory and practice, maintained from the earlier period, was channeled into a cumulative and self-correcting process of winning reliable facts about the natural world. The successes of the new philosophy and its methods were patent by the end of the 17th century, and, even though the pace of advance slackened during the next century, the earlier achievements in knowledge and in methods were never lost. Hence a maturing European science was available for its next phase of interaction with practice, in the Industrial Revolution and beyond, and from this came the matured science of the epoch immediately preceding the present one. Also , the philosophy of dead matter turned out in the long run to be a fruitful strategy for scientific advance in that, although it suffered from many false could make their eventual triumphs in the 19th century only on the basis of this reductionist conception of the natural world.

In summary, therefore, European science owes its part successes and its special character to its sharing, in its metaphysics and methods, the basic features of European society: aggressive individualism tempered by a principle of cooperation for a common good.

SCIENCE IN THE AGE OF MODERN REVOLUTION

Toward the end of the 18th century, there began an industrial revolution that transformed European from an agrarian to an urban society; at the end of the century occurred the French

Revolution, in which modern political ideas were first realized in practice. The activity of science experienced analogous changes. It was in this time that social and institutional foundations were laid for the maturing of science in the 19th century. Simultaneously there occurred a romantic reaction in literature and the arts that had important repercussions in science was a very small-scale activity, mainly pursued by gentlemen of means or by trained professionals, such as physicians and engineers, in their spare time.

Only a very few universities (for example, Edinburgh and Leiden) provided effective instruction of science. The mathematical sciences (mathematics, astronomy, mechanics, optics) were well developed, but physics was still a scattering for experiments with qualitative and mainly speculative theories, chemistry was nearly entirely empirical, and the life sciences were concerned mainly with colelctors' activities. By the end of the period there were successful examples of organized scientific work, and the foundations had been laid for coherent and effective theories in most areas of science.

Science during the Industrial Revolution. In the gradual but deep transformation of European industry, the direct contribution of science was at first small. Most of the early progress came through the rationalization of craft techniques and the invention of simple machines to replace manual operations. Even there, elementary materials and experimental approach, derived from the Power technology as the first to be influenced by the applications of advanced science. The English Newcomen steam - vacuum engine (1711) came from 17th century pneumatics, and the improvements made by the English engineer James Wati from 1763 onward were intimately related to developments in the theory of heat. Industrial chemistry was similarly assisted through the organisation of chemical knowledge achieved by the great Dutch medical teacher. Hermann Boerhaave and his fellowers.

The contribution of the Industrial Revolution to science was at first similarly indirect. In the industrializing regions of

Britain (Lowlands Scotland, the Midlands, and Cowrnwall), there developed an audience for scientific results, Philosopher –manufacturer: such as Josiah wedgewood, the potter and social reformer, combined with physicians to pursue research, to form local societies, and to patronize scientists. By the end of the century, not only free-lance lecturing but also the publication of journals for the specialist became economically feasible. On the Continent, the more progressive monarchs established specialized colleges of engineering, either industrial, civil, or military, these provided a training for potential recruits and also jobs. In Britain, in spite of its early start and broad interest, advanced training remained rudimentary, and locally sponsored institutions for aritsans' education were the rule through this period and the following. Although most of the problems that emerged in industrial practice and in medicine were beyond the reach of the existing scientific theories of the time, there is no doubt that engagement in solving them provided a stimulus and audience for research and so led indirectly to scientific progress.

Intellectual origins of revolution. Starting somewhat earlier than the Industrial Revolution was a movement centred in France that first brought science into the realm or politic. Called the Enlightenment, it had as its program the struggle against church dogma and popular superstition, and it used the facts of science and its rational methods as the main weapon. It was started in the 1730s by Voltaire in a wave of anglophilia, who used the doxy of Decartes's cosmology and physics. The Philosophes operated in the sophisticated environment of Paris salons and encouraged a growing readership for popular science books, for example, *Newtonianism for the Ladies* was a best seller. By mid-century the movement had matured. The Encyclopediste Denis Diderot and the mathematician Jean d'Alembert edited the huge *Encyclopedie,* in which the democracy of knowledge was displayed by the alphabetical ordering of articles, and craft techniques were given equal dignity with metaphysical and scientific discussions. Aided by a hatred of a stupid and

eventually demoralized censorship, the Philosophes scon recruited all the best all the best minds of France. They consciously considered themselves as carrying on the work of Bacon in advancing practical knowledge, but they did so in the style of Descartes, subjecting all things, social as well as philosophical, to the criticism of reason. The movement soon split into factions: the mathematician –rationalists, d'Alembert and his disciple Marie-Jean –Amtoine Condorcet (who was a victim of the Terror during the Revolution); the romantics, Denis Diderot and Jean-Jacques Rousseau; and the atheist materialist, led by Paul-Henri Holbach. Nevertheless, they all agreed that their main enemy was the church. For all of them, natural science was philosophically committed, which was the opposite f being be neutral and positive. From the ideas of these men came the slogans of the French Revolution, and their conflicts were eventually fought out in the realm of power politics.

The organization of science in the French Revolution. Natural science was deeply involved in the French Revolution. From the Enlightenment the revolutionaries inherited a faith in science and its methods that permitted the greatest scientists to devote themselves to the organisation of war industry for the defense of the republic in its hour of need. During and after the Revolution, there appeared a state-supported system of education, with scholarships for talented boys, jobs in teaching and examining, sunsidies for research, and rewards for inventions. The center of the system was the Ecole Ploy technique of Paris, mainly serving to train army engineers, but the greatest scientists taught there, and there they found their most promising students.

The dominant style of this Revolutionary science was mathematical. In applications, its method was rationalization, one lasting product of which is the metric system, which was intended to produce a coherent system of measures based on natural units and the decimal. At the time of the Revolution, France already had distinguished mathematicians)Pierre-Simon Laplace, Joseph –Louis Lagrange, and Gaspard Monge);

and their pupils and successors (Jean-Baptiste-Joseph Fourier, Simeon-Denis Poisson, and Augustin-Louis Cauchy) maintained their excellence. Even in chemistry, the reform of nomenciature achieved by Antoine Lavisier and his colleagues was mathematical and abstract in style, chemical compounds were to be described by a regular scheme of combination of the names of their constituents elements, and all traditional names were to be discarded.

At the height of the Revolution there emerged a counter movement in science that condemned the mathematical approach as sterile and elitist. Drawing inspiration from the democratic and romantic ideas of Rousseau and led by the former physician and journalist, the Revolutionary Jean-Paul Marat, this movement called for "science for the people," open to the self-educated artisans and based on practical chemistry and natural history. They achieved the dissolution of the Academy of Sciences, while promoting the more popular Museum of Natural History. The ideological struggle over the nature of chemistry was probably a factor in the execution of Lavoisier (1794) during the Terror, but, with the collapse and destruction in late 1794 of the Jacobins (a political club that was extremely effective in supporting the democratic radical movement within the Revolution and of which Marat was the leader for a while), the populist conception of chemistry was suppressed and the rationalistic, meritocratic style of French science was established in force.

Under Napoleon, the surviving grand old men and their first generation of disciples enjoyed patronage and prestige, but he "school of Laplace" went into eclipse after the restoration of the monarchy in 1815. A new group of distinguished scientists took over, but somehow the impetus was soon lost. Although Paris was the mecca of the scientific world in the 1820s, stagnation was setting in. one clue to this is the exclusion, almost certainly for political grounds in both cases, of two young men of outstanding genius: Sadi Carnot, who established the basic principles of thermodynamics, and Evariste Galois, the creator of group theory in abstract

algebra. After 1830, the scientific scene in Paris, which had always drained talent from the provinces, was dominated by careerism, and the great achievements of 19th century science were made elsewhere. Historians of science now appreciated that this decline was not an accident but a significant problem requiring explanation.

Romantic reaction and science. At the same time as the Revolution in France, *Naturaphilosophie* flourished in Germany. Its devotees, led by the poe: Goethe and the philosopher schelling, denounced the dry, soulless mathematical and experimental science of the Newtonian tradition. Instead, they proposed a philosophy of nature in which hand and eye, mind and spirit would all be united. Goethe unsuccessful, attacked Newton's theory of colours, but he gave inspiration to biological speculation on the organizing and unifying principles behind the structure of vertebrate animals. His followers, like other German thinkers of the time, attempted grand speculative physical and spiritual syntheses of all the world.

In England, the effects of *naturphilosophie* are seen most clearly in the Romantic poets Samuel Taylor Coleridge had studied it and shared his vision with William on the same mystical sources as *Naturphilosophie,* and he denounced "The Atoms of Democitus and dehumanized culture of his age.

The lasting scientific achievements of the adherents of *Naturphilosophie* are few, although many more may be recognized when more sympathetic historical research is done. For example, the discovery of electromagnetism (1820) by the Danish physicist Han Christian Qrasted in over many years, for effects of display the unity and polarity of the forces of nature. Similarly, the earliest announcement of the notion of conservation of energy was made in 1841 by a physician, Julius Rober von Mayer, who had the same sort of program. The common pattern was for a young man to be captured by the vision of such a unified wisdom while at a university and then to spend his life trying to rescue as much of it as possible by dedicated research. This sort of career is well illustrated by that of Hermann Ludwig Helmholtz, a German physiologist and physicist.

Eventually *Naturphilosophie* became an orthodoxy taught by university professors. The founders of experimental science in Germany in the 1840s found their way blocked by them, and bitter struggles ensued. Though the scientists won, they were haunted for generations by the ghost of *Naturphilosophie,* and they reacted by curbing all speculative tendencies most severely, reinforcing the dry, inhuman style of science that the poets had found abhorrent.

AGE OF MATURE SCIENCE

During the 19th century, in industrially advanced nations of Europe assimilated the consequences of the Industrial and French revolutions. Modern urban society developed in one nation after another with a constantly improving industrial base, elaborated state bureaucracies for regulation of trade and welfare, and increasing participation of the mass of people in social and political life. In one scientific discipline after another, there was similar steady progress in the achievement of coherent systems and in the creation of institutions for the development of scientific activity. Science as a whole shared the general optimism of the age, receiving credit for its supposed contribution to industrial progress.

Science in the 19th century. In retrospect, the 19th century appears as a golden age. Science expanded successfully into a new fields of inquiry, including a combination of mathematics and experiment in physics, the application of theory to experiment in chemistry, and controlled experimentation is biology. This was greatly aided by the establishment of new and reformed universities in which research was fostered as well as teaching, and of communication through specialists journals and societies. National and international meeting for both general science and specialists, became common by the end of the century. The principle of socially organized research, rather than inquiries by isolated individuals, became effective. In all fields of learning there was increased rigour of

methods and depth of scholarship. The end-of-century editions of the *Encyclopadia Britannica* with their long historical accounts of each science are a monument to this period and remain a valueable source of information for the student.

Differences in styles of research. There were still striking differences among the leading nations regarding the circumstances and styles of research. In Britain, there was a marked absence of institutions providing jobs for researchers, and so the tradition of the gentleman-amateur lasted longer than elsewhere (for example, Charles Babage the mathematicians, James Joule, the physicists, and the biologist Charles Darwin). This made British science thin in comparison with German, especially in applied fields such as chemistry; but the scope for individual style and eccentricity compensated for the quantitative deficiencies. In Germany, the natural sciences shared in the rise in size and prestige of the university system. There, research and teaching were joined, and genuine laboratory research training was established for the first time, notably by the German chemist Justus von Liebig and his school. With this institutional base and a highly developed scholarly apparatus of handbooks and journals, German science rose in the half century from 1830 to a position of leadership in most fields. During this same period, French science declined from what had previously been its commanding position during the Revolutionary and Napoleonic periods. On the edge of Europe, Russia had a strong Academy and several progressive universities amid generally backward conditions, and a tradition of scientific excellence (set by men like Nikolay tradition Lobachevsky and Dmitry Mendeleyev) was available for helping the rapid modernization that followed the Revolution of 1917. Through the 19th century the United States remained a cultural colony of Europe, except to some extent in the field sciences. Its larger universities were oriented toward utility, giving little social support to pure research. Around the end of the century, American scientists went to Germany in large numbers and on returning established strong traditions, but the attainment of qualitative leadership by the U.S required the influx of refuge scholars from Nazi Germany in the 1930s.

The commitment to so-called pure science could flourish best within the German universities system. In Britain, men of science freely engaged in both philosophical debates and in industrial application, a notable instance being Lord Kelvin in physics; the issue was not the scholar's remoteness from the world but the gentleman's independence of action. Also, the dominance of mathematical and experimental sciences over field sciences grew very slowly through the period. Early in the century, geology was the leading science. It had both a philosophical side in its speculations on the history of the Earth and a practical side in the utilization of resources. Natural history, inherited from the 18th century, served the squire and also the free-lance explorer and collector, such as Thomas Henry Huxley in biology. Only in the latter part of the century was there a marked trend toward dominance of the specialized professional research man, with the abstract experimental scientists as the leaders. An indication of the gradualness of this change in England can been in the resistance to the two terms scientist and physicist.' Although suggested for general use in the 1830s, they were condemned by men of science as well as by natural philosophers until the beginning of the 20th century.

The relationship of science to its applications had an equally gradual change; in spite of claims to the contrary, the direct transition of processes from the laboratory to factory became effective only toward the end of the century. At the beginning of the period, the most successfully applied sciences were those traditional ones that were descriptive techniques of interest to the state. These were either the abstract disciplines of mathematical cartography fortification or the very detailed natural-history studies. Later physics was directly involved in qualitatively new processes, such as improved steam-power generation and electrical telecommunications. Chemistry contributed at first to the nationalization of industrial processes and also to effective theories of agriculture and nutrition. The

invasion of medicine by applied science came very late, with the germ theory of disease; and it is worthy remembering that the improvement in life and longevity owed more through the century to soap and sewers-that is, to sanitary reform and economic improvement-than to medical science. Synthetic dyestuffs were the first example of a laboratory discovery turned directly to profit, ad this was a German achievement. Actually, the invention was made in 1856 by an Englishman, William Henry Perkin; but he was a pupil of the German chemist August Wilhelm von Hofman, and the Gemans soon took a commanding lead in this industry thanks to their system of higher technical education for industrial scientists. By the end of the century they dominated all of industrial chemistry, as well as the heavy electrical equipment industry. Only the Americans, with their combination of a large market and independent inventors, could compete effectively. The French had long since lost the early lead they had gained with their rational approach to engineering, and the British rested on their early prestige as the workshop of the world. World War II found the German capable of synthesizing ammonia for nitrate explosive from the air (the Haber process), while the Britis depended for their explosives on nitrates from Chile.

Progress in physics. During the 19th century, each of the major branches of experimental science made such great progress that in retrospect its earlier state seemed to be rudimentary. Physics achieved that close union of precise experimentation with abstract mathematical theory that brought unprecedented depth of knowledge and power in application of that knowledge. Different fields were brought under control and then successively unified by the concept of energy. Thermodynamics united the sciences of heat and work and then enabled a theory of chemical change to develop. The roots of this lay in the work done by physicists in power engineering pioneered by Said Carnot of France and James Joule of England, in a variety of experimental fields pioneered by the German Herman Helmholtz, and in the speculative search for the single agency of physical change. Electricity and magnetism were united, first experimentally and then theoretically, by the Dane Hans Christian Qrsted and the Englishmen Michael Faraday and Kelvin; and a fundamental constant in the theory of electromagnetic measurement, determined by the German Wihelm Weber, was observed to be equal to the astronomically determined velocity of light by the Englishman James Clerk Maxwell. Thus, the general properties of matter were successively masterd and made coherent. Later physiciets justly called the century the classical age.

BIOLOGY

Producing an Experimental vaccine

Tagging a Bear Cub for study in the wild

Developing New Plant

Photographing a file clam

BIOLOGY is the scientific study of living things. There are more than 2 million species of ling things on the earth. They range in size from micro-scopic bacteria to huge blue whales and towering red-wood trees. Living things also differ greatly in where and how they live. However, all forms of life share certain characteristics that set them apart from nonliving things. These characteristics include the ability to reproduce, to grow, and to respond to changes in the environment.

Traditionally, biology has been divided into two major fields. *Botany* deals with plants, and *zoology* with animals. Botany and zoology are further divided into various branches and specialized areas of study. But most be branches of biology - for example, *anatomy* (the study of the structure of

living things) and *genetics* (the study of heredity) - apply to both plants and animals.

Biology may also be divided into *ecology, physiology* and *systematics.* Ecology deals with the relationships among living things and between organisms and their environment. Physiology concerns life functions, such as digestion and respiration. Systematics, also called *taxonomy*, is the scientific classification of plants and animals.

Biologists often make use of the methods and findings of other sciences. Fr instance, they rely on physics and chemistry to help them understand the processes that occur in living plants and animals. They use statistics in studying changes in the size of an animal or plant *population* - that is, the number of organisms of a particular species in an area. *Exobiologists* work with astronomers in searching for life elsewhere in the universe.

Achievements in biological research have greatly affected people's lives. For example, farm production has soared as biologists have help helped develop better varieties of plants and new agricultural techniques. Discoveries in biology have enabled physicians to prevent, treat, or cure many disease. Research on the relationships between living things and their environment has helped in the management of wildlife and other natural resources.

What Biologists Study

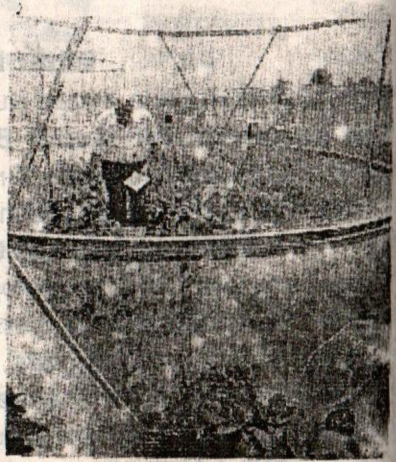
Biology is such a broad subject that most biologists specialize in some area of study. But in whatever area they work, all biologists are interested in both the parts of living things and how the parts work together.

Certain biologists study organisms that live in a specific environment. *Marine biologists,* for example, investigate life in the ocean. Some biologists concentrate on a particular type of organism. *Ornithologists,* for instance, study birds. Many biologists examine the parts of living things. *Cylologists,* for example, deal with the structure, composition, and functions of cells. Other biologists analyze life processes. *Embryologists,* for example, investigate the formation and development of animals and plants before they become independent organisms.

The techniques and tools that biologists use depend on what they are investigating. Many biologists conduct experiments to gain information and to develop and test theories. Their experiments may involve making a change in an organism's way of life or its environment and then observing the effects of that changes. For example, a biologist may change the diet of an naumal and study how the animal's growth and functioning are thereby affected. The microscope has long been one of the biologist's most useful tools. An entire branch of biology, called *microbiology*, is devoted to the study of organisms that can be seen only with microscope. Other techniques and tools used by biologists range from aerial surveys of plant animal populations to techniques and tools used by biologists range from aerial surveyors of plant and animal populations to techniques that isolate the molecules of living cells.

HISTORY OF BIOLOGY

Beginning: In prehistoric times, people gradually developed a great deal of practical biological knowledge. They learned to grow may kinds of plants and to tame and raise certain animals.



In ancient times, people of China, India, and the Middle East accumulated further knowledge of plants and animals. For instance, they knew how to use numerous plants as medicines or poisons. The Egyptians learned some anatomy and physiology through embalming their dead.

The ancient Greeks made major advances in biology.

Unlike most other people of the time, some Greek thinkers did not believe that gods or spirits caused natural events. Instead, they saw nature as operating according to laws that people could discover. About 400 B.C., a Greek physician named Hippo-crates taught that diseases have only natural causes. He also emphasized the relationships among the parts of an organism and between an organism and its environment. Hippocrates is often called the father of modern medicine.

During the 300's B.C., the Greek philosopher Aristotle gathered a vast amount of information about plants and animals. He was one of the first thinkers to classify animals according to their own characteristics rather than according to their usefulness to people. Pliny the Elder, a Roman naturalist who lived during the first 100 years after Christ's birth, also collected many facts about plants and animals. He included the information inhis 37 - volume *Natural History*.

During the A.D. 100's, Galen, a Greek physician who practiced medicine in Rome, contributed greatly to advances in anatomy and physiology. He gained much of his knowledge from treating injured gladiators and dissecting apes and pigs.

The growth of biological knowledge slowed during the Middle Ages, a 1,000 year period in European history that began in the 400's. However, works by Hippocrates, Sristotle, Galen, and other ancient authorities were collected, preserved, and translated by Arab scholars in the middle East. The Arabs also made major contributions of their own in biology. The works of the ancient Greek and Arab scientists eventually made their way to Europe. During the Middle Ages, the authority of ancient writers was unquestioned, though their works contained many errors.

The Renaissance. From the early 1300's to about 1600, a new spirit of inquiry spread across western Europe. During this period, called the Renaissance, many anatomists and physiologist began to challenge the authority of the ancient writers. They believed that people should be rely on experimentation and observation rather than accept without question the ideas of the ancients.

The emphasis on observation stimulated the development of a high degree of naturalism and accuracy in biological illustration. During the late 1400's and early 1500's the great Italian artist Leonardo da Vinci made hundreds of drawings of the human body in which he paid careful attention to detail and proportion. Leonardo based his work on dissections of human corpses. The first scientific textbook on human anatomy was published in 1949. This work, titled on the fabric of the Human body, was written by Andreas Vesalius, an anatomist born in what is now Belgium. Like Leonardo, Vasalius based his work on dissections he had made of human corpses. The book, richly illustrated with exceptionally lifelike drawings of human anatomy, corrected many of Galen's mistaken ideas.

One of the most important discoveries in physiology in the 1600's was made by William Harvey, an English physician. In 1628, Harvey published the results of his experiments showing how blood, pumped by the heart, circulates through the body.

Early Discoveries with Microscope. The introduction of the microscope led to great discoveries in biology during the middle and late 1600s. About 1660, an Italian anatomsit named Marcello Malpighi, with the aid of a microscope, became the first person to observe the movement of blood through the capillaries. In 1665, Robert Hooke, an English experimental scientist, published *micrographia,* a book containing detailed drawings of many biological specimens as seen with a microscope. The book included the first drawings of cells. In the mid-1670's, Anton val Leeuwenlock, a Dutch amateur scientist, discovered microscopic life forms, thus opening up a new world for investigation.

The origins of scientific classification. During the 1700's, Europeans came into increasing contact with distant parts of the world and thereby learned of many unfamiliar plants and animals. Naturalists realized that they needed a classification system that could include those plants and animals. In 1735, the Swedish naturalist Carolus Linnaeus (also called Karl von

The Cultivation of a Date Palm is this ancient Mesopotamian carving Much early biological knowledge dealt With farming and other practical matters

Dissections of Animals were carried out by the Greek physician Galen during the A.D 100's. Galen's studies greatly advanced the knowledge Anatomy.

A Recipe for cough syrup made from plants appears in an Arabic manuscript from the 220's. The Arabs made major Contributions in botany and medicine

Linne) published a system of classification in which he grouped organisms according to structural similarities. His system forms the basis of scientific classification used today.

Classifying organisms according to structural similarities stimulated interest in *comparative anatomy* – the comparison of the anatomical structures of different organisms. The leading comparative anatomist of the late 1700's and early 1800's was Baron Cuvier of France. Cuvier noticed that most kinds of animals have one or another of a very few basic body types. He devised a system of classifying animals according to basic body types that is stilled used in modified form. Cuvier also applied the methods of comparative anatomy to another field he helped established, *paleontology* – the study of fossils.

The Theory of Evolution. Most of biologists had long believed that each species of life had remained unchanged and no new species had appeared since the world began. However, biologists began to question those beliefs during the late 1700's. They noted that farmers had produced new varieties of plants and animals by selective breeding. In addition, voyages of exploration had revealed isolated groups of plants and animals that contained many species which varied only slightly from one another. Biologists wondered why there should be so many species with little variation. Such observations led many biologists to believe that species change over time and that some species change over time and that some species had *evolved* (gradually developed) from others.

During the early 1800's, several biologist proposed explanations of how species evolve. The most convincing theory was eventually reached interpedently by two British naturalist - Charles Darwin and Alfred Russel Wallace. However, Darwin presented his ideas in a widely read book, and his work became better known.

Darwin detailed his theory of evolution in *The origin of Species* (1859). According to Darwin, some organisms are born with traits that help them survive and reproduce. They pass the favourable traits on to their offspring. Other members of the same species that have unfavourable traits are less likely to survive and reproduce. The unfavourable traits eventually die out. Darwin proposed that species evolve as more and more favourable traits appear and are passed from generation to generation. He called the process natural selection.

Materialistic Physiology and the Cell Theory. Many physiologist of the late 1700's had come to think of life as the total of the physical and chemical processes occurring in an organism. Unlike some other biologists, they did not believe that living things are guided in their functioning by any spiritual or supernatural forces. Instead, they felt that living things are nothing more than special combinations of materials and function like machines. Such views are called *materialistic physiology* or *mechanistic materialist physiology*

Antoine Lavoisier, a French chemist, applied the techniques of chemistry to physiology in the late 1700's..He compared respiration on the burning of a candle because both processes use oxygen and produce heat and carbon dioxide. Beginning in the mid-1800's, the French physiologist Claude Bernard saw living things as highly organized sets of control mechanisms that work to maintain the internal conditions necessary for life. He pointed out that in a mammal, for

example, such mechanisms keep body temperature constant in spite of variations in the temperature outside the organism.

Paralleling developments in physiology was growing understanding of the cell. In the late 1830's, two Germans- the botanist Matthias Schleiden and the physiologist Theodor Schmann-proposed that the cell was the basic structural and functional unit of all plants and animals. In 1858, Rudolf Virchow, another German scientist, published his theory that all diseases were diseases of the cell. In combination, these ideas are called the *cell theory*.

Building on materialistic physiology and the cell theory, Louis Pasteur, a French chemist, and Robert Koch, a German physician, firmly established a new theory of diseases are caused by microscopic organisms.

The Growth of Modern Biology. During the late 1800's, Darwin's theory of evolution had stimulated much speculation among biologists about the origin, nature, and development of organisms. By the early 1900's, however, many biologists strongly rejected the emphasis on theory and speculation.

The Human Muscular system is shown in this illustration from Andreas Vesalius *On the Fabric of the Human body (1543)*. The first scientific text on human [illegible]

A Detailed Drawing of a Fly was published in *Micrographia* (1665) by Robert Hooke of England. Hooke pioneered in studying specimens with the microscope

A Flower "Clock" by the Swedish naturalist Carolus Linnaeus in 1745 arranges species by the times of the opening and Closing of the blooms.

Instead, they stressed the value of carefully controlled experiments and the application of mathematical techniques to biological knowledge, particularly in the understanding of the chemical and molecular basis of life.

Genetics was established as branch of biology in the early 1900's. It developed chiefly from experiments conducted during the mid-1800's by Gregor Mendel, an Austrian monk. On the basis of his experiments, Mendel, discovered that physical characteristics are produced by basic hereditary units that transmit traits from generation to generation. About 1910, Thomas Hunt Morgan, an American biologist, found that Mendel's hereditary units - later - called *genes* - are located on structures called *chromosomes* within cells. Biologists at the time also noted that changes in hereditary traits correspond to visible changes in chromosomes structure.

During the 1940's generticists found that genes guide the manufacturer of the proteins by which cells regulate their chemical processes. In 1953, biologist James .D. Watson of the United States an physicist Francis H.C. Crick of Great Britain proposed a model of the molecular structure of DNA enabled biologists to understand the molecular basis of many life processes.

Breakthroughs in genetics helped alter biologists' approach to the studying evolution in terms of changes in the kinds of and numbers of genes in a population.

The field of ecology began to develop dramatically in the early 1900's. Scientists had long recognized the importance of the relationships among organisms and between organisms and their environment. But the development of ecology as a separate branch of biology occurred only after the introduction of such techniques as the statistical analysis of complex systems of relationship. Since the 1960's, concerned about the environmental effects of pollution has stimulated research in ecology.

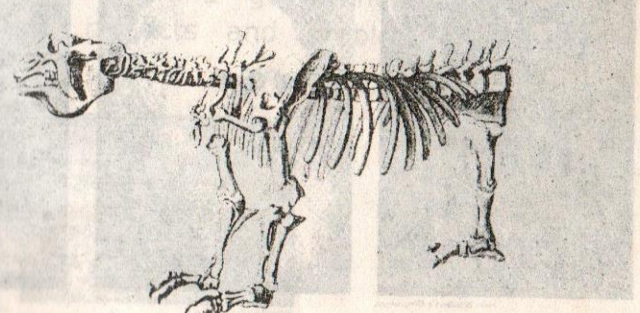
Great advances have also been made during the 1900's in *neurobiology* - the study of the nervous system. Neurobiologists have learned much about how nerves function individually and in organized groups.

Current Research and Issues. The study of the human *immune system* - that is, the body's defense system against disease and foreign substances - is one area at the frontier of biological research. Scientists are learning how our bodies produce a seemingly endless variety of disease-fighting proteins called *antibodies.* Each antibody is tailored to combat one of many foreign substances called *antigens.* Biologist have discovered that the body can produce a great number of different antibodies because certain genes rearrange themselves to produce antibodies that attack specific antigens.

Since the 1950's, biologists have been collecting evidence for the theory that life began in a series of chemical reactions early in the earth's history. They have produced complex biological molecules in chemical experiments that reproduce conditions thought to have existed on the earth billions of years ago.

Since he 1970's, growing number of biologists have questioned the idea that evolutionary change occurs only as a result of a gradual process. Instead, they accept the idea that

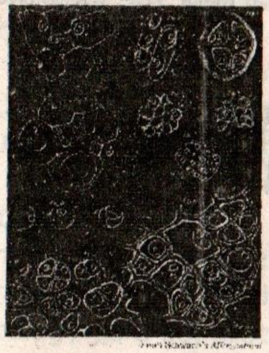
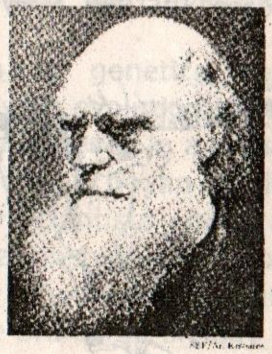
An Experiment on Respiration is shown in this engraving of [illegible] laboratory. The French chemist studied [illegible] processes in the [illegible]



The Skeleton of an Extinct Giant Sloth was drawn by Baron Cuvier of France, the leading comparative anatomist of the late 1800's Cuvier pioneered in *paleontology,* the study of fossils. He used the methods of comparative anatomy to determine the structures of prehistoric animals from their fossil remains.

evolution may proceed at times by abrupt changes leading to the replacement of one species by another. Although there is questioning over details, most biologists believe in the general outlines of the theory of evolution. However, some other people reject the theory because of the many gaps in our understanding of how particular species evolved. Still other people object to the idea of evolution because it conflicts with their religious beliefs about the creation of life. See EVOLUTION.

By the late 1970's, scientists had learned how to remove genes from one species and insert them into another. The process is called *genetic engineering.* Genetic engineering offers many potential benefits in medicine, industry, and agriculture. For example, scientists have transferred to bacteria the human gene that produces *insulin* – a hormone that regulates the body's use of sugar. The bacteria then produce insulin, which can be used to treat people who have diabetes. However, some people question the morality of interfering with the hereditary makeup of living things through genetic engineering. Genetic engineering has also caused that


the release of genetically engineered organisms into the environment may have harmful effects. For this reason, scientists involved in genetic engineering have developed safety guidelines.

CAREERS IN BIOLOGY

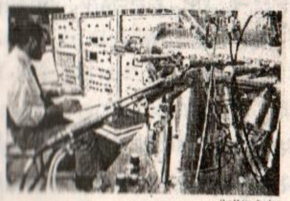
Biology offers a wide variety of careers and a broad range of work settings, from research laboratories to national parks. High school and college courses helpful to students preparing for a career in biology include chemistry, mathematics, and physics well as courses in Biology. A bachelor's degree is sufficient for some careers on biology, but many positions require a graduate degree. Some people with a bachelor's degree teach in junior high and high schools. Other works as technician in research laboratories. Many biologist with advanced degrees teach and conduct research at universities

Job opportunities for biologists in agricultural research and in industry are increasing, especially in the areas of genetic engineering and ecology. Such biologists may work to develop new varieties of food crops to create organisms capable of producing drugs.

Many government agencies responsible for public health, sanitation, and water quality employ biologists. Careers in biology also include work in zoos and botanical gardens. In addition, some companies and governmental effects of proposed construction projects and problems caused by environmental pollution.

Fermentation Process

Building a Three-Dimensional Model of a Molecule

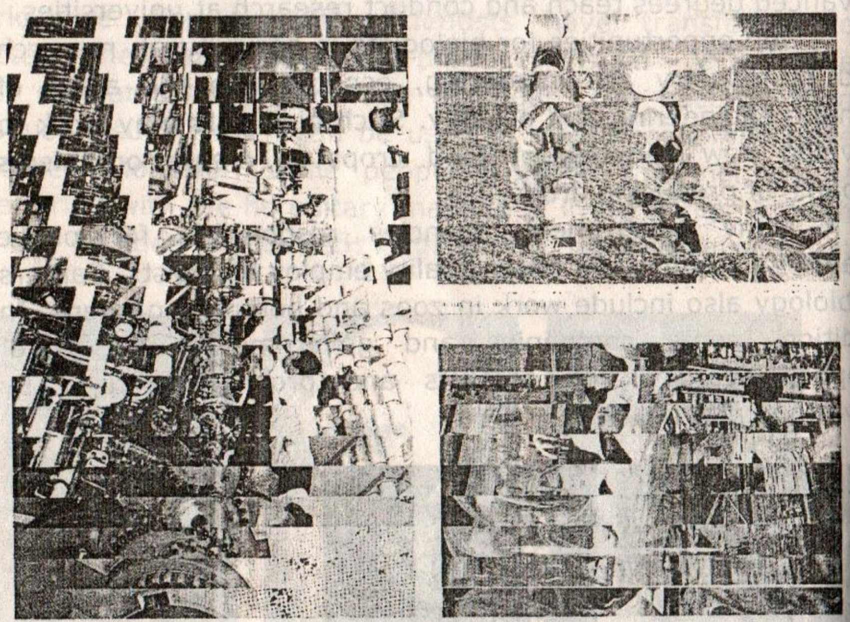


Measuring Molecular Weights with a Mass Spectrometer

attempts to answer questions about the nature of substances. Some
understand the chemical changes that substances go through. Others
advanced instruments to explore the structure and composition of

CHEMISTRY

CHEMISTRY is the scientific study of substances. Chemistry investigate the *properties* (characteristics) of the substances that make up the universe. They study how those substances behave under different conditions. They attempt to explain the behaviour of a substance in terms of the substance's structure and composition. Chemists also seek to understand chemical changes. Chemical changes involve alterations in a substance's chemical make up. The combination of iron with oxygen from



The Practical Applications of chemistry range from the development of new methods of disposing of hazardous wastes to the discovery of new formulas for perfumes. Cosmetics, drugs, dyes, fertilizers, and synthetic fibers are only a few of the products resulting from chemical research.

the air to form rust is a chemical change. Substances may al through physical change without altering their chemi makeup. Water changes physically but not chemically when freezes.

Chemical changes occur constantly in nature and make life on the earth possible. During a thunderstorm, for instance, lightening causes a chemical change in the air. The electrical energy and heat of a lighting bolt cause some of the nitrogen and oxygen in the atmosphere to combine and form gases called *nitrogen oxides.* The nitrogen oxides dissolve in raindrops that fall to the ground. In the soil, they are chemically changed into *nitrates,* substances that serve as fertilizer.

Chemical changes also occur as wood burns and becomes ashes and gases. The food we eat goes through many chemical changes in our bodies. Chemical changes that take place when gasoline burns supply power for automobiles.

Chemists have learned much about the chemical substances and processes that occur in nature. In addition, chemical researchers have created many useful substances that do not occur naturally. Products resulting from chemical research include many artificial fibers, drugs, dyes, fertilizers, and plastics. The knowledge gained by chemists and the materials they have produced have greatly improved people's lives.

THE WORK OF CHEMISTS

Chemistry involves the study of many different substances. Substances differ greatly in their properties, structure, and composition. The methods that chemists use and the questions that they attempt to answer also differ greatly. However, all chemists share certain ideas that are fundamental to their work.

Fundamental Ideas of Chemistry. The most basic chemical substances are the chemical elements. They are the building blocks of all other substances. Each chemical element is made up of only one kind of atom. The atoms of one element differ from those of all other elements. Chemists use letters of the alphabets as symbols for the elements. They symbols for the elements carbon, hydrogen, oxygen, and iron, for example, a re C, H, O, and Fe. There are 92 elements known to exist in nature. About 15 more have been produced artificially. See Element chemical.

Electrical forces at the atomic level create chemical bonds that join two or more atoms together, forming molecules. Some molecules consist of atoms of a single clement. Oxygen molecules, for example, are made up of two oxygen atoms. Chemists represent the oxygen molecule by the chemical formula O_2. The 2 indicates the number of atoms in the molecule. See MOLECULE.

When atoms of two or more different elements bond together, they form a chemical compound. Water is a compound made up of two hydrogen atoms and one oxygen atom. The chemical formula for a water molecule is H_2O. See COMPOUND.

Compounds are formed or broken down by means of chemical reactions. All chemical reactions involve the formation or destruction of chemical bonds. Chemists use *chemical a questions* to express what occurs in chemical reactions. Chemical equations consist of chemical formulas and symbols that show the substances involved in chemical changes. For example, the equation.

$$C + O_2 \rightarrow CO_2$$

express the chemical change that occurs when one carbon atom racts, or bonds, with an oxygen molecule. The reaction produces one molecule of carbon dioxide, which has the formula CO_2.

The Broad Range of Study. Chemists study substances according to questions they want to answer. Many chemists study special groups of substances, such as compounds containing carbon-carbon bonds. Some chemists specialized in techniques that enable them to analyze substance and identify elements and compounds it consists of. Other chemists study the forces involved in chemical changes. Much chemical research deals with the atomic and molecular structures of substances. Certain chemists try to predict chemical behaviour from theories about the forces at work within the atom. chemists also work to create new substances

and to make synthetic forms of rare but useful natural materials. Their field is called *synthetic chemistry*. A number of chemists apply their knowledge to finding ways of using substances and chemical processes in agriculture, industry, medicine, and other fields.

In some cases, chemistry overlaps such science as biology, geology, mathematics, and physics to such an extent that *interdisciplinary sciences* have been established. *Biochemistry,* for example, combines biology and chemistry in studying the chemical processes of living things.

Tools and Techniques. Chemists use a wide variety of tools and techniques. Specialized instruments and electronic computers help chemists make accurate measurements. A device called a *mass spectrometer,* for example, enables chemists to determine the *mass* and atomic composition of molecules. Mass is the total quantity of matter that anything contains. Chemists can identify how atoms are arranged in molecules by using instruments that measure the radiation absorbed and given off by the molecules. A technique called *chromatography* enables chemists to separate complicated mixtures into their parts and to detect and measure low concentrations of substances, such as pollutants in air and water.

HISTORY OF CHEMISTRY

Beginnings. In prehistoric times, people made many useful discoveries by observing the properties of natural substances and the changes those substance go through. About 1½ million years ago, people began to use fire. Fire was the first chemical reaction that human begins learned to produce and control. The use of fire enabled to produce and control. The use of fire enabled people to change the properties of substance. They used fire for such purposes as cooking, hardening pottery, and smelting metal ores. Fire also enabled them to create new materials. About 3500 B.C., for example, people learned to make bronze by melting copper and tin together.

The people of many ancient cultures believed that gods or spirits caused natural events. About 600 B.C, however, certain Greek philosophers began to regard nature in a different way. They believed that nature worked according to laws that people could discover by observation and long.

Several ancient Greek philosophers developed theories about the basic substances that make up the world. Empedocles, who lived during the 400's B.C., argued that there were four primary elements – air, earth, fire, and water – and that they combined in various proportions to form all other substances.

About 400 B.C., Greek philosopher named Democritus taught that all matter was composed of a single material that existed in the form of tiny, indestructible units called atoms. According to his theory, differences among substances were caused only by differences in the size, shape, and position of their atoms.

The Greek philosopher Aristotle, who lived during the 300's B.C., claimed that each of the four primary elements proposed by Empedocles could be changed into any of the other elements by adding or removing heat and moisture. He stated that such a change – called *transmutation* – occurred whenever a substance was involved in a chemical reaction or changed from one physical state – solid, liquid, or gas – to another. Aristotle believed that water, for example changed to air when it was heated.

Alchemy. During the first 300 years after the birth of Christ, scholars and craft workers in Egypt developed a chemical practice that came to be called *alchemy*. They based their work on Aristotle's theory of the transmutation of elements and tried to change lead and other metals into gold. Alchemy began to spread to the Arabian Peninsula in the A.D. 600's and to much of western Europe in the 1100's. Until the 1600's, alchemy was a major source of chemical knowledge.

Despite centuries of experimentation, alchemists failed to produce gold from other materials. They did gain wide knowledge of chemical substances, however, and invented

many tools and techniques still used by chemists. Alchemists used such laboratory equipment as funnels, strainers, balance scales for weighing chemicals, and *crucibles* (pots for melting metals). They also discovered new ways of producing chemical changes and learned to make and use various acids and alcohols.

Alchemists also searched for a substance that could cure disease and lengthen life. During the 1500's, some alchemists and physicians began to apply their knowledge of chemistry to the treatment of disease. The medical chemistry of the 1500's and 1600's is called *iatrochemistry* (produced *eye AT roh KEHM uhstree*). The prefix comes from *iatros,* the Greek world for *Physician*. Latrochemsits made the first studies of the chemical effects of medicines on the human body.

Robert Boyle, an Irish scientist of the 1600's, was one of the first modern chemists. He taught that theories must be supported by careful experiments. Boyle conducted many experiments that showed that air, earth, fire and water are not true elements. He believed that the best explanation of the properties of mater was provided by an atomistic theory that described substances as composed of tiny particles in motion.

The phlogiston Theory (pronounced *noh JIHS tuhn*) was a very successful chemical theory, though it was eventually replaced by a better one. The theory was developed in the early 1700's by a German chemist and physician named Georg Ernst Stahl. Stahl wrote that all flammable materials contained a substance called *phlogiston*. According to his theory, materials gave off phlogiston as they burned. Air was necessary for combustion plants, in turn, removed phlogiston from the air. They therefore became rich in the substance and burned when dry. Like all other good chemical theories, the phlogiston theory provided an explanation for the results of a variety of experiments and offered clues to areas of study in which new discoveries could be made. For that reason, the theory was widely accepted in the 1700's and led to many findings in chemistry.

Chemists of the middle and late 1700's developed techniques for isolating and studying gases. They based their work on the phlogiston theory and made numerous discoveries. In the 1750's, a Scottish chemist and physician named Joseph Black identified carbon dioxide. It was the first gas recognized to have properties different from those of air. In 1766, Henry Cavendish, and English chemist and physicit, discovered hydrogen. Because hydrogen is very flammable, Cavendish believed it was pure phlogiston. Oxygen was discovered independently by a Swedish chemist named Carl Scheele in the early 1779's and an English chemist named Joseph Priestly in 1774. wood burns more vigorously in oxygen than in air. Priestly therefore believed that oxygen could absorb great quantities of phlogiston. He called oxygen *dephlogisticated air*(air without phlogiston).

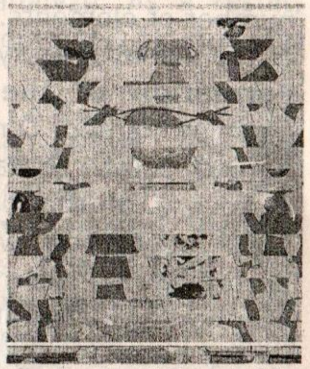
Lavoisier's contributions. Antoine Lavoisier, a French chemist, revolutionized chemistry in the late 1700's. He repeated many of the experiments of earlier chemists but interpreted the results far differently. Unlike earlier chemists, Lavoisier paid particular attention to the weight of the ingredients involved in chemical reactions and of the products that resulted. He found that the weight of the products of combustion equals that of the original ingredients. His discovery came to be known as the *law of the conservation of mass (or matter).*

Lavoisier noted that the weight of the air in which combustion occurred decreased. He found that the weight loss results from the burning material combining with the removing a substance in the air. That substance, which was the same as dephlogisticated air, Lavoisier called oxygen. Lavoisier's oxygen theory of combustion came to replace the phlogiston theory.

Lavoisier and the Marquis de Laplace, a French astronomer and mathematician, also carried out experiments demonstrating that respiration in animals is chemical similar to combustion. Their studies of the chemical processes of living organisms were among the first experiments in biochemistry. Lavoisier also helped work out the present -day system of

mental Smelting and Casting are shown in this Egyptian wall painting from about 1474 B.c Ancient people knew how to use various substances to make many things they needed.

The Alchemist's Workshop was the forerunner of the modern chemical laboratory. Alchemists used such laboratory equipment as funnels, Strainers, and balance scales.



An Air Pump built by Robert Boyle and Robert Hooke in the mid-1600's was used to investigate the nature of vavccums.

chemical names. He published his ideas on combustion, respiration, and the naming of compounds in *Elementary Treatise on Chemistry* (1789), the first modern textbook of chemistry.

Dalton's Atomic Theory. In 1803, an English chemist named John Dalton developed an atomic theory based on the idea that each chemical element has its own kind of atoms. He believed that all the atoms of a particular element had the same mass and chemical properties. He theory could explain and predict the results of various experiments and was gradually accepted.

According to Dalton's theory combined with a fixed number of atoms of another substance informing a compound. Dalton realized that substances must combine in the same proportions by weight as the weight proportions of their