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SCIENCE AND ITS BACKGROUND



By courtesy of the British Association for the Advancement of Science

CHARLES DARWIN'S STUDY AT DOWN HOUSE, DOWNE, KENT

Years of patient work in this homely atmosphere led to the announcement of the theory of Organic Evolution by Natural Selection, which has had a profound influence on human thought and progress

SCIENCE AND ITS BACKGROUND

BY

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PREFACE

> History embraces ideas as much as events, and derives its best virtue from regions beyond the sphere of State.
>
> LORD ACTON, 1901

DURING the years between the two World Wars many histories of science have appeared. Sometimes the author has restricted his treatment to one branch, sometimes to one period, or even to one country ; biographies, memoirs and diaries have all played their part in making accessible the facts and romance of scientific discovery. On the other hand, historians during the same period have recognized the importance of science, whether their histories have been written from a national, European or world point of view.

The present work attempts to fuse these two approaches by giving something of the story of *science*, together with the background of *history* in which that story is set. To achieve this, two features have been introduced. First, most of the chapters are centred on the work of individual men of science, selected, not merely as a part of scientific history, but because of the value of their work today. Secondly, the historical background is not only that of isolated biography, but continuous history of human affairs. In this connection, the various time-charts should prove valuable.

Sir Richard Livingstone, using the metaphor of a rope by which man has climbed to his present position, maintains that the rope consists of three strands : one of action, another of knowledge, and a third of vision. These three are interwoven, and in the following pages the strand of knowledge, as developed by men of science, is not separated from that of action, as represented in history, or that of vision, in the realm of ideals. This method of treatment should therefore appeal to those whose interest in " the arts " has been

at the expense of " the sciences ", and equally to those, so much engrossed in the latter, that they have found but little time to appreciate the former. The tendency to divorce these two branches is a reflection on our educational policy. As recently as March 23, 1946, *The Times* commented, " the debate in the House of Commons yesterday on technical education afforded striking evidence of the dichotomy between vocation and culture, and of the urgent need to achieve a new synthesis between them ".

In this age of specialization, one may easily become lost amid the subdivisions of science, and bewildered at their ever-increasing number. But despite such confusion the general reader has every right to believe that science has played an important part in building up our modern cultural heritage. That heritage cannot be ignored in our plans for a better future. The following is an attempt to state simply, and within the limits of a small volume, some of the achievements of science as a whole, in relation to the background of history, the progress of European civilization, and the life of today.

It has been a pleasure as well as a privilege to have the co-operation of so experienced an editor as Mr. A. J. V. Gale, M.A.; without his advice and help the book could not have appeared in its present form. Acknowledgement of the source of illustrations is made under each one; I am under special obligation for particular pictures to the Royal Society, the Royal Institution, Prof. E. N. da C. Andrade, Mr. M. C. Burkitt, Dr. O. J. R. Howarth (Curator of Down House) and Prof. J. R. Partington.

H. D. ANTHONY

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THE charts are intended to illustrate the theme of the book. In a Foreword to Steinberg's *Historical Tables* (which give a detailed survey of world events from the rise of the Roman Empire to 1938), Dr. G. P. Gooch refers to the belief that civilization is a co-operative achievement and a common heritage. " Peoples are connected with one another by a network of contacts and obligations, visible and invisible. The older the world grows, the greater the debt of each to all and of all to each. Every one of us is a citizen of the world ; each nation is a branch of the human tree. Geographical, racial and linguistic barriers blur but cannot destroy the fundamental unity of mankind." It is in this atmosphere that the story of science and its background should be viewed.

Just as there are no sharp lines of demarcation between historical periods, so the three strands of Action, Knowledge and Vision are interwoven in the fabric of human affairs, and their division into three columns on the charts is not intended to suggest otherwise. The central column — Knowledge — has special reference to science.

In the interests of clarity, many important names and events have had to be omitted. In the main, however, those mentioned in the following pages, because of their importance today, have been included.

INTRODUCTION

CHAPTER I: GEOLOGICAL TIME AND HUMAN HISTORY

The Importance of Background

THE word "science" comes from the Latin *scientia*, which means knowledge. Its present use is restricted to systematic knowledge, and has special reference to those branches of study not included in literature, art or history. Popular usage lays emphasis on the physical and natural sciences, and the very fact that science nowadays does not embrace all knowledge is a reminder of its relation to other fields of thought and activity. No branch of knowledge can be isolated, even though sometimes methods of instruction may give that impression. In other words, every subject has its own setting, and in order to appreciate its full significance, a study must be made, not only of the subject itself, but also of the background associated with it, and of the human interests around which it centres. Science is no exception, and in the following pages important scientific discoveries are closely knit to the men who made the discoveries, and the times in which they lived.

Any thought about science soon leads to questions about ourselves and the world which forms the background of our lives. Such questions are easier to ask than to answer, but there is a great deal of information concerning the earth and man's history which is now generally accepted, and which will make a suitable starting point for this survey.

One of man's earliest questions related to the universe, and there were great differences of belief throughout the world concerning its origin and creation. For example, from the account given in the Old Testament, together with various secular incidents mentioned throughout the Bible,

it was thought possible to work back to a definite year when the world was created. In the sixth century a Roman monk calculated the number of years since the birth of Christ, and from this we get our method of dating as B.C. or A.D. James Ussher, Archbishop of Armagh in the seventeenth century, introduced into the Anglican Church the year 4004 B.C. as the date of the Creation.

The popular Christian belief of the Creation was held until the end of the nineteenth century and is well portrayed by Milton in *Paradise Lost*. The following lines are taken from Book VII and describe the return of the Creator to Heaven after the work of Creation :

> Up to the Heaven of Heavens, his high abode,
> Thence to behold this new-created World,
> . . . Up he rode,
> Followed with acclamation, and the sound
> Symphonious of ten thousand harps, that tuned
> Angelic harmonies. . . .
> The planets in their stations listening stood,
> While the bright pomp ascended jubilant.
> " Open, ye everlasting gates ! " they sung ;
> " Open, ye Heavens, your living doors ! let in
> The great Creator, from his work returned
> Magnificent, his six days' work, a World ! "

In Persia the past was thought to be limited to 12,000 years, whereas in India the Brahmins regard time and the earth as eternal. The discovery of historical records referring to 4241 B.C. showed that 4004 B.C. could not be the year of Creation ; but so far as earlier dates are concerned, it is not likely that similar historical records will come to light. Nature has, however, provided an extensive record in the rocks of the earth itself, and it seems likely that the estimate of just over 2 million years based on Chaldean chronology can safely be replaced by one of about 3350 million years.

Geological Time

Geology (Greek *ge*, earth ; *logos*, word) is the science that deals especially with the composition, arrangement and history of the rocks which compose the earth's crust, but most sciences contribute to the story of the past that is still being unfolded. The modern theory of the origin of the universe will be referred to in a later chapter ; it is sufficient for our present purpose to assume that the earth was originally detached from the sun, and its gaseous mass gradually cooled to form the crust which exists today.

The word " rock " in geology is used to include all constituents of the earth's crust, whether hard like granite, or soft like clay, whether bound together in large pieces, or loose like gravel. Beneath the crust of the earth very high temperatures exist, as is very evident during volcanic eruptions ; and certain rocks show that they have cooled from such temperatures. As we should expect, in such rocks there is no trace of the remains of life ; but in others there are numerous remains — or fossils — which show that originally these rocks were formed under the sea where the animals represented by the fossils could live. The importance of this subject is discussed later in connection with the theory of evolution, but we may note here that the careful classification of fossils has been of great value in discovering the order in which the various layers, or " strata ", of rocks throughout the world have been formed.

The chart on page 5 gives some idea of the time that has elapsed since the oldest of the rocks came into being. Palaeozoic (Greek *palaios*, old ; *zōon*, animal) indicates that the rocks formed during that period contain fossils of very early types of life. Mesozoic (Greek *mesos*, middle) is intermediate between Palaeozoic and Cainozoic (Greek *kainos*, new). Tertiary corresponds to the original names by which Palaeozoic (primitive) and Mesozoic (secondary) were known. Following the same idea, the period in which we are now living follows the Tertiary, and is called Quaternary : it

has extended over the last million years. The chart is to be read from the bottom upwards. The lowest system of rocks in the Palaeozoic group can be seen to good advantage at Harlech in Wales; it is called Cambrian. All rocks older than Palaeozoic are known as Pre-Cambrian. For convenience the Palaeozoic is divided into Lower and Upper groups. The column on the right indicates the order of development of plant and animal life, culminating in man.

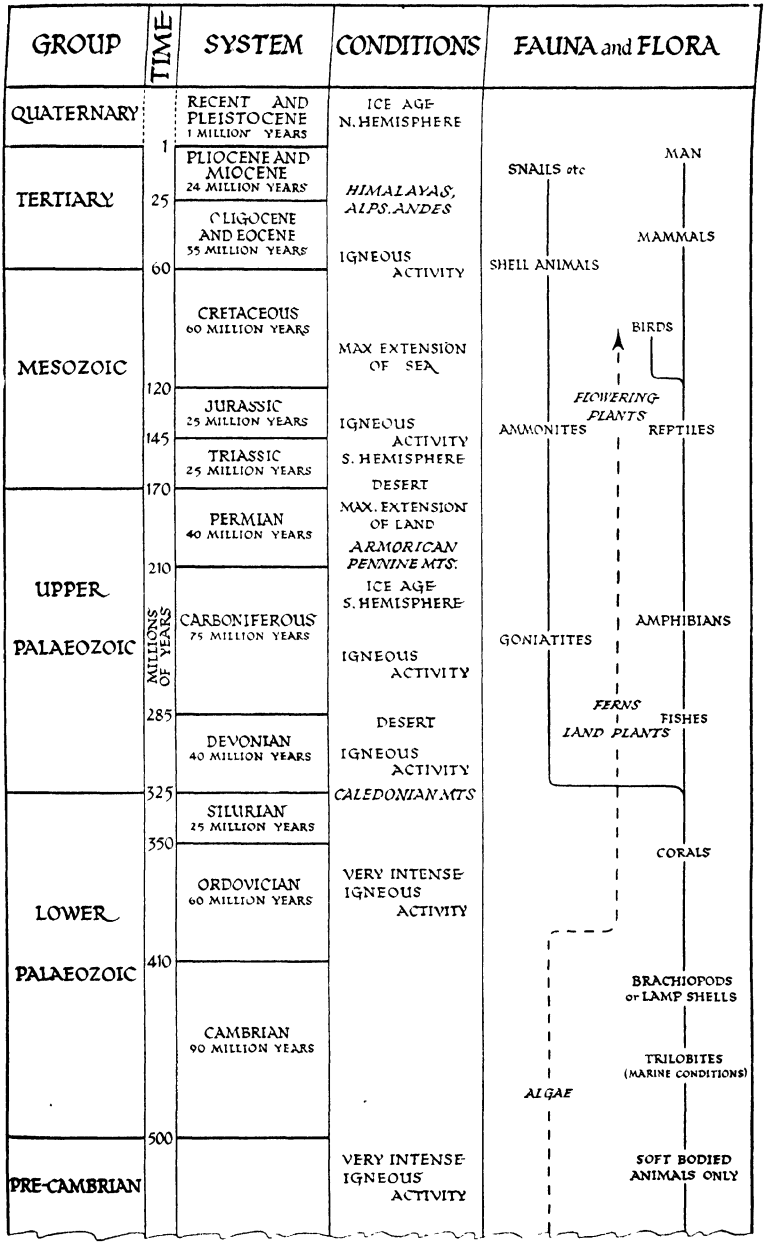
The story, as represented on the chart, has been greatly simplified ; but even so it gives some idea of the enormous lapse of time since the earliest rocks were formed, and life made its appearance on our planet. Of the countless millions of years during which the stellar universe has been evolving, no conjecture can at present be reasonably made.

Human History

One effect of the study of geology is to emphasize the comparatively recent date at which even the earliest types of man appear. Far more recent still is the beginning of recorded history. The anthropoid apes, which are the main stock from which human beings have evolved, arose during late Tertiary times. The beginning of the Quaternary period was marked by a colder atmosphere in the Northern Hemisphere, resulting in the Great Ice Age. These severe conditions drove animals to the edge of the advancing ice, and stimulated man's ancestors to hunt. Gradually weapons of stone were used, and these ultimately were developed for use as tools, and so the skill of eye, brain, hands and muscles separated the earliest men from their fellow animals.

The detailed study of the records showing the development of man from the anthropoid apes is beyond the scope of this book, but reference may be made to one interesting discovery in England. In 1908 Mr. Charles Dawson, a Sussex lawyer, noticed that a road was being repaired with an unusual kind of flint ; this turned his attention to a gravel

THE EARTH AND ITS INHABITANTS



pit at Piltdown.' Fragments of a fossilized skull were found in this pit, and in 1912 a jaw ; further digging produced most of the remainder of the skull, and all the fragments were put together by Sir Arthur Smith Woodward. It is probable that these remains represent an early form of true man, and the name of *Eoanthropus* (Greek *eos*, dawn ; *anthropos*, man) is given to this Piltdown man ; it may well be that he and his fellows lived in the early years of the Great Ice Age. It has been estimated that this ice age which was prevalent in the Northern Hemisphere probably lasted for not less than a million years. It does not appear to have been continuous, as in the Alpine region there is evidence of about four interglacial periods when conditions were less severe. The most southern limit of the ice in England was approximately a line drawn from Bristol to London.

By a careful study of the deposits of certain lakes in Scandinavia, and also of the Baltic Sea, it has been determined that about nine thousand years have elapsed since the ice retreated from the Stockholm region, and fourteen thousand since it began to recede from the south of Sweden. The retreat of the ice in Germany was at a still earlier date. The ten or twenty thousand years that have passed since Europe was held in this glacial grip seem a long period in comparison with the recorded pages of history, yet when compared with the million years of the Great Ice Age it is obvious that, from the point of view of geological time, we are only just emerging from that age. Again, from the point of view of the hundreds of millions of years since life was first manifest on the earth, the time of man's emergence and particularly of recorded history sink into insignificance.

Science and Its Background

But this insignificance is in relation to time only. The story of science and its background reveals another aspect of human progress, measured not so much in terms of time as of achievement. Successive chapters will unfold the

results of man's attempt to conquer Nature. First the dim dawn of civilization, with its ultimate development on the banks of the *Great Rivers*. Then the settlements on the shores of the *Mediterranean*, with the inspiration of Greece and the organizing power of Rome, followed by the slower pace of the Middle Ages, but ending in a rebirth of the spirit of inquiry, and the discovery of the Americas, known as the New World. Lastly, with contributions from both sides of the *Atlantic*, the spirit of modern science culminates, in the twentieth century, in a *World* Period, and is ready and able to break down the barriers of time and distance.

So the great drama unfolds, and through successive phases, moving always towards the west — Rivers, Mediterranean, Atlantic — the growth of knowledge and the pageant of empires proceed. Yet something still is lacking. The World Period, which science has made possible and for which science holds out such promise, is one in which strife and selfishness, want and war still hold sway. In attempting to conquer Nature, man has failed to conquer himself. Our survey, therefore, will not be complete without the recognition that, in addition to the march of empire and the progress of science, there is a third thread running through this story of achievement. It is the awakening of the indomitable spirit of man. With all his desire for *action*, and with all his search for *knowledge*, man will not be denied the *vision* of a better world, and his conviction that ultimately Tennyson's dream in " Locksley Hall " will be realized :

For I dipt into the future, far as human eye could see,
Saw the Vision of the world, and all the wonder that would be !

. . . . . .

Till the war-drum throbb'd no longer, and the battle-flags were furl'd
In the Parliament of man, the Federation of the world.

The story of science and its background as portrayed in the following pages does not therefore end when the latest discovery has been noted, or the most recent theory put forward. It is a living record of men and their endeavours,

of success and failure, and as such cannot proceed to a note of finality. The last chapter looks forward, in the hope that by recognizing their true place in Nature, men may also realize their true relationship to one another, and transform the international conflict of the past into world co-operation in the future.

CHAPTER II: THE GREAT RIVER BASINS AND THE ORIGIN OF CIVILIZATION

The Emergence of Man

In the preface to a book entitled *Man Makes Himself* (1936), Prof. V. Gordon Childe, of the University of London, writes: "Almost every statement in prehistory should be qualified by the phrase: 'On the evidence available today the balance of probability favours the view that'". Particularly is this true of any attempt to provide the background of man's emergence from the dim and distant past of unwritten history. The difficulties can easily be appreciated when it is remembered that the fossil remains of man's early ancestors, whether human or ape-like, are exceedingly rare. The articles used by early man are only likely to survive provided they were durable. Hence clothing and wooden material leave but little trace, whereas stone, pottery and metals may reasonably be expected to endure.

The division of the prehistoric period of man's activities is accordingly based on the materials that have survived, and the terms "Stone", "Bronze" and "Iron" are used to denote the successive ages in which these materials were dominant. It must be emphasized that these ages did not occur at the same time all over the world, and that any particular group of men did not necessarily pass through every one of the ages. The Stone Age is conveniently divided into two parts, the Palaeolithic Age (Greek *palaios*, old; *lithos*, stone) and the Neolithic Age (Greek *neos*, new or young). The division of pre-history into the groups already mentioned, and based on the surviving materials of primitive tools, is also, as we shall see in the next section, a suitable one for describing the economic background which

the use of these tools demanded.

The Great Ice Age, to which reference has already been made, had a considerable bearing on the nature and place of man's appearance on the earth. The man-like apes probably left Europe with the advent of the colder conditions which preceded the Ice Age, and so man's earliest ancestors may be looked for in present-day tropical regions. One discovery, in Java, is held to fill the gap between the ancestral apes and man, but the remains are so fragmentary that their evidence is not conclusive.

There is reason to believe that the continents have at certain times in their history been linked together by land connections or "bridges", so that animals both on land and in the shallow waters of the sea were able to migrate. In the same way, at the beginning of the Great Ice Age, early man is believed to have spread throughout the world. His descendants travelled far in search of food and good hunting, and ultimately four main groups are evident: African, Australian, Mongolian and European.

The species of man which includes existing human beings is called *Homo sapiens* (Latin *homo*, human being; *sapiens*, wise). The date of the emergence of this species can only be approximately indicated, bearing in mind that the earliest fragments of skeletons belong to the closing period of the Great Ice Age, perhaps 25,000 years ago. The physical differences between such men and ourselves are small, whereas the cultural differences are immense. In other words, progress in culture had already practically taken the place of further organic evolution.

Early Cultures and Skills

Man, as represented by the Piltdown finds, had reached England at any rate by the early days of the Ice Age, about a million years ago. He possessed a brain-case comparable in size to our own, though there were probably still ape-like features such as a heavy lower jaw and projecting canine

teeth. But significance attaches to the brain, which is large in comparison with the size of the body, for it is this endowment that enables man to make his own culture. Associated with the brain are other endowments. " Binocular vision " is one, which means simply that man sees with his two eyes only one picture, whereas other mammals see two. Delicate focusing muscles, together with sensations of touch, enable him to see and handle things in the solid. The co-operation of hand and eye become so perfectly adjusted that the making of weapons and tools is possible, and supersedes the mere grasping of missiles to hurl in attack or defence.

Another endowment associated with the brain is the power of speech, involving the precise control of the muscles of the tongue and larynx, and the corresponding muscular sensations, due to the movements of these organs, with the sense of hearing. In *Homo sapiens*, in addition to these developments in brain and nervous system, there is a special modification in the attachment of tongue muscles, not found in any other species of man, but making possible the production of a great variety of sounds, and distinguishing him also from all other animals. The longer period of education of the human offspring assumes a new importance when the power of speech is available, so that experience can be gained from precept as well as by example. This prolonged infancy produces family life, and speech is not only desirable there but also is a means of communication between all members of the group who have adopted the same language.

Progress in language leads to the naming of things ; and with names there is developed the power of thinking of qualities, and of abstract ideas. The beginnings of mythology and magic may well be related to the idea of endowing superbeings and animals with human attributes, such as the power of speech. An idea like that of winged men may ultimately have led to the desire to fly and the invention of a flying machine.

The presence of man's ancestors in England and other parts of Europe during the Great Ice Age indicates his power of living amid colder conditions. This was not achieved by



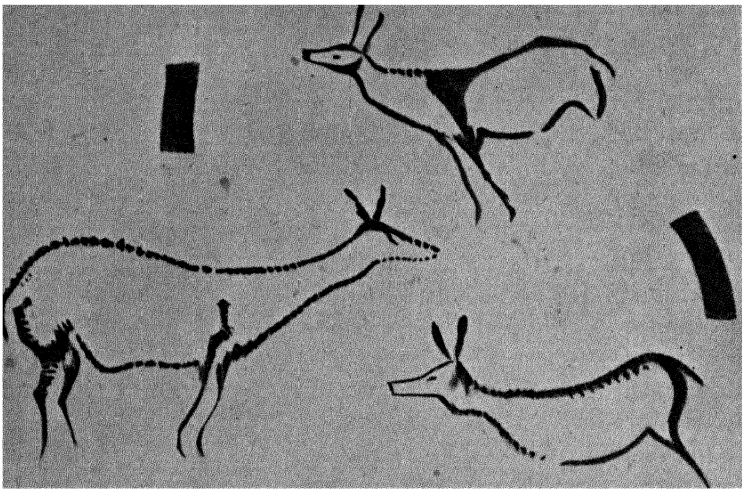
Courtesy of the American Museum of Natural History

Prehistoric man, having learned to make fire, discovered that it could be carried about and used to illuminate his cave shelters. The picture is a mural in the Hall of Man in the American Museum of Natural History, and represents men drawing the famous " Procession of Mammoths " in the Cavern of Font de Gaume, Dordogne, France. Painting by Charles R. Knight

his body developing a shaggy coat like the mammoth, but by the improvement of his material culture involving the control of fire and the making of protective coverings from the skins of the hunted. Fires, at first produced by natural means such as lightning, would be tended, preserved and never allowed to go out. In Roman mythology Aeneas brought the sacred fire from Troy to Italy, where it was guarded by the Vestal Virgins, who had dedicated themselves to " Vesta ", the goddess of the hearth. Control and distribution of fire would, ultimately, be followed by its artificial production, such as the spark made by striking flint against iron pyrites. Control of fire must have been one of the first steps in the emancipation of man from his environment, and its production a matter of no small wonder. Man's attitude to fire distinguishes him from the behaviour of other animals, for in this he assumed control of one of the great forces of Nature.

The inter-glacial periods, when conditions were milder, enabled man to develop his weapons and implements. He frequently lived in caves, and from them we have a glimpse of his activities before the end of the Great Ice Age. The well-known paintings at Altamira in Spain were discovered by chance in 1879. The Marquis of Santuola, accompanied by his small daughter, was exploring a cave on his estate when the child, who was carrying a lighted candle, suddenly called to her father " Toros ! Toros ! " (*toro* is the Spanish for " bull "), and pointed to coloured figures drawn on the ceiling. The illustration on page 14 shows drawings of deer drawn on the wall of a cave in northern Spain.

Perhaps here in these early forms of art are the beginnings also of primitive religion, for it is generally supposed that the cave paintings had some magical significance, no doubt to ensure good hunting. The use of pigments is in itself a skill. There were also elaborate methods of burial, which included the charms that had been worn in life, and a quantity of red ochre to supply blood for the next existence. Art, religion and family life had been developed before the final retreat of the ice ; but man was still a nomad, wander-



From M. C. Burkitt's "Prehistory"

Photograph of a prehistoric drawing of a group of Hinds in red from a cave at Covalanas, northern Spain

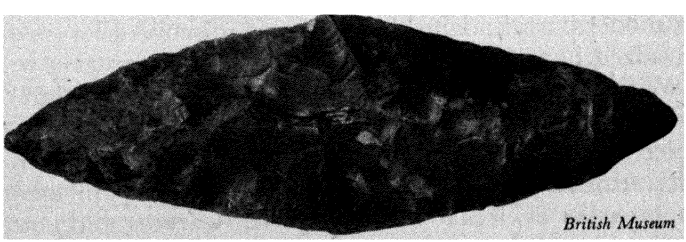
ing to those regions where the hunting was best. Towards the close of the Ice Age more elaborate implements of stone were made, and bone was used as well.

Thus there developed between about 20,000 and 10,000 B.C. a considerable amount of skill in shaping various materials and, as is natural, a number of tools for the purpose. Early man began to foreshadow the skilled mechanic of today. Not only were flints shaped into forms hitherto unknown, but also work was carried out in bone, horn and ivory. Some of the flints have a "tang" (the end of a tool which is driven into its haft) so that handles could be attached to them; others have serrated blades for sawing. Awls, drills and graving tools were made. Needles appear to have been made from bones by splintering and boring a hole for the "eye". "Throwing-sticks" were probably a means of increasing the propelling power of the human arm. Though apparently bone implements were polished, this process was not extended to flints until the Neolithic or New Stone Age.

The Beginnings of Civilization

After the close of the Great Ice Age, man continued his nomadic life in search of food, and there seems to have come into western Europe a race of men who had progressed to such an extent that they were able to conquer the decadent races of the Old Stone Age. These conquerors are known as Neolithic men. The masses of empty shells of edible shell-fish, especially round the coast of Denmark, are believed to mark the sites of their living places or those of their immediate predecessors. The accompanying photograph of a Neolithic axe-head gives some idea of the skill in craftsmanship that had been acquired.

The significance of tools and other archaeological remains lies, however, not only in the degree of technical skill and knowledge attained, but also in the general mode of living which they reveal ; in other words, their economic background. Each succeeding age, whether stone, bronze or iron, may be considered as inaugurating an economic revolution comparable to the " industrial revolution " of the eighteenth century. Thus the men of the Old Stone Age were restricted in numbers owing to their reliance on hunting, fishing and gathering wild berries, roots, slugs and shell-fish. Their weapons and tools were limited, and community life presumably not developed. We shall see that in the New Stone Age men began to control their food supply, and also animals. With the increase of food the population was able



A typical flint " axe "

to expand, and permanent settlements became common. The Bronze Age demanded specialized industries and organized trade, with such a surplus of foodstuffs that would support the miners, smelters and smiths. The Iron Age again expanded trade, and because the ores were widely and plentifully distributed, tools became cheap and the clearing of fresh land made possible for increased food production.

But to return to the New Stone Age. The introduction of agriculture is attributed to these Neolithic peoples. It may be conjectured that, with a dearth of reindeer and the spreading of a thick growth of forest across Europe, man was reduced to a diet of fish and wild fruit. But there is doubt as to the place of origin of agriculture. A plausible theory suggests the Nile Valley, where wild ancestors of wheat and barley are probably native. The regular overflowing of the Nile banks, caused by the monsoon rains on the Abyssinian plateau, was conducive to the growth of these wild grasses. The desirability of obtaining food easily would lead to the use of such grains long before formal cultivation began. Handfuls of seed thrown on the wet silt left when the Nile flood receded would multiply, and such a procedure could easily become a recognized method of obtaining food. How the final step was taken that led to cultivation we cannot expect to discover. Perhaps a woman was responsible ; this may be pure speculation, but nevertheless it was the goddess of corn who earned the grateful thanks of the Egyptians as Isis ; the Asiatics, as Cybele ; the Greeks, as Demeter ; the Romans as Ceres, and remembering that her Roman name is perpetuated in our household word " cereal ", we can add our modern gratitude to that unknown discoverer of the first organized harvest.

With the rise of this primitive agriculture, the hunters had less need to roam in search of food, and so a more settled state became possible. Social improvements naturally followed. The crafts of spinning and weaving supplemented man's earlier devices to clothe himself. Carving and pottery developed. Ultimately, as will be seen in the next chapter, stone implements gave way to bronze, and then followed

iron. Building materials became more varied, and devices for moving them involved the basic principles of the lever and the wheel. Transportation by water was improved by the use of a sail. The cultivated clearing was doubtless accompanied by the domestication of animals, and gradually the hunter acquired the arts of stock-breeding and farming. The wheel, the sail and the domestication of animals have been described as three of the most important inventions in human history.

All the activities which have been mentioned can justly be associated with the beginnings of civilization. Some sort of organized society was showing itself. Peril and want had sharpened man's intellect, and the advantages of community life became evident if he was to succeed in the long struggle with Nature on which he had entered. There arose also the peasant, who for centuries upon centuries has lived close to Nature, and through the regularly succeeding seasons of summer and winter, cold and heat, has proved himself a skilled worker of no mean order. Ploughing, sowing, reaping, tending stock and battling with the elements, there has come to man that urge to look ahead and plan. Patience and perseverance, so essential in engineering skill, enabled Neolithic man to develop into more than a mere maker of implements ; he was a fitter — he could assemble parts and erect structures. Initiative and resourcefulness were emerging.

One of the most remarkable features of the life of primitive man is the almost universal acceptance of religion. Prof. A. N. Whitehead traces in human history four factors or sides of religion : ritual, emotion, belief and rationalization (in which beliefs and rituals are adjusted to make religion the central theme in a life which is ordered, both in thought and conduct). Ritual goes back beyond the dawn of history and is discernible in the period under discussion. Just as flocks of birds, such as rooks and starlings, perform their ritual evolutions in the sky, so man takes his place in the primitive communities. He follows a ritual by repeating the actions necessary in hunting for food, or in other useful

pursuits, and in their repetition he repeats also the joy of the chase and the emotion of success. Ritual, the first factor in religion, though not the most important, is already present before men settled into the more highly organized communities of towns and cities.

The Rivers Period

We have seen the results of man's early strivings in art, craft and religion. The development of agriculture and the consequent improvement in social conditions depended ultimately on a sufficient water-supply for the crops, as well as for drinking. The Nile has already been mentioned in connection with the origin of agriculture, and we should expect similar settlements round other great river basins. The great change in economic conditions due to the introduction of agriculture took place gradually, and the effects of this Neolithic revolution were evident in the settlements of the New Stone Age which sprinkled the area from the Nile and the Eastern Mediterranean across Syria and Iraq, to Iran and the Indus Valley beyond. A part of this area has been aptly described as the " Fertile Crescent ", and includes the Nile delta, Syria and the alluvial tract of the Tigris and Euphrates, formerly called Mesopotamia (Greek *mesos*, middle ; *potamos*, river), which now approximates to the State of Iraq.

Somewhere within the area roughly extending from the Nile to the Ganges, and some time between 6000 and 3000 B.C., man had learnt to harness oxen, and had invented the plough, the wheeled cart and the sailing boat ; he had discovered the art of smelting copper ores, and had started on an accurate solar calendar. Such progress is remarkable both with regard to its speed and also the importance of the discoveries made. It paved the way for the urban and community life of recorded history.

With the assurance of adequate water, which also supplied easy and safe transport by boat, there arose on the

river-banks civilizations which quickly developed from the beginnings which have already been traced. A convenient term to denote this early epoch is the Rivers Period, and during this time considerable knowledge was acquired. The need for protecting flocks, especially at night, provided opportunity for watching the apparent movement of the heavenly bodies. The beginnings of science can be traced from the men of the New Stone Age to the craftsmen and astronomers of Egypt and Mesopotamia.

CHAPTER III: EGYPT AND MESOPOTAMIA

Progress in Civilization

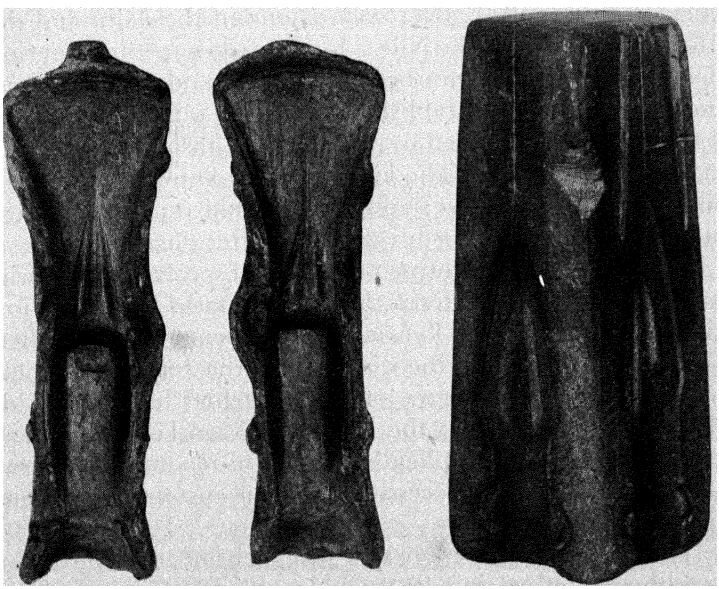
IT is not to be expected that the advantages of agriculture and the possibility of settled life would be realized at the same time by all the various races of mankind. Hence the early stages of civilization are found to occur in different parts of the world at different periods. Further, when agriculture had been accepted, there still remained the problem of finding a suitable site for permanent settlement. Towards the end of the fifth millennium before Christ, there are records of organized social life in Egypt, so that tribes who had knowledge of agricultural practice had by then found in the Nile Valley and delta a suitable area for domestic life. But such a settled life did not prevail everywhere, and though the New Stone Age was about to end in Egypt, it was many centuries before the same could be said of Europe.

The beginnings of peaceful and ordered life in Egypt were quite simple, but there were three discoveries which had an important bearing on the future of civilization. The first was the invention of a *calendar*. This was introduced about 4241 B.C. and superseded the earlier methods of reckoning by the moon-month. The Egyptian calendar consisted of twelve months of thirty days, and the difference between this and the solar year was adjusted by the addition of five days holiday feast at the end of the twelfth month. According to legend, these five days had been "won" at play by the moon-god Thoth from the moon-goddess. To identify the year it was given the name of an important event which had occurred during that year. Later the name of the king and the number of the year of his reign were used.

The second important discovery was that of the *smelting of metals*. This was probably made by chance, about 4000 B.C.

A traveller in the Peninsula of Sinai may have banked up his fire one night with stone which was copper ore, and in the morning have been surprised to see metallic coloured fragments glittering amid the wood ash. For some centuries copper was produced in this way by roasting the ore, and was only used as an ornament by women ; but ultimately the method of casting the metal into a blade was discovered. Admixture with tin, as bronze, was found to produce a harder edge and was employed for tools and weapons. The illustration shows two ancient moulds used for casting.

The third discovery was of a different nature. Early man had already used pictorial signs for sending messages, but it was the Egyptians who made the first *alphabet*, and this was developed from picture writing. For example, the figure of a rectangle with an opening represented a house. In course of time this figure was associated with a definite sound. An



British Museum

Man has discovered that metal implements can be produced by pouring the molten metal into carefully made moulds

alphabet of twenty-four letters was actually in existence before 3000 B.C. Papyrus grass cut into strips and fastened in position with gum was used as paper. Pointed reed nibs were charged with ink which consisted of water made thick by the addition of gum and soot.

The invention of easy writing may have had a greater influence in the uplift of mankind than any other intellectual achievement. Men were no longer limited by the need for personal contact for the exchange of news and views: records could be made of the traditional tales, and a beginning is apparent of the historical record. More important still, writing made possible a coherent form of government.

The Organized State

About the middle of the fourth millennium B.C. there emerged two central governments, one in the delta and the other in the valley of the Nile ; but in 3400 B.C. after a period of fierce fighting, Menes brought Upper and Lower Egypt under one rule and established what was ultimately known as the First Dynasty, and by 3000 B.C. an absolute monarchy had been developed. The king was now known as Pharaoh (meaning the Big House) and the Pyramid (an even greater palace) was required for his existence after death.

The farm labourer formed the basis of society, and he was also called upon to perform the haulage tasks in connection with the building of the Pyramids. The next grade was filled by the craftsmen, and the diversity of the remains of their craft show the high degree of skill that had been attained. Then came the scribes, the intellectual workers who were responsible for the complicated system of records in government, and in business, necessitated by the custom of payment in kind.

The three classes of workers just mentioned were under the influence of rulers with varying power. First were the priests, responsible not only for the public ritual associated with the temples throughout the land, but also for the wor-

ship of the dead, which was an important part of Egyptian religion ; secondly were the nobles, who seem to have had their fill of the luxuries and pleasures of life ; finally, Pharaoh himself. Pharaoh was revered as the son of the great god Ra, in whose body gold took the place of blood ; by magical powers this gold was transferred to the veins of Pharaoh, and at the latter's death as much gold as possible was buried with him to maintain his life in the next world.

Magic was held in high esteem in the life and thought of the ancient world, and it will be seen later that one of the first tasks of the early men of science was to attempt to break down such superstition and replace it by a scientific approach.

Mesopotamia

There has been considerable controversy as to whether the Egyptian or the Mesopotamian civilization is the older. For the present purpose, however, it is intended to review briefly the progress made in the area of south-west Asia, while Egypt was developing along the lines already indicated.

The rivers Tigris and Euphrates, on their long course from the mountains of Armenia to the Persian Gulf, provided a fertile area, which though liable to flood, proved suitable for early settlement. The influence of this civilization was more far-reaching than that of Egypt, owing to the importance of its position between East and West. There were two centres, the earlier a Semitic one at Akkad in the north, and the other in the south known as the Sumerian with its capital at Ur. By the end of the fourth millennium B.C. the Sumerians had reached an advanced stage of civilization. They wrote with a bevelled reed pen on soft clay tablets, and their wedge-shaped picture signs are referred to as cuneiform (Latin *cuneus*, wedge ; *forma*, shape). Their buildings were solid and massive, and recent excavations at Ur have revealed a tower some three hundred feet in height, perhaps the origin of the Tower of Babel mentioned in the Old Testament. Craftsmanship in Mesopotamia reached a

standard almost equal to that of Egypt ; the lavish scale of burial included numerous articles made of gold, such as helmets and daggers. At the death of a king, his court and servants died also — perhaps by drinking poison — and were buried with him, ready to continue their service in the next world.

About 2100 B.C. another Semitic tribe appeared, and ultimately one of their kings, Hammurabi, ruled the whole of Mesopotamia from Babylon. He was a good organizer and his code of laws, engraved on a stone which is now in the Louvre at Paris, dates from the twentieth century B.C. This code of laws reveals a poorer class, destined for the soil, small tenants, tradesmen, a strong military class, priests, nobles and governors, and above all the king, an autocrat. There was an elementary sense of justice, and widows and orphans were protected ; and though a well-disciplined sense of obligation to the community is in evidence, there was never a democracy.

In the fourteenth century B.C., the Hittite tribes from Asia Minor which possessed the iron mines on the south coast of the Black Sea set up a kingdom on the Euphrates, but were ultimately driven back, and the Assyrians appeared as an important military power. By the eighth century B.C. the Assyrian Empire had become the most extensive the world had seen. Nineveh its capital extended for two and a half miles along the banks of the Tigris. Roads were established with a regular system of posts, whereby reports were received from the governors of the sixty districts into which the Empire was divided ; and new military weapons were devised.

The military power of Assyria was not destined to last long. Almost the whole population was conscripted into the war machine. A revolt broke out under a subject-prince who afterwards formed an alliance with the rising power of the Medes from the country south of the Caspian Sea, known as Chaldea. Nineveh fell in 612 B.C. This Chaldean Empire flourished under Nebuchadnezzar (604–561 B.C.), who made its capital Babylon so resplendent that the Hanging Gardens

built on the roof of the Royal Palace were regarded as one of the Seven Wonders of the World. The city was carefully laid out and is one of the earliest and best examples of town planning. The first bridge of which we know was constructed over the river Euphrates. Under Nebuchadnezzar art and industry flourished and the foundations of astronomy were laid by the Chaldeans. But their rule did not survive and proved to be the last Semitic empire. A hardier race, the Persians, entered Babylon without resistance in 539 B.C. under their king Cyrus.

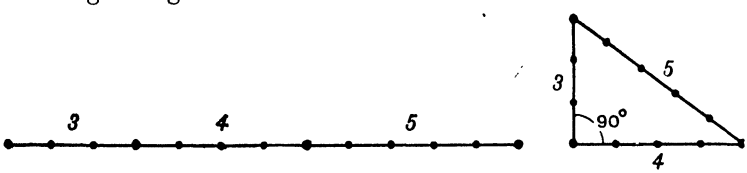
The Threshold of Science

The brief survey of civilization in Egypt and Mesopotamia made in this chapter has revealed an improvement in both theory and practice on the earlier achievements of the New Stone Age. In fact, the strides made had brought man to the threshold of Science, the beginning of systematic knowledge.

As a prelude to any scientific progress there must be a means of recording, a framework of time within which to record, and a system of measurement: an alphabet, a calendar and a system of counting. All these were made possible in these early civilizations. The Babylonians used two systems of counting, one based on 10 and capable of running into the hundred thousands, and the other based on 60 for mathematical and astronomical purposes. From the latter we get our division of hours into sixty minutes, and minutes into sixty seconds; and a similar division of degrees (used for measuring angles) into minutes and seconds of arc.

In astronomy many preliminary observations had been recorded. A particularly noteworthy piece of work by the Chaldeans was the discovery of the *Saros*, a period of 6585 days, or little more than 18 years, in connection with the recurrence of eclipses. Of the planets, Mercury, Venus, Mars, Jupiter and Saturn had been observed. These five planets, together with the sun and moon, formed, from early

times, the basis of the week of seven days. This correspondence can still be seen in the English Sunday (Sun), Monday (Moon) and Saturday (Saturn), and in the French *mardi* (Mars), *mercredi* (Mercury), *jeudi* (Jupiter) and *vendredi* (Venus). Astronomical observations were also carefully made by the Egyptians ; for example, they recorded more than 350 solar and 800 lunar eclipses before 300 B.C. Geometry (Greek *ge*, earth ; *metron*, a measure) and surveying were essential in lands subject to floods, where land-marks of private property were likely to be obliterated. In Egypt the " rope-stretchers " were responsible for obtaining a right angle. They used a rope of length 12 units and divided by knots into sections of 3, 4 and 5 units. When the rope was stretched, a triangle could be formed, as shown in the figure, and the angle opposite the side of length 5 units would always be a right angle.



The 12-unit rope used for land measurement in Egypt

The oldest known mathematical treatise, dating from between 2000 and 1700 B.C., comes from Egypt and is known as the Ahmes Papyrus. The scribe Ahmes begins with these words, "Direction for attaining knowledge of all dark things". The document contains rules for finding the volumes of barns and the areas of fields ; fractions are used as well as whole numbers, and problems are solved similar to those which, in the language of algebra, involve one unknown. References occur to writings five hundred years older.

On the more practical side, considerable experience was gained of irrigation canals, and the control of water. Building made great progress, and some idea of the results achieved can be gained from the dimensions of the Great Pyramid. More than 2 million blocks of limestone were used, each block averaging $2\frac{1}{2}$ tons in weight. The basement stones

THE RIVERS PERIOD

ACTION		KNOWLEDGE	VISION	
B.C.				B.C.
5,000				5,000
		ORGANISED SOCIAL LIFE IN EGYPT		
4,000		SMELTING OF METALS	The Calendar	4,000
	Egyptian Dynasties founded (?)			
		THE PYRAMIDS		
	Advanced civilization in Mesopotamia			
3,000		HIGH STANDARD OF CRAFTSMANSHIP	The Alphabet	3,000
	Civilization in Crete		Cuneiform writing in Sumeria	
2,000			Hammurabi (Babylon)	2,000
		THE 'AHMES' PAPYRUS	Abraham	
	Hittites on the R. Euphrates			
	The Fall of Troy		Moses	
	Phoenicians in the Mediterranean			
1,000	King Solomon			1,000

weigh 46–57 tons. This means that nearly 6 million tons of stone were quarried, transported and erected. The base was about 250 yards square, and height 480 feet. (The spire of Salisbury Cathedral is 404 feet high.) The error in setting out the base is almost negligible, being less than a hand-breadth. 100,000 men are said to have been employed for twenty years. The earliest known " working drawing " dates from 2400 B.C.

Methods of transportation were developed, involving the use of levers, sledges, rollers, wheels and lubricants. Roads and bridges were constructed, and the primitive boats of early man improved and sails used. The discovery of copper and the use of bronze paved the way for the scientific extraction of metals from their ores and the manufacture of alloys.

Much experience and considerable knowledge had accumulated in Egypt and Mesopotamia, and despite superstition and primitive beliefs, man is seen standing on the threshold of science. As the great empires of the Rivers Period fade, the scene moves westward to the shores of the Mediterranean Sea. In the civilization of the East, in India and China, there is little evidence of outstanding achievement in science. The philosophical and contemplative approach to life is specially characteristic of these countries, and although to India may be traced the origin of Arabic numerals, so valuable in calculation, and to China may be attributed the invention of gunpowder, the making of paper, and a means of detecting the direction of earthquakes, these are isolated achievements rather than factors leading up to an organized system of knowledge. Until the comparatively recent impact of Western ideas on the East, there is little trace of the scientific spirit among teachers and leaders. The present survey, therefore, is confined to the growth of science as it is revealed in the trend of civilization westward.

CHAPTER IV: PHILOSOPHY OR SUPERSTITION?

Early Mediterranean Civilizations

WHILE the civilizations described in the last chapter were leading men to the threshold of science, the inhabitants of Europe were comparatively uncultured and unlettered. Gradually the European acquired the peaceful arts of agriculture, and of living in huts and villages, and also the use of metals. Into this passive atmosphere, however, during the second millennium before Christ, there came different and more forceful peoples from the adjacent lands of Asia. Their names and places of origin are lost in obscurity, but enough has survived of their language, which is now known as Indo-European or Aryan, to associate them with the Persians and Indians. There is no scientific basis for the existence of an Aryan "race" on which the Nazis in Germany based so much propaganda.

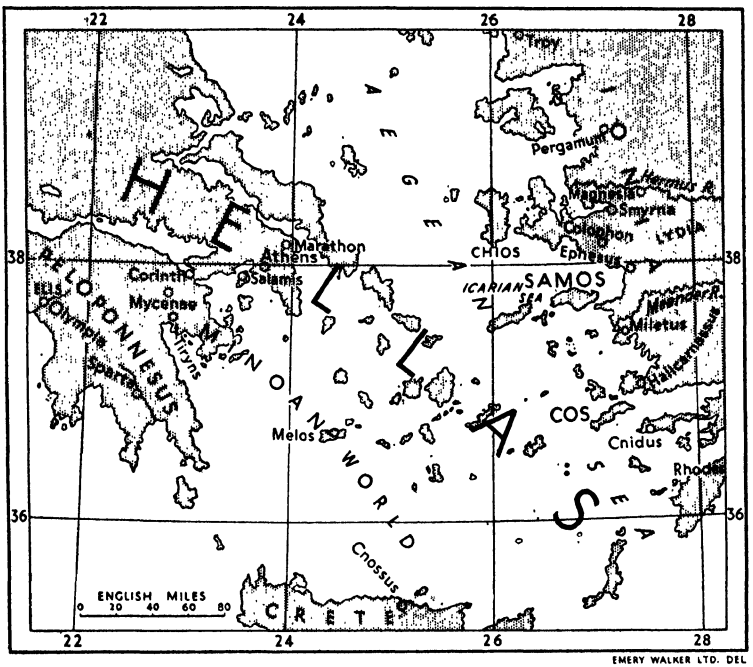
The invaders did not obliterate the former inhabitants of Europe, but introduced into their primitive civilization two factors destined to be of supreme importance in subsequent periods of peace and war. These were the domestication of the wild horse, and the use of iron, which proved decisive against the softer weapons of bronze. From the mixture of these Asiatic tribes with the early dwellers in Europe spring the races who have been responsible for the subsequent development of Europe — the Greeks and Latins, the Celts, Teutons and Slavs. Despite the claims made between the First and Second World Wars on behalf of the German nation, purity of race does not exist in Europe.

There were also other influences at work. Before the invasions of Europe from the mainland to the east, civiliza-

tions were flourishing in the Eastern Mediterranean, though their remains have only been brought to light in comparatively recent times. The evidence is convincing, and gives credence to much that was previously but legend. It is significant that the attempt to produce the evidence was made during the second half of the nineteenth century, when the spirit of scientific inquiry was beginning to leaven all departments of human activity. The name which will always be associated with this work is that of Heinrich Schliemann, a German archaeologist who was born in 1822. As a boy he was so enthralled by the stories of Homer and the Trojan War, that he learnt Greek in the intervals between serving in a small grocer's shop, and determined that one day he would find the site of the ancient city of Troy. After a series of misfortunes, which included shipwreck while serving as a cabin-boy, he ultimately made a fortune in America; and when nearly fifty years of age set out to fulfil his boyhood's ambition. As a result of excavations the position of Troy was located on the southern shore of the entrance to the Dardanelles, and much valuable information obtained with regard to the nine cities built successively on the site.

At a later date Schliemann turned his attention to the mainland of Greece, and excavated the fortress castles of Mycenae and Tiryns to the south of Corinth, thereby revealing another early civilization. It only remained at the beginning of the present century to explore the evidence for the legendary King Minos of Cnossus in Crete. This time the work was undertaken by an Englishman, Sir Arthur Evans of Oxford, and once more the evidence was convincing, and the palace of Minos was revealed with its complicated system of halls, staircases and passages, genuinely described as a labyrinth.

The early civilizations thus brought to light — the Cretan, the Mycenaean and the Trojan — have all had their influence on the building up of what ultimately became Greece. When it is remembered that the great civilizations of Egypt and Mesopotamia also made their contributions,



The Aegean Sea and neighbouring countries

and that the influence of the Eastern invaders is present as well, it is not surprising that the rich Greek culture ensued, which enabled man to pass from the threshold of science to the very beginnings of systematic knowledge.

Thales of Miletus, and Philosophy

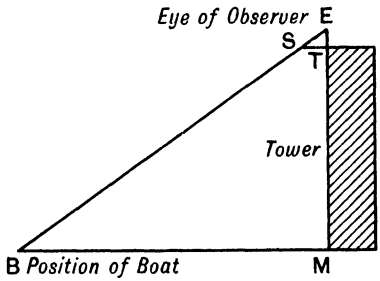
At the beginning of the first millennium before Christ, men of the stock of the Eastern invaders were established on the coast of Asia Minor, the islands of the Aegean, and in Greece itself. The sea played an important part in the relations between these peoples. One clash, in the twelfth century B.C., has been made immortal in Homer's *Iliad*, a story, probably dating from the ninth century B.C., of the

struggle between the dwellers on the Greek mainland and the Phrygian inhabitants of Troy.

By the eighth century B.C. power in Greece was largely in the hands of a number of city-states, in which loyalty to the city took precedence over loyalty to the country. This development was due largely to the mountainous nature of the latter, which made communication between its different parts difficult. The year 776 B.C. is the one from which the Greeks dated their events, and was known as the first Olympiad, from the Olympic Games held every four years. In these games Greeks from far and near took part in contests held in honour of Zeus at Olympia in the north-west of the Peloponnese. To this eighth century also belongs the traditional date of the founding of Rome. (753 B.C.), and the building of Carthage by the Phoenicians from Tyre (800 B.C.). In Palestine the eighth-century prophets were proclaiming to the Jews that what God really demanded from men was justice, mercy and humility rather than sacrifices and burnt offerings. Thus the three influences to which Western civilization owes so much — the Greek, the Roman and the Hebrew — were all represented in that *eighth century*.

It was, however, the coastal regions of Asia Minor that produced the pioneers of philosophy and science in the seventh and sixth centuries B.C. A brilliant group of Ionian cities, among which Miletus was outstanding, had sprung up on the eastern borders of the Aegean, and it is from among this civilization that the first name appears in the long story of science. *Thales of Miletus* (*c.* 624–565 B.C.) is reputed to have visited Egypt, and from the practical use made there of geometry he was able to formulate certain general theorems, such as the well-known one concerning the squares on the sides of a right-angled triangle generally known as the Theorem of Pythagoras. He also discovered that the angles at the base of an isosceles triangle are equal, that when two straight lines intersect the vertically opposite angles are equal, that the angle subtended by the diameter of a circle, at any point on the circumference, is a right angle;

that the sum of the angles of a triangle is two right angles; and that the ratio of the corresponding sides of equiangular triangles remains constant in any such set of triangles.



In particular, the last proposition enabled him to ascertain heights or distances by using a stick and comparing similar triangles. Thus the distance of a boat B from a tower TM can be found by using a horizontal stick ST adjusted so that the observer's eye, E, the end of the stick, S, and a convenient point B in the boat, are all in one straight line. Then since the triangles EBM and EST are similar,

$$\frac{BM}{ST} = \frac{ME}{TE},$$

and as ST, ME and TE can all be measured, the unknown length BM can be calculated.

But Thales' interests were not confined to geometry; he was an engineer, a merchant, statesman, astronomer. His reputation in the latter role was much enhanced when his prophecy was fulfilled, "that night would enter upon the day, the sun hide himself, the moon place herself in front, so that his light and radiance would be intercepted". The predicted eclipse is probably the one of 585 B.C., and as a result (according to the Greek historian Herodotus, 484–425 B.C.) the Lydians and Medes, who had been at war for six years, both became desirous of peace.

It is, however, as a philosopher that Thales is best known, for he broke away from the old idea of the legends of gods and goddesses taking a practical part in the affairs of men. To him the whole universe was natural and possible of explanation by ordinary knowledge and inquiry, and though his own theory that water or moisture is the essence of all things was wide of the mark, it is in the true spirit of philo-

sophy that such matters should be discussed and investigated. Philosophy comes from a Greek word meaning "love of wisdom" and it involves the study of the causes or laws of what is observed. Thales asked questions about the nature of the universe, and used his powers of reasoning to answer them instead of merely accepting traditional views. Such an attitude is a necessary prelude to any scientific work, and is as fundamental in the twentieth century as when its value was first realized in the school of philosophy that centred around Miletus.

Greece and Persia

Miletus may be regarded as the birthplace of European philosophy, but this title to fame was short-lived. Though the immediate successors of Thales maintained his attitude in dealing with the problems of the universe, it was only a matter of some fifty years after his death that the city sustained the complete annihilation of its population at the hands of the Persians — its men slain, and its women and children deported. The transition had been brief. Cyrus, King of Persia, with horsemen and long-range archers, had advanced towards the west, defeating Croesus, the fabulously wealthy king of Lydia, and occupying the Ionian cities of Asia Minor. The latter revolted and, though supported by the Greek mainland, the revolt was crushed ruthlessly.

Lydia had been the buffer State between Greece and Persia, and the Greek support that had been given to the revolt brought Athens face to face with the great oriental power. Thanks to the work of Solon at the beginning of the sixth century B.C. and the democratic reforms of Cleisthenes at the end of the century, the Athenians were united in their determination to sacrifice everything in the defence of the democracy that they had so recently achieved. The battle of Marathon was the result. In the summer of 490 B.C. the blow fell, and some nine thousand Athenians defeated a Persian army of at least double that number which had landed to the north of Athens. Pheidippides the runner,

having been dispatched to Sparta for aid, a distance of some seventy miles, on returning took part in the battle. He then covered the twenty-six miles from Marathon to Athens, and as he reported the victory to the fathers of the city, he died with the word " *nikomen* "— we conquer — on his lips. Browning recalls this feat of endurance in his poem, " Pheidippides ", and the victory of democracy over despotism which it marked has been commemorated in recent years in the annual international Olympic Games, one of the chief features of which is a " Marathon Race " — a cross-country run of twenty-six miles corresponding to the original distance from Marathon to Athens. An annual Marathon Race, from Windsor to London, was instituted in 1909.

But Persia was still a menace to Greece, and it was again fortunate that another statesman, this time Themistocles, advocated the maintenance of a powerful Greek navy. At the same time silver had been discovered at Laureion, in southern Greece, so that payment for equipping the navy and strengthening the land fortifications was made possible. In ten years, Persia under Xerxes was strong enough to make another attempt, but finally at Salamis a naval victory sealed the ultimate fate of the oriental empire. The result was a triumph materially, but even a greater one in the realm of the spirit. The weak in numbers had conquered the numerically greater ; the defenders of democracy had defeated dictatorship ; those who were believers in freedom and humane feeling had outwitted the autocracy of cruelty and oppression. A further clash with Persia took place in the middle of the fifth century B.C., which resulted in the coasts of the Aegean becoming safe for the Greeks, and ushered in the age of Pericles with its achievements in art and architecture, drama and human affairs through which Athens has had a noteworthy influence on European culture.

The policy of Pericles, democrat and imperialist, was to make the influence of Athens dominant throughout the Western Mediterranean, and to build the city itself into one befitting a great empire.

Hippocrates of Cos, the Physician

It is to the outlying island of Cos, near the peninsula of Cnidus in Asia Minor, that we must turn to appreciate the work of one who has been called the Father of Medicine. *Hippocrates* (born *c.* 460 B.C.) came of a family of physicians, and there were medical centres both on Cos and at Cnidus on the mainland. The significance of his work, and of the school of medical practice associated with him, lies in the emphasis on a "natural" rather than "supernatural" origin of disease and its treatment. Thales believed that the universe could be explained by reason; Hippocrates, adopting the same attitude, put that belief to the test in relation to the human body. Just as Thales dispensed with mythology in his explanation of Nature, so Hippocrates broke with superstition in his treatment of disease. In fact, through the Latin of the Middle Ages, his doctrine has come down to us as *vis medicatrix naturae* — "the healing power of nature" — and all the refinements of modern medicine and surgery are to enable Nature to exercise this power more efficiently.

As an illustration of the hold of superstition, the case of epilepsy or "falling sickness" may receive special notice, as it was regarded as a divine visitation and called a "sacred disease". The treatise on this disease, written before 400 B.C., shows the truly scientific approach of what has been called the "Hippocratic Method": "As for this disease called divine, surely it has its nature and causes, as have other diseases. It arises — like them — from things which enter and quit the body, such as cold, the sun and the winds, things ever changing and never at rest. . . . All have their antecedent causes which can be found by those who seek them."

The idea of being "stricken" by God has persisted despite the work of Hippocrates, and such "acts of God" have sometimes included infectious diseases. We are reminded of this in the word "plague", which comes from the Latin *plaga*, meaning "blow" or "stroke".

No account of Hippocrates would be complete without

a reference to the Oath which bears his name, and which is an excellent code of professional life. The Oath is still taken by medical men, and is a tribute to Hippocrates' keen sense of duty, impartiality and interest in all that affects the patient's welfare. The seriousness of the Oath, in its original form, is emphasized by its reference to Greek religious belief. Two names mentioned have become especially familiar in "hygiene" (Greek *Hygeia*, the goddess of health, daughter of Asclepius, the god of medicine) and "panacea" (Greek *pan*, all; *akos*, remedy). The Oath itself pays respectful tribute to those who teach the art of healing; and the following extract shows the responsibility of the physician to his patients. "I will follow that method of treatment which according to my ability and judgement I consider for the benefit of my patients, and abstain from whatever is deleterious and mischievous." The physician himself is to be free from suspicion — "With purity and with holiness I will pass my life and practise my Art. . . . Into whatever houses I enter I will go into them for the benefit of the sick, and will abstain from every voluntary act of mischief and corruption." The medical man's confidence is also included. "Whatever, in connection with my professional practice or not in connection with it, I may see or hear in the lives of men, which ought not to be spoken abroad, I will not divulge, as reckoning that all such should be kept secret." Finally, the penalty of unprofessional conduct: "While I continue to keep this Oath unviolated, may it be granted to me to enjoy life and the practice of the Art, respected by all men at all times; but should I trespass and violate this Oath, may the reverse be my lot".

So great was the veneration of succeeding generations for Hippocrates, that more than seventy works on medicine were attributed to him; but many of these are by his disciples, and some even of an earlier date. Probably six were written by Hippocrates; these include part of a treatise on "Epidemics", the "Prognostics" and "Air, Earth and Locality", the latter dealing with the effect of environment on health. To Hippocrates also is attributed the *aphorism*:

" Life is short, and the Art long; the opportunity fleeting; experiment dangerous, and judgement difficult. Yet we must be prepared; not only do our duty ourselves, but also patient, attendants; and external circumstances must co-operate."

Prof. Charles Singer has very aptly described the faith of these early physicians as the " Religion of Science " — the belief in the constant and universal sequence of cause and effect in the material world — and adds : " The first prophet of that religion was Thales. The first writings on that religion bear the name of Hippocrates. The first great exponent of that religion whose works are still substantially extant is Aristotle." Before the indebtedness of science to the last-mentioned is discussed, the story must be told of another power which threatened Greece and finally overran the Athenian Empire ; but, partly through Aristotle, was the means of spreading the spirit of Greek culture and inquiry throughout the known world.

CHAPTER V: CLASSIFICATION AND BASIC PRINCIPLES

Greece and Macedon

REFERENCE has already been made to the enlightened rule of Pericles, in the second half of the fifth century B.C., during which Athens became famous, not only for its political administration as the centre of an increasing empire, but also in relation to the human interests of art and architecture. To crown all, Pericles restored the temple of the goddess Athena, daughter of Zeus, by authorizing the building of the Parthenon, which housed the statue of the goddess. Although the Parthenon is in ruins, and the statue has disappeared, a part of the frieze, the work of the sculptor Pheidias, can still be seen at the British Museum.

It is one of the tragedies of history that, towards the close of the fifth century B.C., a fierce war raged between Athens and her rival, Sparta. The conflict proved disastrous and the Athenian Empire, associated with the age of Pericles, crumbled. Yet during the long struggle, Greek drama reached its height and Socrates, a stone-cutter, came into prominence, questioning the accepted beliefs of mankind, and laying the foundation of future thought on matters of right and wrong. His free and logical inquiries led to his condemnation to death, by drinking the deadly hemlock, in 399 B.C.; but his teaching was preserved by his pupil Plato, whose writings even today are of interest and value to all concerned with the ideal community and the status of the individual in it.

The fourth century B.C. is memorable as the great age of Greek prose, and also for the change that took place in the political atmosphere of the Mediterranean. In Macedonia, to the north of Greece, there arose an unexpected military

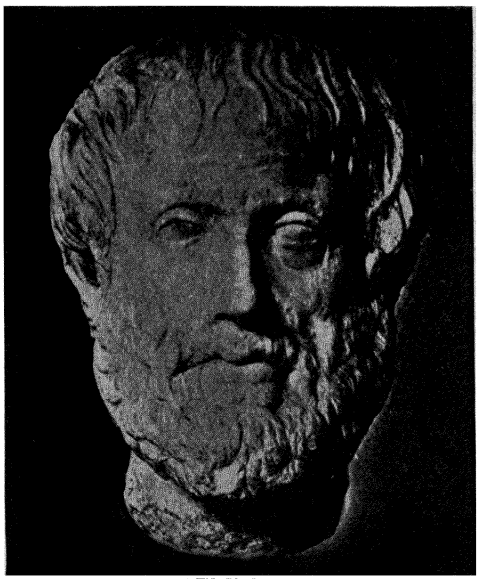
power, led by Philip of Macedon, who created fresh tactics in warfare. The Macedonian "phalanx" of spearmen marched against and held the enemy, whilst cavalry charged the flanks. Philip's army gained control of Greece in 338 B.C., and though he himself was assassinated two years later, his son Alexander proved an even greater general, founding an empire which dominated not only the Eastern Mediterranean but also extended to the north of India.

The prowess and wide outlook of Alexander were due in no small measure to the care with which his father, Philip of Macedon, had planned his education. Beside training the boy in the arts of war, so that at the age of eighteen he was capable of commanding the cavalry in the victorious battle against Greece, his father also placed him under the tutelage of the philosopher Aristotle.

Aristotle and the Value of Classification

Aristotle (384–322 B.C.) was born at Stagira, a Greek colony on the Aegean Sea, nearly two hundred miles north of Athens. As this town was almost within Macedonia, it is not surprising that Aristotle's interests were not limited to Greek culture. His father was physician to the court of Macedon, and he himself at the age of seventeen went to Athens; ultimately he became the pupil of Plato, until the latter's death in 347 B.C. About four years later, Aristotle was ordered by Philip of Macedon to undertake the education of Alexander, then a boy of thirteen. The association of the future general with the mature philosopher is one of the coincidences of history; and though Aristotle may not have realized the full significance of the Macedonian Empire, his influence on the young Alexander is seen in the way the latter stimulated and encouraged the Greek spirit of inquiry among the peoples whom he conquered.

Originally it was intended that Aristotle should follow his father's profession of medicine; he was not only interested in biological studies, however, but also in the laws



From Prof. J. R. Partington's "Short History of Chemistry"

ARISTOTLE
"Father of Natural Classification"

of thought. It will be seen later how his system of logical thinking dominated the intellectual life of Europe for nearly two thousand years. He himself was a keen observer of Nature and collector of specimens, being particularly at home on the shores of his native Aegean Sea. His contribution to biology has been all the more valuable, owing to his method of classifying his observations.

Several of his books have been preserved, and those on biology are on the following subjects: The Mind; Observations on Animals; On the Parts of Animals; On the Reproduction of Animals. His descriptions of sea-life are particularly reliable, and his insistence on exact observation foreshadows the demands of present-day science with regard to accuracy in detail. As a naturalist he arranged his specimens in groups and so prepared the way for future biological workers. It had been the custom to divide

animals into opposites, for example land and water animals, winged and wingless ; but Aristotle recognized the unsoundness of such grouping especially in relation to ants, which can be both winged and wingless. His own system of classification is nearer modern usage than any previously used. Though it cannot be claimed that he forestalled the nineteenth-century theory of evolution, the following sentence from his *History of Animals* is significant : " Indeed, there is observed in plants a continuous scale of ascent toward the animal ".

Aristotle's influence as a philosopher was far-reaching, but his work was also important in the story of science. To his clear reasoning, careful observation, and power of classifying his results, biology owes much, though his arguments concerning properties of matter and astronomy were based chiefly on faulty assumptions. It was left to Archimedes to develop some of the basic principles in mathematical and physical science ; but Aristotle's authority was so respected that his views were accepted without question down to the Middle Ages. It was not until nearly two thousand years had elapsed that a final break was made with the Aristotelian tradition.

Hellenistic Influences

It has already been pointed out that the conquests of Alexander the Great resulted in Greek civilization spreading throughout the Macedonian Empire. Where the soldiers went, there also were to be found the language and customs of Hellas, the land of Greece ; for it must be remembered that one of the ambitions of Philip of Macedon was to absorb Greek ways of life as much as possible, and that his son Alexander had been taught by Aristotle. The language of Alexander's soldiers was Greek, but not the classical tongue as spoken and written in Athens, even as in the modern citizen army of Britain the language of the King's soldiers cannot always be described as " King's English ". The colloquial Greek used by Alexander's armies has been called

" Common " or " Hellenistic " to distinguish it from " Classical " Greek, and it became the accepted language throughout the civilized world. This was only established some fifty years ago when excavations, which were made among the rubbish heaps of ancient Egypt, brought to light numerous papyri, and other materials, on which letters, accounts and similar private and official matter could be deciphered. In fact, a marriage contract on one Greek papyrus is dated as early as 311 B.C. The Greek of the New Testament, which, by comparison with Classical Greek, was held to be of a lower standard, is now recognized as Hellenistic, and a reflection of the vernacular of the day. The civilization which grew up in the wake of Alexander's armies has also been called Hellenistic to distinguish it from Hellenic, which refers to the more limited area of the Western Mediterranean where Greek influences had hitherto penetrated.

Alexandria, founded in 332 B.C. by Alexander the Great, became a centre of Hellenistic learning, and was destined to play an important part in the progress of science. After the death of Alexander in 323 B.C., his empire was divided among three of his generals, and a succession of rulers known as the Ptolemies was established in Egypt. Under their rule a fine block of buildings, the " Museum " (that is, the place dedicated to the Muses), was erected at Alexandria, including a library, an observatory and a school of science. Among the first teachers at Alexandria was *Euclid* (*c.* 330–260 B.C.), well known for his systematic treatment of geometry ; mathematics and astronomy flourished, and there was also a school of medicine where human dissections were made, and experiments performed on animals. The atmosphere of Alexandria was not confined to the Museum, for the influence of this great centre of thought and experimental work was carried to various parts of the Hellenistic world by those who came to study there. Among such no greater name is to be found than that of Archimedes of Syracuse.

Rome and Carthage

To understand the place of Syracuse in the struggle for political control of the Mediterranean, it is necessary to appreciate the relations between Rome and Carthage. The founding of the latter city by the Phoenicians about 800 B.C. resulted in a strong maritime power being built up on the shores of the Mediterranean nearly opposite Sicily. The gradual increase in power of Rome, since the traditional date of the founding of the city in 753 B.C., ultimately threatened the trade of the Carthaginians, and when, during the third century B.C., the Romans had conquered Magna Graecia, the Greek settlement in the south of Italy, they soon came into conflict with the Greek king Hiero of Syracuse in the east of Sicily. Naturally, with the Carthaginians established at the western end of the island, war followed. This First Punic War lasted intermittently for twenty-three years and was concluded by a peace which ceded the important granary of Sicily to Rome.

During the next twenty-three years, 241–218 B.C., Rome extended her frontier to the Alps, as well as building a navy which gave her command of the Mediterranean in the region of Italy. During the same period, Carthage had founded an empire in Spain, and produced Hannibal, a military genius comparable with Alexander the Great. Hannibal picked a quarrel with Rome and so started the Second Punic War. Despite reverses, Rome at last found a gifted commander in Cornelius Scipio, and Carthage lost her overseas possessions and became a tributary vassal of Rome in 201 B.C.

Archimedes and Basic Principles

It was in this atmosphere of struggle for the mastery of the Mediterranean that *Archimedes of Syracuse* (*c.* 287–212 B.C.) lived and died. When the First Punic War broke out in 264 B.C. he was a young man, and at the age of seventy-five years he was killed at the siege of Syracuse during the Second

Punic War. In his long and eventful life he formulated those basic principles which underlie civil engineering and ocean travel, as well as devoting himself to the study of pure science. Archimedes was the son of an astronomer at the court of King Hiero of Syracuse, where it is reasonable to suppose that his boyhood was spent with the king's son, Gelon.

During a visit to Alexandria various discoveries were made by Archimedes and discussed with friends there. Egypt, the very existence of which depends on irrigation, proved a suitable place for producing what has since been known as "Archimedes' Screw". By turning a screw, carefully fitted inside a cylinder, water was raised from a stream for distribution over the adjacent land.

On his return to Syracuse, Archimedes devoted his life entirely to his scientific work, and although he loyally placed his skill at the disposal of King Hiero as a military engineer, he was really more interested in pure science than in applying his knowledge to mechanical inventions. One of the best-known stories of his life is to the effect that he had been asked by King Hiero to find out whether a certain crown, supposed to have been made of gold, did not in fact contain some silver. On one occasion, having filled his bath quite full, it naturally overflowed as he got into it. Evidently a solution to the problem had presented itself and Archimedes, according to the story, ran through the streets of Syracuse shouting in Greek, "Eureka! Eureka!" ("I have found it! I have found it!"). A solid gold crown put completely into a full bowl of water would displace a certain quantity of water. A crown *of the same mass* but made entirely of silver, would displace nearly twice that quantity of water, because the density of silver is about half that of gold. If, however, the crown had some silver in it, although it was covered with gold on the outside, it would displace a quantity of water somewhere between the two quantities already measured. By comparing the amount of water displaced by Hiero's crown with that displaced by equal masses of pure gold and pure silver, it was possible to determine the composition of the crown.

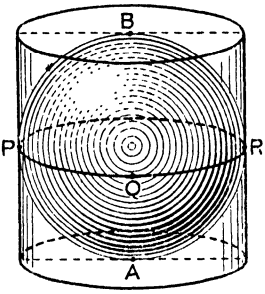
This is the origin of the well-known *Principle of Archimedes*, and was described by him as follows : " Every solid body lighter than a liquid in which it floats, sinks so deep that the mass of liquid which has the same volume with the submerged part, weighs just as much as the floating body ". The principle is the basis of all problems of flotation and naval architecture.

In the realm of applied mathematics Archimedes also formulated the principle of the *lever*, and starting from the simple case of equal masses balancing when placed at equal distances from the fulcrum, or point of support, of the lever, he realized that, by increasing the arm, a comparatively small force applied at its end could balance a heavy mass placed at the end of the smaller arm ; as we should now say, the " moments " of the forces about the fulcrum were equal and opposite. From this realization came his famous saying, " Give me somewhere to stand and I will move the earth ". One of his feats is reputed to have been hauling a galley laden with men and cargo by means of some sort of capstan operated by hand.

As a pure mathematician, Archimedes developed the work of Euclid and successfully solved many of the problems connected with the curves of intersection when a cone is cut by a plane. He worked out, to a high degree of accuracy, the ratio of the length of the circumference of a circle to its diameter, and also found that the area of a circle is equal to that of a triangle the base of which is the length of the circumference, and the height of which is equal to the radius of the circle. He successfully calculated the area of a parabola, and investigated the spiral curve which bears his name. In fact his definition of a spiral shows the practical nature of his approach to mathematics : " If a straight line moves with uniform velocity in a plane about one of its extremities which remains fixed, until it returns to its original position, and if at the same time a point [on the rod] moves with uniform velocity starting at the fixed point, the moving point describes a spiral ".

Archimedes considered that his greatest achievement con-

sisted in discovering the ratio of the volume of a sphere inscribed in a cylinder to that of the cylinder. The figure shows the sphere touching the cylinder in a circle PQR along the curved surface, and at two points A and B, the centres of the base and the top of the cylinder. The ratio of their volumes is 2 : 3. It was Archimedes' wish that a diagram representing this theorem should be inscribed on his tomb; the site of the latter was forgotten for many years, but it was recognized and restored by Cicero when he was quaestor in Sicily (76 B.C.). Since then, however, all trace of its whereabouts has vanished.



Archimedes' cylinder and sphere problem

The story of Archimedes' death is bound up with the siege of Syracuse in 212 B.C. After the First Punic War at Syracuse, King Hiero remained friendly with Rome, but after his death in 215 B.C. he was succeeded by his grandson, who supported the Carthaginians in the Second Punic War, then in progress. Accordingly, the Romans under Marcellus laid siege to Syracuse. Although nearly seventy-five years of age, Archimedes helped in the defence of the beleaguered city. His engines of war frightened the investing fleet. He directed the working of the catapults, and possibly employed "burning glasses" to set fire to the Roman ships. With large grappling irons thrust over the walls of the city he lifted up the prows of the vessels in the harbour. Some were sunk, and Marcellus could not persuade his followers to face further attack. A later historian states that the Romans were so frightened that "If they did but see a piece of rope or wood projecting above the wall they would cry 'There it is', declaring that Archimedes was setting some engine in motion against them, and would turn their backs and run away, insomuch that Marcellus desisted from all fighting and assault, putting all his hope in a long siege".

At length Syracuse fell, but Marcellus gave orders that

this great military engineer should be spared. Archimedes' absent-mindedness, perhaps, cost him his life. He was engrossed in a problem and did not realize that the city was taken. As was customary, he had a diagram in sand on the floor, and a Roman soldier trod on it. On being told to get off the figure, the soldier became enraged and Archimedes was killed.

Until recently it was not understood by what steps Archimedes worked his way to the discovery of some of the great geometrical theorems, but in 1906 a copy of one of his lost works called *The Method* was found. It appears that Archimedes made use of something very akin to the methods of the "calculus", together with the principle of "moments". The document consists of nearly two hundred leaves, and is what is called a " palimpsest " (Greek *palin*, again ; *psestos*, rubbed), that is, the original writing had been washed off, so that the parchment could be used again. Fortunately, in this case the original writing is sufficiently clear for the Greek characters to be deciphered, and the work translated. It is an additional confirmation, if this were necessary, of the way in which Archimedes was concerned with basic principles ; and from this point of view alone he provided the foundations on which succeeding generations of mathematicians and engineers have built.

The present chapter marks a development in the story of science. From the pioneer work of Thales of Miletus in mathematics and philosophy, and the attempt which Hippocrates of Cos made to remove superstition from the realm of medicine, it is not surprising that the study of Nature should proceed along the lines of logical reasoning and classification laid down by Aristotle, and that basic principles should emerge from the work of a genius such as Archimedes. Of the importance of these principles to modern science no greater tribute can be paid than that by Prof. A. N. Whitehead, himself a distinguished mathematical physicist and philosopher : " Archimedes, who combined a genius for mathematics with a physical insight, must

rank with Newton, who lived nearly two thousand years later, as one of the founders of mathematical physics. . . . The day (when having discovered his famous principle of hydrostatics he ran through the streets shouting Eureka ! Eureka !) ought to be celebrated as the birthday of mathematical physics ; the science came of age when Newton sat in his orchard."

CHAPTER VI: FORMULATION OF THEORIES

The Expansion of Rome

DURING the centuries that elapsed between the death of Archimedes in 212 B.C. and the birth of Newton in A.D. 1642, the long story of slow progress in science can be traced through the vicissitudes of political power. The achievements in thought and practice described in the last chapter gave promise of an early harvest, in which the fruits of scientific inquiry might disclose more of Nature's secrets for the benefit of mankind. But it was not to be. The basic principles revealed by Archimedes and the fresh beginnings in natural philosophy inaugurated by Newton are separated by nearly two thousand years, and the greater part of that time is marked by indifference or hostility to science, and implicit acceptance of any theory recognized by authority or tradition.

The first political administration within which the framework of science appears after the death of Archimedes is Roman. Although the Second Punic War ended with the triumph of Rome, Carthage remained a fortified city on the Gulf of Tunis, with a population of about 700,000, and with a power of swift recovery. No wonder the slogan " Carthage must be destroyed " met with a sympathetic response, and that a pretext was found for a Third Punic War (149–146 B.C.). This time, after a terrible siege in which the women are reputed to have given their hair to make ropes for the catapults, Carthage was successfully stormed and burned to the ground, and the North African shore became a Roman province.

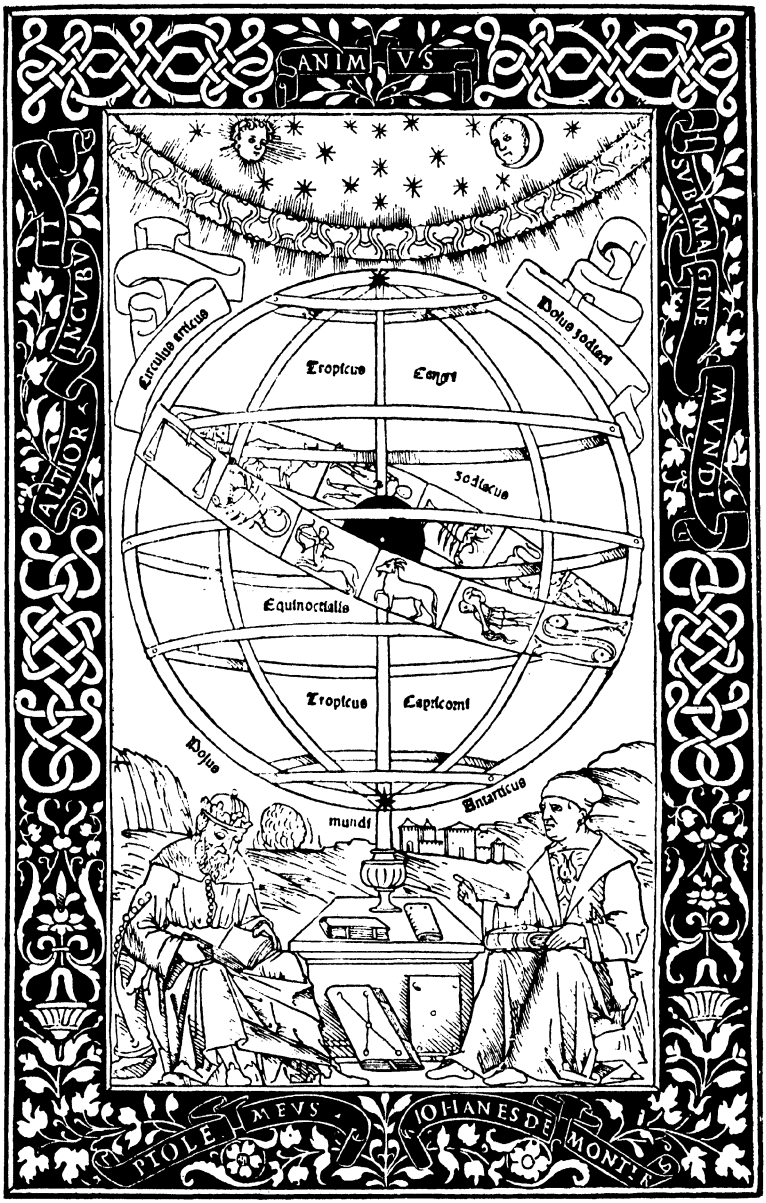
The expansion of Rome was proceeding apace. From the time of the expulsion of the foreign kings in the sixth century B.C. there was a keen hatred of anything approaching

" kingship " in government. Gradually, through many setbacks and internal disputes, a republican form of government emerged. But it had its drawbacks, especially with regard to the executive power necessary for an increasing overseas administration. Actually, in the first century B.C., Sulla, an able Roman general, was waging a successful war against a revival of oriental power in the Eastern Mediterranean, but it was done without the support of the home Government, and while active opposition was being fomented in Rome by Marius, an older and also successful general.

The solution of the difficulties facing the republic was found in the person of Julius Caesar, the nephew of Marius. In the realms of administration and generalship no task which he set out to accomplish was left undone. To English-speaking peoples his name is a household word, both from his expeditions to Britain and from Shakespeare's portrayal of his assassination, which took place in 46 B.C. It was he who laid the foundations of the Roman Empire, and made possible the period of peace and prosperity associated with his nephew Octavius (later Augustus), who succeeded him. During this Augustan age literary genius flourished ; outstanding were Virgil, the inspired poet, and Livy, the historian. Throughout the Empire reigned the Pax Romana, and before the death of Augustus, the Christian era had been ushered in by the birth of " The King of the Jews " in Judaea, an obscure province, administered by Herod the Great on the eastern shores of the Mediterranean. The Empire reached its greatest extent under Trajan (A.D. 98–117), when it stretched from the Persian Gulf to Spain, and from Egypt to Britain.

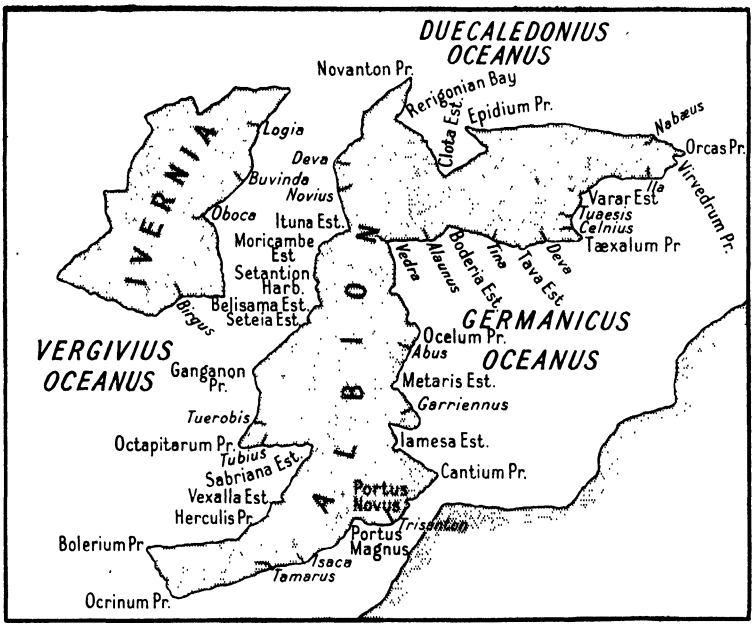
Ptolemy's System of the Universe

The general tendency of Roman influence on science was to emphasize its practical use rather than stimulate further discovery. In the second century A.D., two con-



From Prof. Charles Singer's "From Magic to Science"

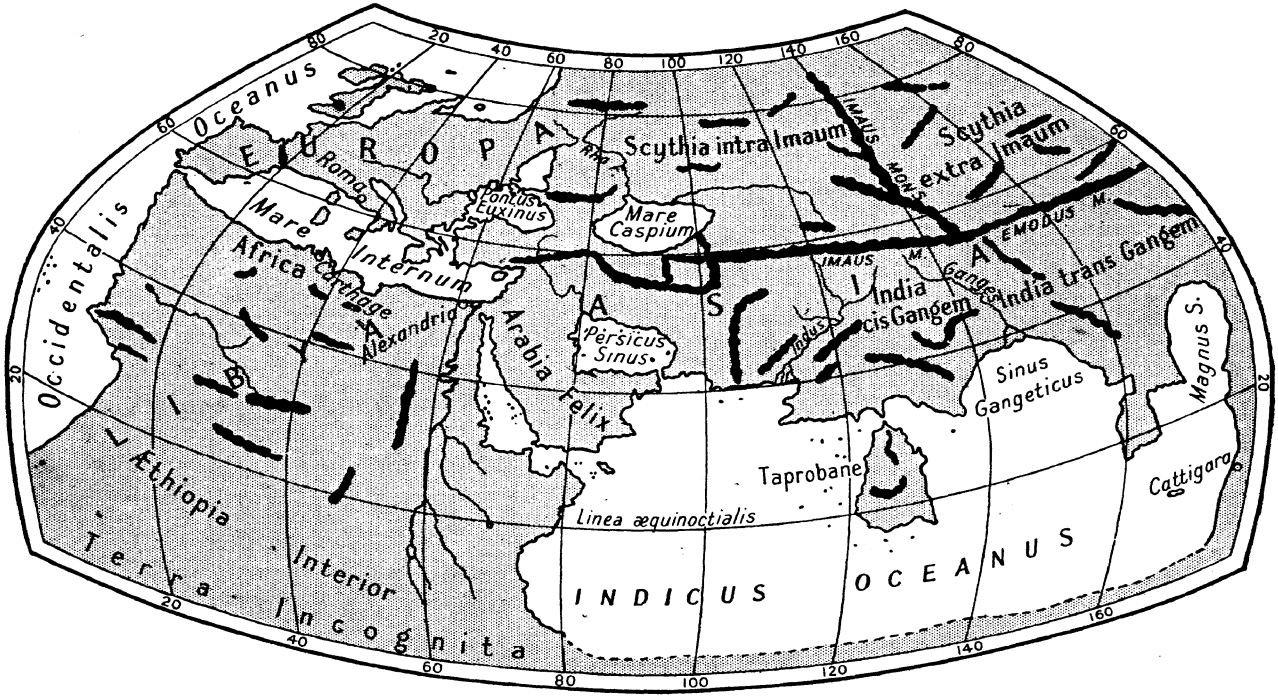
Frontispiece to the Epitome of Ptolemy's *Almagest*. By Johannes Müller (Regiomontanus), Venice, 1496



Map of the British Isles according to Ptolemy

temporaries, Ptolemy and Galen, so organized knowledge in their respective spheres of astronomy and medicine, that their systems were generally accepted for some fourteen hundred years. *Ptolemy* — he must not be confused with the king of Egypt who succeeded Alexander the Great — made numerous astronomical observations in Alexandria between A.D. 127 and 151 and also taught there. He prepared an encyclopaedia of astronomy, which was based on the work of Hipparchus (first century B.C.). This was known at the time as " the great composition ", but the Arabic translation " Almagest " is the title by which it is known today. Ptolemy's *Almagest* remained the standard treatise until the sixteenth century.

The diagram opposite shows the general conception of the " Ptolemaic System " of the universe, with the earth



Map of the World drawn from Ptolemy's accounts of travels and countries

as the centre of the universe, and the heavenly bodies revolving round it. For this reason it may also be described as " geocentric ".

The motions of the planets (Greek *planetes*, wanderer) could not be explained by the simple circular motion suggested by the above diagram, and elaborate schemes were devised whereby it was assumed that the earth was not quite in the centre of the planetary orbits, and that the planets themselves really moved in circles, the centres of which described the large circles indicated in the diagram. Thus there grew up methods of " excentrics " and " epicycles " to explain the motions of the heavenly bodies. Ptolemy retained both methods in his system.

In addition to his work on astronomy, Ptolemy wrote on geography. He reckoned longitude from the " Fortunate Isles " situated on the western boundary of the known earth. The maps which probably accompanied his work have disappeared, but it is possible to reconstruct them from the latitude and longitude of the places he mentions. Two examples appear on pages 53 and 54.

Galen and Medical Theory

While Ptolemy was making astronomical observations in Alexandria, there grew up in Pergamum in Asia Minor the second most renowned physician of the ancient world, *Galen* (*c.* A.D. 130–200).

Pergamum and Alexandria were rival seats of learning, and the enmity between the two cities is reflected in the English word " parchment ". The Alexandrian books consisted of rolls of papyrus (from which the word " paper " is derived), consisting of strips of the stalk of the papyrus reed gummed together. To prevent Pergamum from making copies of such books, Egypt put an embargo on the export of papyrus. The citizens of Pergamum replied by so improving the preparation of skins for writing purposes that their



A relief from Trajan's Column, Rome, showing that the Roman Legions were equipped to deal with casualties

product was ultimately known as " *membranum pergamentum* ", appearing in English as " parchment ".

The medical knowledge which Galen systematized was, like the Ptolemaic System, accepted as authoritative for very many centuries ; in fact until the discovery of the circulation of the blood by Harvey in the early seventeenth century. Like most men interested in science, Galen visited Alexandria and travelled to other centres, in order to be abreast of all available knowledge. He was therefore well qualified to bring within the purview of one system the views concerning anatomy and medicine which had accumulated in the scientific world. Most of his life was spent in practice at Rome, where he was also physician to the Emperor Marcus

Aurelius, well known as a Stoic philosopher. Galen revived the practice of dissection, and consequently improved the knowledge of anatomy ; he also performed experiments on animals, and made careful examination of the spinal cord and of the action of the heart.

Galen firmly believed that everything was made by God for some definite purpose, and his system of medicine was founded on the idea of spirits of various kinds pervading all parts of the body. Such a view was opposed to a purely mechanical theory of life, and naturally it appealed to Christian, and later to Muhammadan teachers. This partly explains Galen's lasting influence, and the general acceptance of his system, both from the points of view of tradition and authority. The spirit or " pneuma " was drawn from the world-spirit in the act of breathing, and so entered the body. Ultimately there were " natural spirits " giving nutritive properties to the blood, " vital spirits " to enable the various organs to perform their functions, and in the brain " animal spirits " to bring about movement and the higher functions of the body.

From this brief description it will be seen that a change was taking place in scientific attitude, and emphasis was being placed on theory and dogma rather than on observation and experiment. Until the spirit of inquiry of the early Greeks showed itself again, there was little prospect of the " ebb and flow " of the blood, as formulated by Galen, being discarded for the " circulation " discovered by Harvey.

Scientific Method

The death of Galen marks the end of the second century of the Christian era, and during that century the zenith of the Roman Empire had passed. Before describing the subsequent close of the Classical period of Mediterranean civilization, it may be well to pause, and to estimate the position that had been reached in scientific achievement. The significance of progress in this respect does not lie so

much in the importance of discoveries, but in how far scientific method had been accepted. If the latter was not firmly established, then the promise of the former could not be completely fulfilled. A brief review of the landmarks already noted will reveal the position.

By the sixth century B.C. *Thales* had embarked on the true spirit of inquiry ; tradition, even though it did involve gods and goddesses, was not the final authority, for he believed that reason could ultimately solve the problems hitherto only dealt with in the language of mythology. The next century saw an attack on superstition from another angle, and *Hippocrates* proclaimed the natural sequence of disease, thereby holding out the possibility of combating it. Another century, and a further step was taken ; the logical thoroughness, accurate observation and careful classification of *Aristotle* showed a way of recording and using results. The passing of yet another century hints at the importance of basic principles as formulated by the genius of *Archimedes*. Four successive centuries, and four landmarks on the road toward scientific method — belief in reason, discount of superstition, classification of facts, emergence of principles.

Such is the story of progress up to the second century B.C. Then, as if the achievement of four centuries had been made at too great a pace, there was a pause, and during the next four centuries, little to compare with the brilliant insight of the earlier period. In the second century A.D. another landmark appears, and this time not the flash of genius in original work, but the careful bringing together of various information into systems, on one hand by *Ptolemy* concerning the universe, and on the other by *Galen* concerning the human body. Though the freshness and originality of the earlier centuries had to a considerable extent been lost, this bringing together into a system does represent an essential phase of scientific method. We may criticize the information that was selected, and the way it was used ; nevertheless both Ptolemy and Galen arranged and organized their material into systems of knowledge, a characteristic of science.

Unfortunately, it was the passive acceptance of these

systems that delayed the progress of science, and showed that the scientific method had not been completely absorbed. True, there were geniuses such as Aristotle, Archimedes or Roger Bacon who must have been endowed with the full scientific mentality, but we have to wait until the sixteenth and seventeenth centuries before the mere acceptance of a theory, or traditional view, ceased to be recognized as sufficient. Not until then had the last phase of scientific method been reached, and it was realized that the theory which did not fit into the framework of natural phenomena had to be modified or rejected. The acceptance and testing of a theory must go together.

Thus, well after two thousand years from the time of Thales, the scientific method came into its own, and the cycle of observation and experiment, principle and theory, acceptance and testing, had at last been established. In the light of further observation and experiment, this cycle was repeated and new theories formed. But long years followed the passive acceptance of the systems of Ptolemy and Galen, and continued until men realized the importance of active and critical testing. These years were largely devoid of scientific progress, and the chapters which describe them must, of necessity, deal more with the background than with the substance of science.

CHAPTER VII: THE CLOSE OF THE CLASSICAL PERIOD

The Decline of Rome

WHILE the work of collecting information into systems of knowledge was proceeding during the second century A.D., there were signs that the peace which had characterized the Roman Empire would not endure. It was not until A.D. 161 that the defence began to give way, but in that year invaders from Bohemia and Moravia broke through the north-eastern frontier of Italy. The final overthrow of the Empire in the West, however, was not to come for many years, and a variety of reasons led to its decline.

A falling birth-rate had given cause for anxiety ever since the reign of Augustus, and subsequent wars had depleted the virile element of the Roman stock. In A.D. 166 a series of plagues broke out in Rome; they were brought by troops returning from the East, and little effort made to cope with the medical situation. Changes began to take place within the army, and men from the provinces were freely admitted to the legions; even the post of emperor was not reserved for a Roman. For example, Septimius Severus, who repaired Hadrian's Wall from the Solway to the Tyne and who died at York in A.D. 211, was an African. By the fourth century the legions were chiefly composed of, and officered by, Germans. With this increasing dependence on nationalities other than Roman, the Roman citizen himself tended to a life of luxury well within the Empire, rather than face the austerity of defending its frontiers, especially those of colder and less hospitable regions. The unwieldy Empire, including such different races as the Arabs, Italians and Britons, was increasingly difficult to administer, and its division into East and West in A.D. 286 did not solve the problem; civil wars

and corrupt government were additional factors in its decline.

Slaves, who were an adjunct of classical civilization, became less associated with agriculture, trade or industry, and were increasingly employed in ministering to the wants of those who could afford to keep them, and in looking after their children. Agriculture also deteriorated and sank nearer to primitive conditions, smaller areas were under cultivation, and the workers on the land were less able to pay taxes. Coinage grew less important and payment in kind became necessary. Social distinctions increased as to what was considered ordinary work, and what was regarded as " degrading ".

The conditions that have just been described were anything but favourable to the maintenance and growth of the creative spirit in man. Although in the early days of the Greek city-state, the culture of the few became accessible to all the citizens, this did not remain so, and the tendency to restrict the privileges of the mind to those who had created such privileges gradually increased. The spread of Hellenistic culture following the conquests of Alexander did, however, give further scope for that creative faculty which found expression, as we have seen, in the brilliance of the Alexandrian school of natural philosophy. But with the conquests of Rome the creative spirit diminished, although the conquerors added their own contribution of practical utility to the Greek ideals.

Here again culture was in the hands of the few, and with the coming of the Empire the freedom of the individual became subservient to the worship of the emperor. Hitherto religion had included the power of the State, represented by the goddess Roma, together with the mysterious Vesta, symbolizing the undying fire of the hearth of the great Roman house ; but now the " genius ", the divine creative power belonging to Augustus, the head of the great Roman family, was added. This creative power expressed itself in the literary and architectural achievements of the Augustan age.

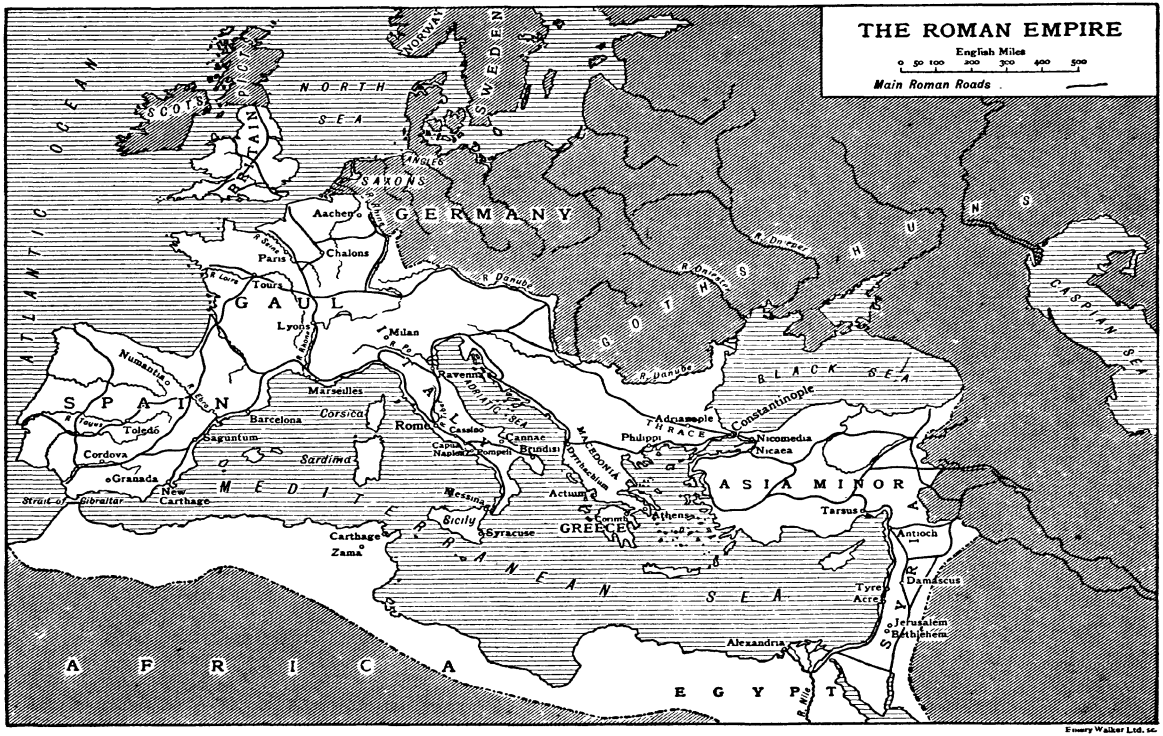
As the Empire expanded, those to whom the privileges

of Roman citizenship belonged were comparatively few, and once more the restricted number of those who enjoyed those privileges was in sharp contrast to the hosts of others included in the Empire. Attention has already been directed to the luxury indulged in by the citizens themselves, and this increased until the creative power itself was almost destroyed, and life seemed empty. With no inspiration from those who should have been leaders, the remainder became apathetic and eventually filled with hatred and envy. It is no small wonder that in such a world of indifference, lack of ideals and hardship, some gave up altogether, while others found religious consolation in their belief in a future life.

For nearly three centuries Christianity had been spreading throughout the Roman Empire, despite restrictions and persecutions. In A.D. 312 the Emperor Constantine proclaimed it as the official religion of the State, and through him various Church councils were held to ensure unity. He was also responsible for founding Constantinople on the site of the ancient Byzantium. After six years of building, the city was completed in A.D. 330 and was intended to be both Christian and Latin. The architecture of the new Christian churches resulted in a structure in which the basilica of the Roman law court was crowned with the Persian dome. The division of the Empire into eastern and western portions for defence purposes, and the founding of Constantinople, which rivalled Rome itself, led ultimately to the continuance of an eastern empire until the sack of Constantinople by the Turks in 1453 ; whereas the western empire came to an end in A.D. 476 at the hands of the Goths.

The Coming of the Germans

The Goths formed the eastern branch of the German race, while the western included Saxons and Franks. Of the early history of the Germans little is known except that originally they came from the region of Scandinavia ; the Swedish, Norwegian and Danish nations are of German



Map of the Roman Empire before invasion from the north

stock. Those who migrated travelled southwards and divided into two branches, the western moving towards the Rhine, and the eastern towards the Black Sea.

The influences which had hitherto dominated European civilization were Greek, Roman and Christian ; the coming of the Germans introduced another element. From the map (p. 61) it will be seen how widespread were these people. Ultimately the western branch produced the great medieval States of England and France ; whereas the eastern or Gothic, although giving much greater promise, did not endure, and this name is often associated with what is barbaric and destructive. The influence of the German peoples on the Roman Empire cannot be explained merely by the successes of the Goths in Italy in the fifth century, such as the sack of Rome by Alaric the Bold in A.D. 410 or the deposing of the emperor by Ordovacar in A.D. 476. It was more subtle ; the fall of the Empire was largely brought about by a process of infiltration extending over a hundred years, whereby the government of Italy, Gaul, Spain and Africa came step by step into German hands.

During the fourth century A.D. another race also made its appearance. The Huns, a wild Mongolian people from central Asia, entered south-eastern Europe carrying all before them, and forcing the Visigoths or western Goths from their pleasant country of Dacia (Transylvania, now a part of Roumania), to appeal to Rome for shelter. This was granted, but it was ultimately a Visigoth, Alaric the Bold, who allowed his followers to sack Rome in A.D. 410. By the middle of the fifth century A.D. the Huns, under Attila, had spread over the countries between the Rhine and the Urals, and though a few years earlier they had been auxiliaries of Rome, in A.D. 452 they actually threatened the city itself. The Hun influence, however, was short-lived, and Attila was dead within two years. His name, however, is not forgotten, and it is of interest that the " Hun " was not a " German " despite the popular usage of the word to that effect during the First World War. The origin of the association is, ironically, from the speech of Kaiser Wilhelm

to his troops before their departure to assist in suppressing the Boxer Rising of 1900 in China. They were to adopt methods of terrorism like those of Attila's Huns, so that " no Chinaman will ever again dare to look askance at a German ".

In A.D. 476 Ordovacar, a Goth who held office in the Empire, deposed the last of the Roman emperors in the west, and thus brought to an end the varying fortunes of an Empire that for nearly five hundred years had coloured the history of the Mediterranean peoples.

Position of Science

In the reference to scientific method made at the end of the last chapter, it was pointed out that the theories formulated by Ptolemy and Galen in the second century A.D. were accepted practically without question for some fourteen centuries. The absence of outstanding men of science during the declining years of the Roman Empire is consonant with what has already been mentioned concerning the causes of the decline and the consequent inability to meet the invaders. In particular, the emphasis on a future life, rather than on the present, not only lessened men's interest in the secular affairs of the State, but also damped their enthusiasm for the study of Nature. Rather than attempt to enumerate the few limited contributions to science towards the close of the Classical period, it is better to appreciate the atmosphere which made the position of science as a whole so precarious.

The Roman's greater interest in practical affairs than in pure science has already been mentioned. The remains of such utilitarian undertakings as aqueducts bringing water to the city of Rome from supplies some miles distant can still be seen. Roman engineering ranks with Roman law in importance. The Emperor Constantine in the fourth century wrote : " We need as many engineers as possible. As there is a lack of them, invite to this study, persons of about 18 years, who have already studied the necessary sciences. Relieve the parents of taxes and grant the scholars

sufficient means." The spirit of architecture was certainly not dead, and was able to meet the demands made on it for the increasing number of churches necessary for the new State religion. But in the realm of theory the mind was turned more towards inward speculation, and to traditional religious beliefs and symbolism, than to abstract science or to the observation of Nature. Mental education developed into an appreciation of poetry, philosophy and the fine arts — Nature, history and religion were not included. This omission of the study of Nature would contribute to the lack of inventiveness and progress in science which characterized the declining years of the Roman Empire. Even instruments of war had become stereotyped.

The mystery religions, which also had a considerable influence on the presentation of Christian beliefs, confused allegory and fact to such an extent that the critical faculty in man became dulled. Almost anything could be believed provided that it was supported by the interpretation which the Fathers of the Church put upon the Scriptures. For example, a second-century compilation seriously states that the cubs of the lioness are born dead, but that on the third day the lion breathes between their eyes, and they wake to life, thus typifying the Resurrection of our Lord, " the Lion of Judah ". The belief in the nearness of the end of the world also encouraged an attitude of indifference to the study of Nature, because it " does not help us in our hope of the life to come ". Ignorance tended to be exalted as a virtue ; a branch of the Library at Alexandria was destroyed at the end of the fourth century in the name of religion, and a few years later Hypatia, the daughter of an astronomer, and herself a mathematician, was cruelly murdered on a similar pretext.

The Term Medieval

With such a background, it is not surprising that the lamp of science burned low, and that the years into which Europe was entering have been described as the Dark Ages.

THE MEDITERRANEAN PERIOD—CLASSICAL

ACTION	KNOWLEDGE	VISION
B.C.		B.C.
1,000		1,000
900		Homer 900
800 Phoenicians found Carthage First Olympiad Rome founded		800
700 Greek City States		Hebrew Prophets 700
600 The Ionian Cities		600
Croesus of Lydia 500 Cyrus the Persian Marathon	THALES OF MILETUS	500
The Age of Pericles 400 Athens and Sparta	HIPPOCRATES OF COS	The Greek Dramatists 400
Alexander the Great	ARISTOTLE	
300		300
The Second Punic War	ARCHIMEDES	
200		200
Destruction of Carthage		
100		100
Julius Caesar 0 Augustus		Virgil Livy 0
A.D.		Jesus of Nazareth St Paul A.D.
100		100
	PTOLEMY GALEN	Marcus Aurelius
200		200
300 Constantine		300
400 Vandals sack Rome		400
500		500

With the close of the Classical period and the passing of the Roman Empire in the west, the Mediterranean world entered upon a new era. All attempts to define such eras by actual dates should be avoided. They lead to a distorted view of the nature of the changes in life and thought that occur in history. These changes are not abrupt and do not take place everywhere at the same time.

The usual division of recorded history into ancient, medieval and modern has been challenged by a modern German writer who maintains that it is too European ; he would substitute cycles of civilization, Indian, Classical, Arabian and Western, and within each cycle a seasonal and cultural analogy of spring, summer, autumn and winter ; according to his view the Western cycle is drawing to its close. Very different is the position of H. A. L. Fisher expressed in the preface to the original edition of *A History of Europe* (1934). Referring to those who have discerned in history "a plot, a rhythm, a predetermined pattern", he continues, "These harmonies are concealed from me. I can see only one emergency following upon another as wave follows upon wave, only one great fact with respect to which, since it is unique, there can be no generalizations, only one safe rule for the historian : that he should recognize in the development of human destinies the play of the contingent and the unforeseen. This is not a doctrine of cynicism and despair. The fact of progress is written plain and large on the page of history ; but progress is not a law of nature. The ground gained by one generation may be lost by the next. The thoughts of men may flow into channels which lead to disaster and barbarism."

Bearing in mind the danger which may accompany division into set periods, the thousand years between the end of the Roman Empire in the west in the fifth century and the beginning of the scientific renaissance in the fifteenth may conveniently be described as medieval, so far as science is concerned, though in art and religion there are indications in the thirteenth and fourteenth centuries of a new spirit in human endeavour.

CHAPTER VIII: MUHAMMAD AND THE REVIVAL OF EMPIRE

Developments in the West

IT was pointed out in the last chapter how seriously the Germanic invasions challenged the very existence of the Roman Empire. During the second quarter of the fifth century, while the invaders were advancing in Gaul and Britain, another danger appeared. Forces of the Empire which could ill be spared had to be dispatched to face the growing power, both on land and sea, of the Vandals (peoples akin to the Goths) who had crossed to North Africa, captured Carthage, and ultimately established a kingdom which also included Corsica, Sardinia and the Balearic Isles. Their rule lasted a hundred years, and the resulting wanton havoc can certainly be called " vandalism ". But important effects of the Roman strategy, necessitated by the successes of the Vandals, were the final loss of Gaul, the withdrawal in A.D. 442 of the last Roman garrison from Britain, the conquest of south-eastern England by the Saxons, and the migration of Celtic fugitives from the south-western portion to that part of Gaul to which they have given the name of Brittany. For some hundred and fifty years, until the coming of St. Augustine to Canterbury in 597, scarcely any authentic records of happenings in Britain exist.

Following the usurpation of imperial power at Rome in 476 by Ordovacar, two figures stand out among the invaders. The first, Theodoric the Ostrogoth (that is, eastern Goth), who established a short-lived Gothic kingdom in Italy, and the second, Clovis the Frank, who laid the foundations of the medieval monarchy of France. Though Theodoric was the more powerful of the two and both had embraced Chris-

and the Holy Roman Empire, will be dealt with in a later part of this chapter under the heading "The Frankish Empire"

Age of Justinian

The tradition of the permanence of the Roman Empire was strong, and from a religious point of view, founded on the belief that if the Empire did pass away, there was nothing left but the rule of Antichrist, and the end of all things. Every effort therefore was made from Constantinople, the headquarters of the eastern section, to maintain and unify the Empire as a whole. This was particularly the case in the century following the upheaval in the west; and for a thousand years, through varying fortunes, it was possible to retain the name and theory of being Roman for a State which in reality was partly Greek and partly Oriental.



British Museum

Head and reverse of a coin of Justinian

One man especially in the sixth century undertook the task of preserving the framework and enlarging the influence of the Empire based on Constantinople. It was *Justinian*, an Illyrian peasant who, at the age of forty-four, in 527 succeeded to the title of emperor, a year after the death of Theodoric in the west. An experienced man, a hard literary worker, with wide ambitions for the Empire, he successfully wiped out the Vandals in Africa, and after a long struggle conquered Italy. This, however, did not save Rome or prevent chaos throughout the country, as the last wave of Teuton invaders — the Lombards or Langobards (Long beards) — swept over the land. Justinian's ambition to subdue Gaul and Britain could not be fulfilled

by means of the forces at his disposal, and his power gradually declined, until at the age of eighty-three his death left the Empire weaker than when he assumed control thirty-eight years before.

Yet it is fair to refer to the " Age of Justinian " ; the massive structure of St. Sophia (the cathedral of Hagia Sophia, Greek for " divine wisdom ") with its typical Byzantine dome is a tribute to his interest in architecture, and the legacy of Roman law which has been transmitted to posterity through his legal compilations is a further justification. In western Europe it was not until the eleventh century that the full significance of the Justinian civil code was realized, and it then played an important part in moulding intellectual, social and political life. The code dealt with an earlier and more advanced state of society ; and so, as men were emerging from medieval darkness, pointed back to the higher plane of Classical civilization, and in so doing raised the hope that what had once been possible should again become an established order of life.

Spread of Islam

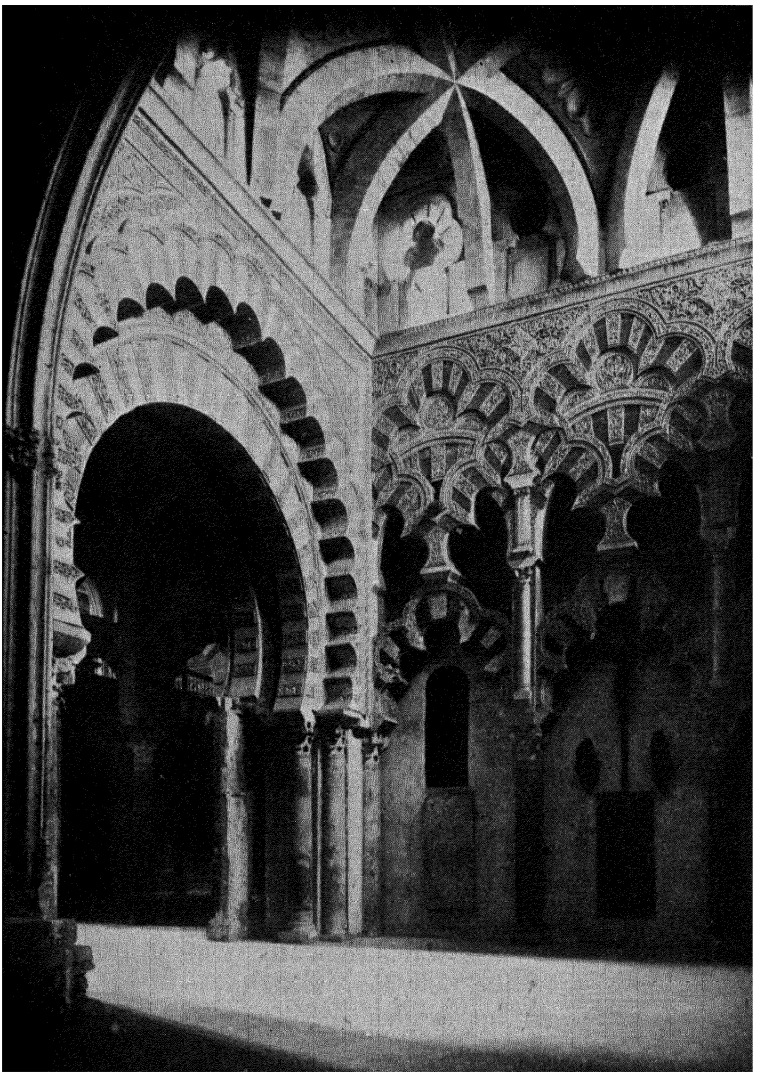
The close of the Classical period in the fifth century A.D. was accompanied by Germanic invasions which affected all the countries bordering the Western Mediterranean. In the east a counterpart to these invasions is seen, two centuries later, when the Arabic conquests mark the end of a thousand years of interaction between West and Near East. The legacy of the Hellenistic culture spread by the armies of Alexander the Great over the eastern end of the Mediterranean about 300 B.C. was overcome by the oriental spirit of the followers of Muhammad about A.D. 700.

From early inscriptions it seems that Arabia was originally occupied by two races, one nomadic, with its roaming-ground from the river Euphrates southwards about half-way into the land of Arabia ; the second, more stationary and settled, in the uplands of the south of the country. In the narrower ethnographical sense the term " Arab " was applied

to the nomadic tribes of the north, but through the influences about to be described, it has come to embrace practically all those who speak Arabic, whether Christian or Moslem.

To understand the spread of Islam it is desirable to recognize two processes which are described by George Antonius in his book *The Arab Awakening* (1938). The first, called " islamization ", is the spread of the Moslem faith, which ultimately included millions of adherents ; the second, " arabization ", consists of linguistic and racial influences, the former resulting in the use of Arabic as a common language, and the latter modifying through fusion and intermarriage the racial characteristics of the conquered peoples. The arabization process had been going on long before the rise of Islam. Syria and Iraq especially had been subject to the Arab influence. The former includes what is now known as Syria and the Lebanon, and Palestine and Transjordan. Iraq is the Arabic name for Mesopotamia. But there was no organized Arabian State, no regular army or political ambition, and only a low form of polytheism as a religion.

Mecca, some fifty miles from the Red Sea, was the principal Arab trading centre, and also the site of the Caba, or Cube, a small square temple of black stones, which had a meteorite as a corner stone. This meteorite was supposed to be a god who protected all the gods of the Arabian tribes, and pilgrims came to worship and kiss this stone. Vague influences from Christianity or Judaism may have reached the city, and possibly dissatisfaction was felt at this form of idolatry among the more thoughtful class of the community. About 570, Muhammad was born in Mecca, his parents being members of the tribe that controlled the local sanctuary. He was employed first as a shepherd boy, and later in the commercial house of Kadija, a rich merchant's widow, whom he afterwards married. His business involved caravan journeys across the desert, and probably he was influenced in talks with Christian and Jewish traders. By the age of forty he had become convinced of a special mission, and proclaimed his visions, first privately, and then to a wider



E.N.A.

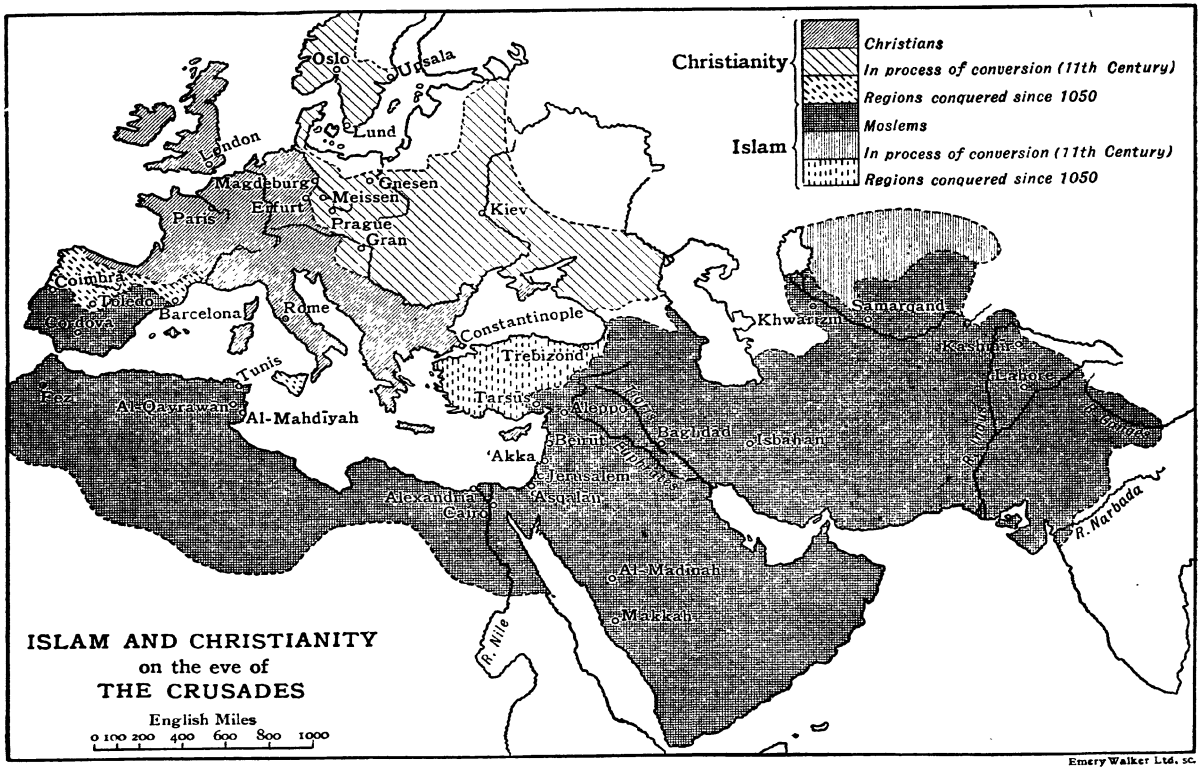
A corner of the Chapel of Villaviciosa in the Cathedral at Cordova, Spain. The Eastern style of architecture is due to the fact that it was orginally a mosque. See also page 82

circle, insisting on there being one God, Allah, instead of the many gods of the various tribes.

The flight of Muhammad, in 622, from Mecca to Medina is called the "Hegira" (pronounced *hej'ira*) and is supposed to have been necessitated by hostility which ended in a plot to kill him. This failed as he had already left, and he foiled his pursuers by going south to certain caves where camels and provisions were hidden. Ultimately Muhammad was received with enthusiasm in Medina, originally called Yathrib, a town 200 miles north of Mecca, but henceforth known as Medina en Nabi, the City of the Prophet. The Hegira marks the beginning of the Moslem era, and the preaching of that simple faith of submission (islam) to the will of Allah and insistence on the regular observances of prayer, fasting and pilgrimage together with abstention from wine. The Koran is a collection of the utterances of the Prophet, and corresponds to the Christian's Bible. Muhammad returned to Mecca in 631, adopted the black stone, and declared that the Caba was the temple of Abraham, who is regarded as the ancestor of the Arab race. All mosques point towards the Caba so that the faithful may turn towards Mecca when they pray.

Within twenty-five years of the death of Muhammad in 632, Egypt, Syria, Armenia and Persia were annexed, and with Arabia formed the Moslem Empire. The processes of islamization and arabization continued side by side during the next hundred years, and were the means of spreading the Empire from the Middle East, along the north coast of Africa, across the Strait of Gibraltar into Spain. By the early part of the eighth century the Moslem Empire extended from the Atlantic to India and threatened the very existence of the European States, both from the east and from the west. But the limit had been reached; the Emperor Leo the Isaurian successfully repelled the formidable Saracen attacks on Constantinople in 717 and 718, and, in the west, Charles Martel of the Franks defeated the Arabs at Poitiers in 732.

The spread of Islam was checked. It has been described as a religion of warriors and shepherds, it has no clergy or


Christianity
Christians
In process of conversion (11th Century)
Regions conquered since 1050
Islam
Moslems
In process of conversion (11th Century)
Regions conquered since 1050
Oslo
Uppsala
Lund
London
Magdeburg
Gnesen
Meissen
Erfurt
Paris
Prague
Gran
Kiev
Coimbra
Toledo
Cordova
Barcelona
Rome
Constantinople
Trebizond
Tunis
Fez
Al-Qayrawan
Al-Mahdiyah
Tarsus
Aleppo
Khwarezm
Samarqand
Kashgar
Lahore
Bagdad
Isbahan
Beirut
'Akka
Jerusalem
Asqalan
Alexandria
Cairo
Al-Madinah
Makkah
R. Nile
R. Narbada
ISLAM AND CHRISTIANITY
on the eve of
THE CRUSADES
English Miles
0 100 200 400 600 800 1000
Emery Walker Ltd. sc.

regular liturgy, and allowed large communities in the conquered territories to keep their old beliefs. The Arabic language was the great unifying power, and through it Arabic learning plays the unexpected role of custodian of the hidden and forgotten stores of Greek knowledge. The significance of this with regard to medieval science will be dealt with in the next chapter.

The Frankish Empire

The people known as the Franks came from western German stock, and the house of Clovis, the Orthodox contemporary of Theodoric the Goth, endured for nearly three hundred years, in contrast to the short-lived Arian kingdom of the latter. The Frankish conquerors maintained an admiration for the imperial spirit of Rome, and were regarded as auxiliaries by the emperors in Constantinople. Further, the Church imposed her Latin culture, so that Roman civilization was secure in conquered Gaul, though in Britain, with Saxon invasions, it had all but died out.

The Teutonic custom of dividing the inheritance among the sons was applied by the house of Clovis to the Frankish kingdom, with the disastrous results of civil war. It was natural therefore that a more vigorous dynasty should rise to power ; this dynasty came from the Eastern Franks and included the successful and warlike Charles Martel, who had earned the title of the Hammer (Martel) by his drastic handling of the Roman Church in Gaul.

After the arrival of St. Augustine at Canterbury in 597, Christianity had spread throughout England, and religious houses were founded at such places as Rochester, London, Peterborough, and towards the end of the seventh century at Wearmouth and Jarrow. At the latter monastery lived the Venerable Bede (672 or 673–735), the ecclesiastical historian, who incorporated into his writings all the knowledge then available in western Europe. Britain was in a far better condition than Gaul to undertake the conversion of Ger-



From Crump and Jacob, "Legacy of the Middle Ages", by courtesy of the Clarendon Press

The House of Learning. From G. Reisch, *Margarita Philosophica*, 1503. This illustrates the medieval conception of stages or grades in the process of learning

scripts. It is probable that the library at York contained the finest store of books north of the Alps. Already education was following the sequence which was to be adopted as the standard method throughout the latter part of the Middle Ages. An elementary "trivium" comprising grammar, rhetoric and dialectic — all dealing with words — and the "quadrivium" of Boethius, music, arithmetic, geometry and astronomy supposedly dealing with things. The following problem is ascribed to Alcuin: "If 100 bushels of corn are distributed among 100 people in such a manner that each man receives 3 bushels, each woman 2 bushels, and each child half a bushel, how many men, women and children are there?" There are six possible solutions, and of these Alcuin gives one, namely, 11 men, 15 women and 74 children.

To Alcuin's influence may be traced the development of episcopal and monastic schools as part of the Church's responsibilities. Human nature — including boy nature — has not changed very much since Alcuin wrote, after he had left York, urging a newly appointed archbishop "to provide masters for the boys . . . so that they may not make a business of pleasure and wander about the place, practising useless games, or becoming addicted to other futilities".

Apparently the making of riddles was a lighter side of scholastic activity, and Alcuin is credited with the following in reply to a gift of an ivory comb with a lion's head carved at each end. "I send you as many thanks as I have counted teeth on your gift. I am not terrified by the fearsomeness of this beast, but charmed with the looks of it. I have no fear of its biting me with its gnashing teeth. I am delighted with its fanning caresses, which smooth my hair." He then propounded the following riddle:

A beast has suddenly come into my house,
A wondrous beast with two heads.
Two heads it has, but one jaw bone only.
Twice three times ten are its terrible teeth,
Yet it does not eat with its teeth,
Which are fed with a crop which grows on my head:
Tell me — what beast is this?

The Frankish Empire which Charlemagne had created did not long survive his death in 814, and by the Treaty of Verdun in 843 it was partitioned. The permanent achievements of the Emperor should not be judged by the boundaries of his Empire, but by the successful effort that he made to lighten the darkness of European ignorance. Charlemagne resolutely withstood the forces of paganism and anarchy, and through his far-sighted policy the lamps of learning and culture were once more lighted. For this alone his name is among the immortals, and in the language of succeeding generations no greater compliment could be paid to a man by his fellows than this: "He is fit to use the stirrups of Charlemagne".

CHAPTER IX: THE MEDIEVAL UNIVERSITIES

The Importance of Arabic Learning

THE spread of Islam changed the aspect of the Mediterranean world. During the seventh and early eighth centuries the inland sea had lost its predominant Roman influences, and had become locked at each end by a powerful and fanatic Moslem empire. The introduction of Arabic as a common language was comparable with the spread of Hellenistic Greek through the conquered lands of Alexander the Great. After the check which the Moslems received at each end of the Mediterranean in the first half of the eighth century, there still remained Arab control in Spain, along the North African coast, and in Egypt, Arabia, Syria and Iraq. From Cordova on the Guadalquivir and Baghdad on the Tigris, emirs and caliphs administered their vast dominions (see map on p. 76).

The importance to science of this civilization, which had come into Europe across the Strait of Gibraltar, can best be realized by a description of Cordova (p. 74) in the tenth century. The neighbouring country showed the results of careful supervision in agriculture, trade and industry. Rice and sugar-cane were tilled in fields which had been irrigated by Arab engineers. Glass, ivory and leather were skilfully worked by craftsmen, and paper had replaced parchment in the careful and detailed manuscripts of the scribes. In the city itself an oriental display of splendour included nine hundred public baths for the physical welfare, and four hundred mosques for the spiritual welfare, of the inhabitants. Stone-paved streets, fountains, illuminations, marble and jasper architecture formed the background of life in Cordova. Christians under Moslem rule were allowed to retain their faith and engage in business on payment of tribute, and Jews played an important part in transmitting, to the rest of the

Mediterranean world, Arabic culture and Greek knowledge.

With such a background of civilization, it is no wonder that encouragement was given to some of the problems that had aroused the interest and speculation of the Classical period. A theory of matter was developed, based on Greek and Indian ideas, and it also included space and time, so that Allah was regarded as constantly re-creating the universe, which would otherwise vanish. More solid is the contribution to medicine and other science, for the ninth century medical schools were in possession of the Arabic translation of Galen's work, and early forms of practical chemistry were developed in connection with metal-working and the preparation of drugs. The influence of Arabic learning on alchemy will be referred to in the next section. The tenth-century writings on optics of an Arabic physicist, Ibn-al-Haitham (965–1020), had, through a Latin translation, considerable influence on Roger Bacon and Kepler.

The Arabic language, as a medium for conveying knowledge, was of great importance because of the translations made from many of the works on science of the Classical period. Such were Euclid's *Geometry* and Ptolemy's *Almagest*. By no means the least contribution was the introduction of the so-called Arabic numerals, which had come to the Moslem world from India. Modern computation would be out of the question if based entirely on Roman numerals.

The Arabs were also influenced by Hindoo work on Algebra (Arabic *aljebr*, reunion of broken parts ; this meaning is specially seen in the two sides of an equation which are united by the equals sign). Classical works, such as Aristotle's writings, ultimately were restored to the Western world through the medium of Arabic translations.

The Alchemists

In view of their importance as the forerunners of experimental chemistry, the work of the Alchemists deserves more than a passing notice in the background of science. The

origin of alchemy is uncertain; there may be a clue in a reference on papyrus found in a tomb at Thebes in Egypt. Among other workshop directions there was one for mixing and colouring metals so as to imitate gold for the manufacture of cheap jewellery. Perhaps one goldsmith, who had become particularly skilled in his art, might have deceived himself into the belief that he had actually changed the cheap metal into gold.

The derivation of the word alchemy is also somewhat confused: it is agreed that it is of Arabic descent, the prefix "*al*" being the Arabic article "the", but doubt has existed whether the main part comes from a Greek word meaning "pouring", or from the Greek name for Egypt; the latter is the more probable, and alchemy may be defined as "the Egyptian art". Emphasis on the art of changing the nature of substances led to the resources of "alchemy" being devoted to the transmutation of baser metals into gold.

One of the traditions among the Alchemists themselves refers to a certain Hermes Trismegistos, who is supposed to have lived about 2000 B.C. He is reputed to have inscribed the secrets of alchemy on an emerald, and presented it to Sarah, the wife of Abraham. Whether Hermes ever lived or not, his name is perpetuated in the term "hermetical" sealing, which is applied to a vessel that is made air-tight.

The Alchemists believed that, by removing impurities from matter, an essence or tincture could be obtained which, by its contact with baser metals, would transform them into gold. The association of alchemy with astrology is seen in the beliefs that the sun generates gold, the moon silver, Jupiter tin, Saturn lead, Mars iron, Venus copper, and Mercury the metal of the same name. It was considered necessary for the "patron planet" to be in the correct position if any chemical action was to take place on one of these seven metals.

Despite the superstitious nature of many of the beliefs held by the Alchemists, there was value in the actual performance of experiments, especially when this led to certain rules which must be observed for successful work. Probably



National Gallery

From a picture by the Dutch painter **Adrian van Ostade** (1610–85) called "The Alchemist", now in the National Gallery, London. From Prof. J. R. Partington's *Everyday Chemistry*

in the ninth century, a Persian alchemist, usually referred to as *Geber*, had at any rate realized the importance of careful observation, as the following extract shows : " I had a lodestone which would lift a piece of iron weighing 100 drams. I kept it for a long time and then tried it upon another piece of iron, which it would not raise. I thought, therefore, that the weight of this second piece must be greater than 100 drams, which was the weight the lodestone had raised before. Upon weighing it, however, I found that it weighed less than 80 drams. The force of the lodestone had therefore diminished, although its weight had remained constant."

The Medieval University

In the experiments of the Alchemists it is natural to anticipate the science of chemistry ; but progress was slow, and the dead weight of superstition and magic was not easily removed. At last, in the thirteenth century, *Friar Roger Bacon* maintained that experiment was the foundation of knowledge. Much of his work was done at Oxford, and it was significant of the times that communities of teachers and scholars were coming into existence outside the monastic schools, and thus paving the way for the modern university.

To appreciate the rise of the medieval university, it is desirable to trace the course of events in Europe, following the spread of Islam. One of the consequences of the fall of the Roman Empire in the west, and the Germanic invasions from the north, was to enhance the influence and prestige of the Church's representative at Rome. The Pope assumed increasing powers and, as we have seen, crowned Charlemagne as head of the Frankish Empire. The work of education, constructional engineering and general administration was associated with the bishops and their representatives throughout the Empire. In the fifth century the monastic movement spread from Egypt into the Christian churches of Europe. The more practical spirit of the Roman ultimately associated work with prayer, in the rule of St.

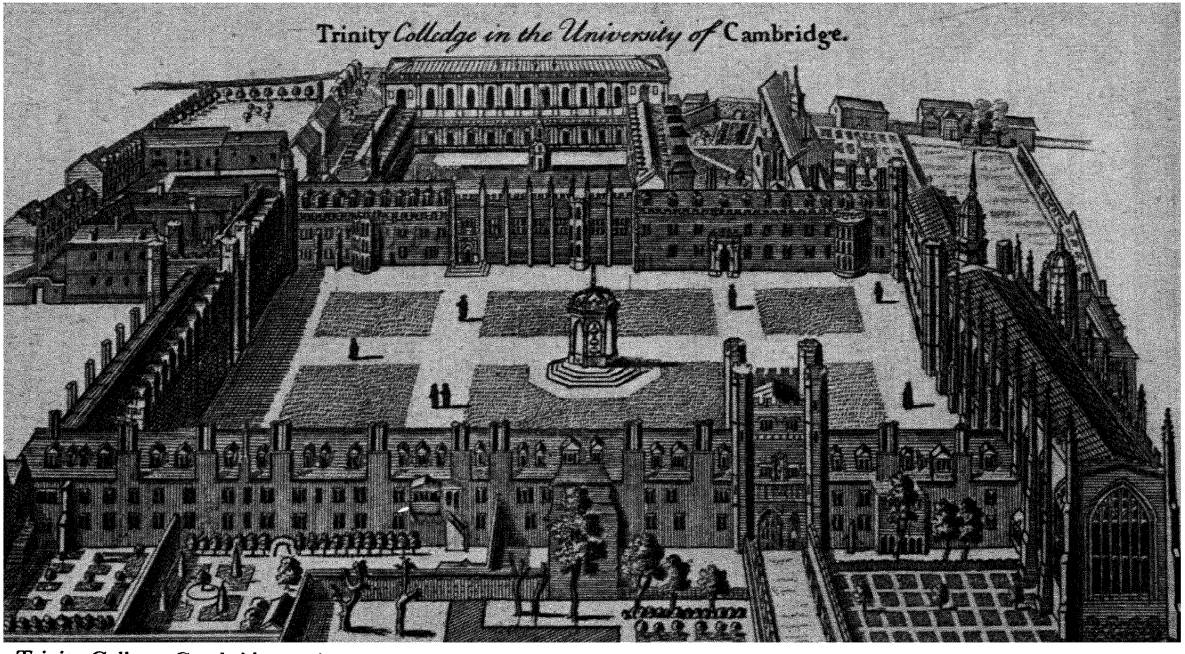
Benedict (480–540) "Laborare est orare". The Benedictines improved agriculture, reclaimed waste land, looked after the poor and carried on the work of copying manuscripts. Monte Cassino, the monastery which suffered so much through the fighting in Italy during the Second World War, was founded by St. Benedict. By the ninth century Benedictine monasteries had spread throughout Christendom. Reforms were started at Cluny early in the tenth century, and various orders such as the Carthusians and Cistercians had been founded by the end of the eleventh.

No sooner was there some semblance in the ninth century of a revival of the Roman Empire in the west, together with a check to the Moslem invaders from the south, than another source of trouble appeared in the north. The Norsemen expanded both to the east and to the west. In the former case the Swedes, having made a base on the borders of Lake Lagoda, migrated along the Volga to the Caspian, and along the Dniepr to the Black Sea, settling at Holmgarth (Novgorod) and at New Garth (Kiev). From their leader Ruric; they gave the name of Ruotsi (Russians) to the Slavonic peoples, to whom they introduced the art of state-craft. By the end of the ninth century they had made unsuccessful attempts on Constantinople, and while Swedes were trading with the Caliph of Baghdad, other prizes were held out to the Norsemen who migrated to the west. The treasures of the monasteries of Ireland, England and France attracted the attention of Danes and Norwegians, the former concentrating on the lands of the North Sea and English Channel, and the latter attacking the Orkneys and Shetlands, the Hebrides and the Isle of Man, and settling in northern Scotland, Northumbria and Ireland. Actually these Vikings also reached Iceland and the Faroes. From Iceland as a base, parts of Greenland and even of the North American coast were explored, some six hundred years before the voyage of Columbus. The skilled workmanship in the construction of their long narrow boats, under oar and sail, is a tribute to the practical knowledge and experience of those hardy sailors.

There is not space to pursue further the complicated movements and interaction of the races of Europe during the great formative period of the later Middle Ages. Alfred (848–899), and his heroic stand against the Danes, is full of interest to every Englishman ; his learning, his care for and education of his people, and the traditional founding of the Navy give just cause for the esteem in which this great West Saxon (or Wessex) monarch is held. The Norman influence at the Conquest, the foundations of English government, the Crusades to wrest the Holy Land from the Moslems, have their counterpart in the seething activity and religious wars of the continent of Europe. But enough has been indicated to reveal the complex forces at work towards the latter part of the Middle Ages, and into which was born that revival of learning which made possible once more the true spirit of inquiry.

One of the features of medieval life from the end of the eleventh century, and at intervals for nearly two hundred years, was the *Crusade*. The original intention was to wrest Palestine, and in particular Jerusalem and the Holy Sepulchre, from the Seljuk Turks, who had previously descended from Turkestan. They overran the eastern Moslem world, and embraced Muhammadism. Other motives entered into the later Crusades, but apart from territorial results, the ultimate trade with the Turks and Saracens brought to Europe the products of Persia, India and China, and formed a prelude to the travels of Marco Polo, through Asia to China, at the end of the thirteenth century. The commercial empire of Venice, and the impetus given to other Italian cities, together with the towns of northern Europe, are products of the spirit of adventure that had been displayed (see map on p. 76).

During this period of the Crusades another change was also evident, and had even more profound results. In particular, it affected the intellectual life of western Europe ; from the twelfth century onwards nothing less than a renaissance of the European mind was in progress. The earliest medical school is found in the eleventh century at



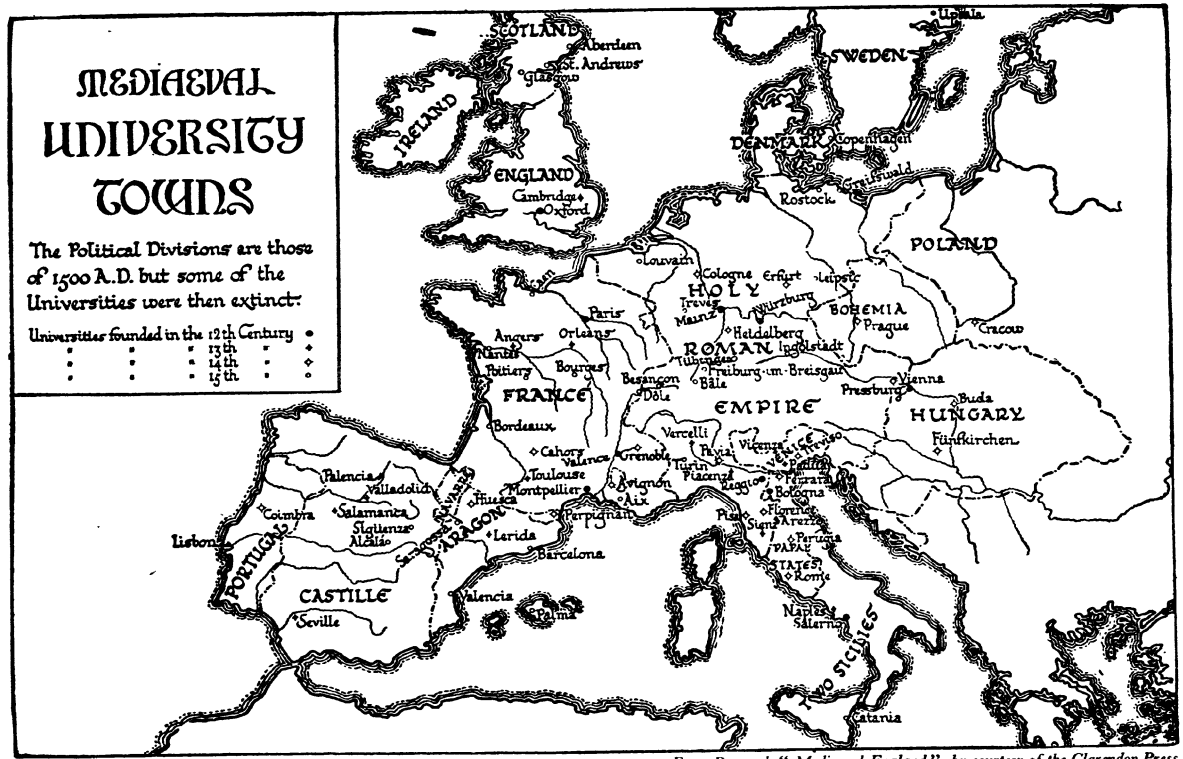
Trinity College, Cambridge, as it appeared in a print dated 1770. The Great Court is typical of the mode of building used in the medieval University

The Fountain (centre), Great Gate, Chapel (right), Master's Lodge (opposite Great Gate), Hall (behind Fountain), Library (centre background) and Neville's Court (left) still stand

Salerno (south-east of Naples, and famous for an Allied landing during the Second World War). The study of medicine there, based on the writings of Hippocrates and Galen, received a considerable impetus by contact with Jewish and Arabian physicians. In the twelfth century a centre of legal instruction arose at Bologna, where a guild of students hired the teachers — and often failed to pay them their wages — imposing fines if they were a minute late or kept their lessons over the appointed hour for closing. A day was graciously allowed in which to get married, but no time for a honeymoon. The northern seats of learning were based on Paris as a model ; here the chief study was theology, and the governing authority a guild of teachers instead of students.

During the twelfth century, conditions in Europe became more settled and travelling safer, and these formed a suitable soil for the nurture of the tree of knowledge. Sometimes singly, sometimes in bands, students, from boys to older men, could be seen travelling the roads from one centre of learning to another. From the " *Universitas* " or guild formed by the students has come the modern word " university ", and the present usage of the term is the result of a twofold process which has gradually evolved. On one hand there was the recognition of the teachers or masters ; on the other, the organization of the students. The university degree, which was the sign or recognition of a qualifying course of study, not only gave a man the right to teach, but also laid on him the obligation to do so.

Before the end of the twelfth century, Oxford possessed an organized body of teachers, whom it is thought may have originally been withdrawn from Paris by order of King Henry II, as a result of his quarrel with the King of France. By the end of the thirteenth century a similar development was in existence at Cambridge. The establishment of the collegiate system in the thirteenth century, whereby accommodation for students was provided, gave permanence to the universities, and was a notable feature at Paris, Oxford and Cambridge. The accommodation for an undergraduate



From Barnard, "Mediaeval England", by courtesy of the Clarendon Press

today may consist of an unnecessarily large living-room leading to a small bedroom (for example in the Old Court at Queens' College, Cambridge), but originally the large room would be used as a dormitory for students and, presumably, the small one for the tutor. The provision of such accommodation must have been urgent at Paris, where the number of students is said to have reached thirty thousand. In addition to the three universities already mentioned, there were two others in France and seven in Italy.

Roger Bacon

To understand the background of Roger Bacon's long life (1214–94), and especially the restrictions to which he was subjected towards its close, it is necessary to make some reference to the friars, and the stirring of men's minds in matters of religion which they represented. St. Francis (*c.* 1181–1226), who made Assisi his headquarters, felt called to a life of poverty, and practised self-renunciation, so that he could work among the outcasts of society — especially lepers. Those who followed his lead were his "brethren" or "friars" (Latin *fratres*, brothers) and were ultimately known as Grey Friars. The Black Friars, founded by St. Dominic (1170–1221), were commissioned to combat heresy by argument, so that learning played an important part in their training. The friars ultimately established themselves in the universities, and among the Franciscans at Oxford the name of *Friar Roger Bacon* stands out as a pioneer of the awakening spirit of scientific inquiry.

Roger Bacon was born near Ilchester in Somersetshire. His parents belonged to a wealthy and ancient family, and later they sacrificed their fortunes in the cause of Henry III in his struggle with the Barons during 1258–65. The normal occupation followed by a boy from such a family would be that of either knight or priest : most of the merchants, lawyers and traders came from the less distinguished households. The young Bacon was taught at home, and no doubt

received the customary instruction with regard to behaviour at court, for it is possible that when about nineteen years old he was a clerk among the courtiers of Henry III. As was the custom at that time, he went to Oxford at an earlier age than the modern undergraduate, perhaps about fifteen ; and with outlaws like Robin Hood and his " men of the forest " abroad, the journey thither would not be the simple matter that it is today. The bulk of the people were serfs, and everywhere superstition and error were to be found.

The recognized language of the nobility was still French, and even as late as the fourteenth century, the founder of one of the Oxford colleges forbade the use of English at the common table. But in the thirteenth century the patriotic chronicle — the " *Brut* " — of Layamon, a priest of a Severn village, was in the language of the English, in honour of the ancient heroes " who had held Britain from the time of the Great Flood ".

The world of Roger Bacon already foreshadowed a wider outlook. The aim of the *Knights Templars* (founded about 1118) was to combine the active crusading life with the discipline of a monastery. The friars had come to England while Bacon was quite young, and Franciscan priories and chapels were built among the poorest and most despised of the people. Possibly the picture of their sincerity in visiting the towns barefoot and lacking the commonest necessities may have remained, and ultimately influenced him in becoming a Franciscan himself.

At Oxford, Bacon studied under Robert Grosseteste (" Great Head "), the Chancellor, who eventually became Bishop of Lincoln. Grosseteste, too, possessed something of a scientific attitude ; he maintained that the Arabic translations of Greek authors were so inaccurate, and in consequence misrepresented the original meaning of the authors, that he introduced Greeks from the Near East as instructors in their own language, so that the works could be studied in the original tongue. With this spirit of accuracy Bacon was imbued, and it is not surprising that in later life he insisted on first-hand information, and laid down as axiomatic that

nothing could be fully known without experiment : incidentally, he was the first to point out that a knowledge of chemistry was an essential part in the training of a physician. Bacon also studied at Paris, and worked at science and languages, especially Arabic, and there obtained a doctor's degree in theology.

In the year 1251 Bacon was again at Oxford and devoted himself to research, spending hundreds of pounds on books and instruments. He was a deeply religious man and soon after his return to Oxford entered the Franciscan Order, becoming a friar, and was able with the help of his friends to carry on his experiments. The following quotation shows Bacon's ideal of a student. Even the most versatile of modern undergraduates or graduates would find the width of interests somewhat exhausting : " He makes no account of speeches and wordy conflicts but follows up the works of wisdom and remains there. He knows natural science by experiment, and medicaments and alchemy and all things in the heavens or beneath them, and he would be ashamed if any layman, or old woman or rustic, or soldier should know anything about the soil that he was ignorant of. Whence he is conversant with the casting of metals and the working of gold, silver, and other metals and all minerals ; he knows all about soldiering and arms and hunting ; he has examined agriculture and land surveying and farming ; he has further considered old wives' magic and fortune-telling and the charms of them and of all magicians, and the tricks and illusions of jugglers. But as honour and rewards would hinder him from the greatness of his experimental work he scorns them."

Bacon became unpopular because of his experimental method, and particularly was this the case after the death in 1253 of his former tutor, the Bishop of Lincoln. He was ultimately forbidden to lecture in Oxford, and later he was sent to Paris, and kept in close confinement for ten years in a Franciscan house. We are reminded of another pioneer of the Renaissance — Peter Abelard (1079–1142) — also a student of Paris, and similarly condemned for his beliefs. In

him also there shone the light of scientific method. "By doubting we are led to enquire ; by enquiring we perceive the truth." "We must not accept the opinion of any doctor, but weigh the reason of his doctrine."

During his time at Oxford, Bacon developed the study of optics. He understood something of the use of a convex lens for magnifying purposes, and also as a burning-glass. By 1385 there had grown up the legend of the magic mirror. "Friar Roger Bacon took such delight in his experiments that instead of attending to his lectures and writings he made two mirrors in the University of Oxford : by one of them you could light a candle at any hour, day or night ; in the other you could see what people were doing in the uttermost parts of the earth. The result was that the students either spent their time in lighting candles at the first mirror instead of studying books, or, on looking into the second and seeing their relations or friends dying and lying ill, left Oxford to the ruination of the University — and so both mirrors were broken by the common counsel of the University."

After being in confinement in Paris for nearly ten years, Bacon was asked by Pope Clement IV to send him a copy of his works. In eighteen months, after working under great difficulties with no instruments, and very likely only a few books, Bacon produced what had been requested, and in 1268 he was permitted to return to Oxford. Unfortunately, his patron Pope Clement IV died, and once more Bacon was accused of meddling with the magical arts ; and at the age of sixty-four he was again condemned to imprisonment in the Franciscan house at Paris. This time for fourteen years he suffered the loss of his liberty, but continued to write. He was released in 1292 and died two years later.

In addition to his work on optics, Bacon was also interested in mathematics and astronomy, which were supposed to have such influence on the life of the world. He is well known in connection with gunpowder, concerning which he says "a little matter, properly dispersed, about the bigness of a man's thumb, makes a dreadful noise, and occa-

sions a prodigious coruscation, and this is done in several ways; by which a city, or an army, may be destroyed after the manner of Gideon's stratagem, who having broke the pitchers and lamps, and the fire issuing out with an inexpressible noise, killed an infinite number of the Midianites". Bacon was also one of the earliest writers in the Middle Ages on geography. In one of his writings he prophesies that one day ships will go on the water without sails, and carriages run on the road without horses, and that people will make machines to fly in the air. This was, of course, pure speculation, but shows the penetrating power of his mind.

The greatness of Roger Bacon in the story of science is not to be found in any one achievement, but in his whole outlook toward the superstition and ignorance by which he was surrounded. In spite of the hostility of accepted belief, and in spite of the imprisonment and loss of liberty he suffered, Friar Bacon pressed onward in his search for truth. He was a bold champion of inquiry, experiment and observation.

CHAPTER X: THE BROADENING HORIZON

Medieval Communications

THE thousand years between the fall of Rome and the discoveries at the end of the fifteenth century may conveniently be divided into three periods, so far as the progress of human knowledge is concerned. The first, from the sixth to the eleventh century, is characterized by the loss of those scientific concepts associated with the Classical period, and their replacement by dogmatic assertions frequently without the support of experiment. The second, from about A.D. 1000 to the beginning of the fourteenth century, is the period of the Crusades, of travel and of commerce. Arabic learning stimulated the spirit of inquiry, and introduced mankind again to the writers of ancient Greece. The third period, comprising the fourteenth and fifteenth centuries, is a culmination of that which had preceded it; practical affairs increasingly took the place of theoretical considerations, and foreshadowed the rebirth of the scientific mind.

The thirteenth century, in which Roger Bacon lived, was also the period when the Scholastic movement reached its zenith under Albertus Magnus and his pupil St. Thomas Aquinas. The term "Scholastic" is derived from the characteristic Schools, like those founded by Alcuin (p. 78), which became the centres of learning and speculation of that period. By these "schoolmen" the whole philosophy of Aristotle was reproduced in systematic order, with constant reference to Arabic commentators, and remodelled to meet the needs of theological dogma.

Another characteristic of those times was that the roads of Europe were increasingly used by parties of scholars moving from one centre of learning to another; the roads were also the means of carrying trade, not only from within

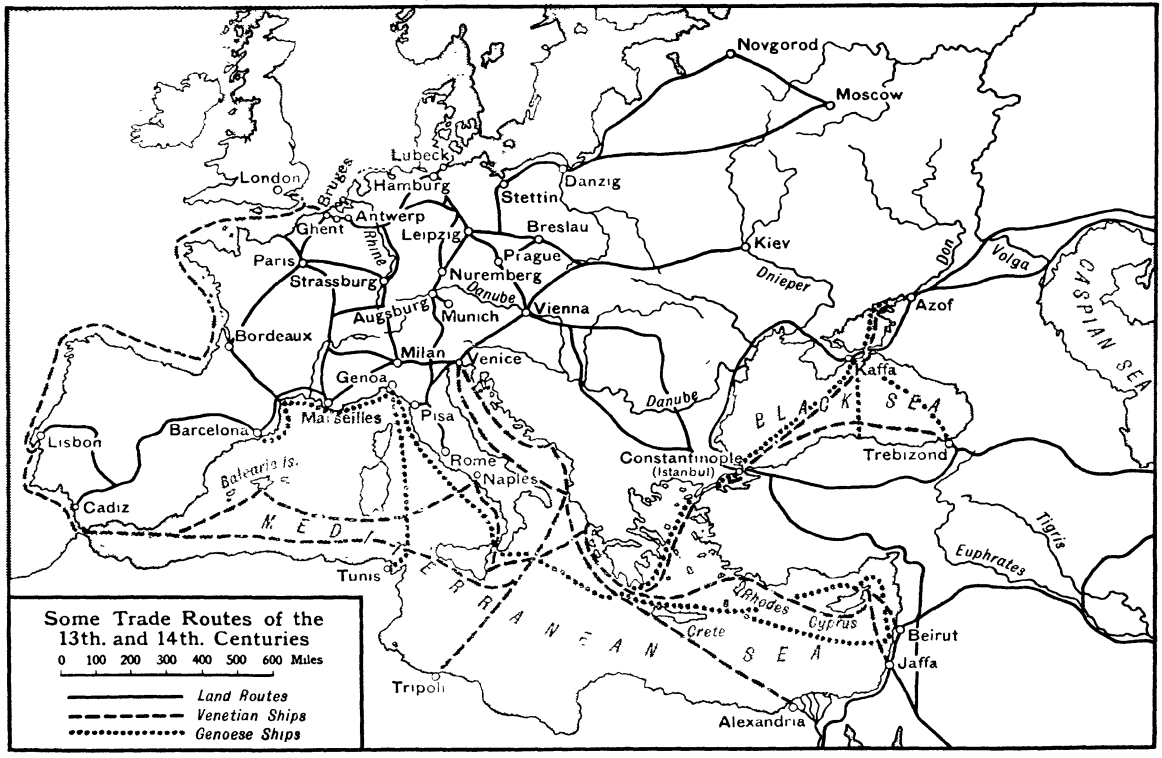


British Museum

Travel in the early sixteenth century was mainly on foot or horseback.
From Royal MSS. 18D ii, fol. 148

the continent itself, but from the ports that unloaded merchandise from the East (see map). Though the galleys of Venice, Genoa and Pisa plied an eastern trade, their ships went only to the ports of the Levant on one hand, and to Alexandria on the other. Beyond these, the routes to China and India were blocked by the Turks, as was also the completely overland route through central Asia.

East and West were therefore shut off from each other, despite the merchandise that passed between them. For one brief period, however, between 1245 and 1345, they were brought into contact, and a considerable amount of information of Eastern lands and peoples was added to the general knowledge of the earth's surface — a very necessary


Novgorod
Moscow
Lubeck
London
Bruges
Hamburg
Stettin
Danzig
Antwerp
Ghent
Leipzig
Breslau
Rhine
Kiev
Paris
Prague
Dnieper
Don
Volga
Strassburg
Nuremberg
Danube
Azof
Augsburg
Munich
Vienna
CASPIAN SEA
Bordeaux
Milan
Venice
Kaffa
Genoa
Danube
BLACK SEA
Marseilles
Pisa
Lisbon
Barcelona
Rome
Constantinople
(Istanbul)
Trebizond
Balearic Is.
Naples
Cadiz
MEDITERRANEAN SEA
Euphrates
Tigris
Tunis
Rhodes
Crete
Cyprus
Beirut
Jaffa
Tripoli
Alexandria
Some Trade Routes of the 13th. and 14th. Centuries
0 100 200 300 400 500 600 Miles
Land Routes
Venetian Ships
Genoese Ships

preliminary to any scientific study of geography or geology. The reason for this contact is surprising; it was due to the conquests of a nomadic Mongol people from central Asia, of the same stock as the Turks, who were known as Tartars. These conquests resulted in an enormous empire stretching from the Yellow River to the Danube, and from the Persian Gulf to Siberia. This was finally administered towards the end of the thirteenth century by four Khans, and ruled over by the Great Khan at Peking: they communicated with each other by messengers over the whole of that vast area. Though in the early part of the century it seemed as if both Christendom and the Moslem world would be engulfed, it was only the latter that was seriously affected, and it became known in Europe that the Tartars were tolerant to all creeds, Buddhist, Muhammadan, Jewish and Christian. So in the West there arose the dream of converting the Tartars to Christianity, and thus achieving the ideals of the crusades by forming a great Tartar-Christian alliance.

The first known travellers sent on a diplomatic mission to the Great Khan were Franciscan friars, who were dispatched about the middle of the thirteenth century. Ultimately, in response to a request for men of learning, *Marco Polo*, then only seventeen years old, accompanied his father in 1271 with letters from the Pope to the Great Khan in distant Cathay. From 1275 until 1292 Marco Polo remained in China, and brought to light hitherto unknown information concerning country, inhabitants and customs. He returned to Europe, reaching Venice in 1295. The long-horned mountain sheep of the icy highlands of Pamir were observed by Polo, and are now known as the *Ovis Poli*. The exact and detailed knowledge contained in his reports stimulated European interest and active support, and for about the next fifty years a steady stream of travellers journeyed east. But at the end of that time the contact between East and West ceased. Islam had once more been successful, and a revolution replaced the Tartar dynasty in China by a native one, the Mings. Of the unification of Asia by the Mongols, Eileen Power quotes a French historian who maintained

that it " was as important a fact for the commerce of the Middle Ages as the discovery of America for the men of the Renaissance ".

Despite the obvious advantages that the century of contact with the East gave to Europe, there was at least one serious result which had far-reaching and disastrous consequences. In all probability the Black Death, which originated in China, reached the West from Kaffa (a port in the Crimea, the modern Theodosia) by means of a Black Sea ship sailing for Italy. This disease, now known as bubonic plague, devastated Europe during 1347–51, and together with the results of the Hundred Years War between England and France left little enthusiasm or even opportunity for progress in science.

Invention of Printing

From such conditions in the fourteenth century, which also included, as we have seen, the loss of contact with the East, we turn to the fifteenth century, in which the art of printing and the adventure of discovery combined to broaden the mental horizon of mankind.

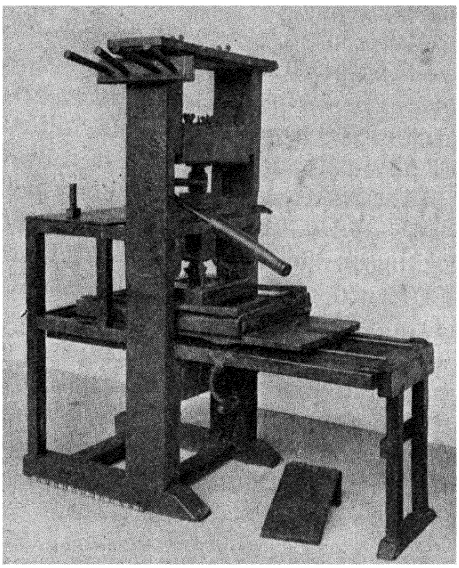
Communications, whether by road or sea, were undoubtedly useful for the interchange of goods and for the journeys of men, but until the invention of printing the spread of information was largely dependent on the comparatively slow method of passing it on by word of mouth. Books were in manuscript, and could only be circulated by the laborious process of making individual copies.

The capture of Constantinople by the Turks in 1453 is frequently taken as a convenient dividing line between medieval and modern history. It is significant that while the spirit of the Renaissance was transforming the outlook of the few, there should arise a mechanical means of spreading the new ideas to the many, which was far superior to any method known in the monasteries, schools or universities of the Middle Ages. The invention of printing with movable

types takes its place among the most outstanding of human achievements, for it opened the possibility of the universal spread of knowledge and of the accumulated experience of mankind. It thus laid the foundation of modern civilization. But the actual date, person or country which should be associated with this invention is still, and may always be, a matter of dispute.

One of the earliest dates that can be assigned to the printing of single pictures, from wood-blocks, is 1423, and refers to the portrayal of St. Christopher ; one of these imprints is now in the John Rylands Library at Manchester. The next stage presumably was the addition of some descriptive text. At first a thin, pale-brownish ink was used on one side of the leaf only, and the impression taken off by means of a burnisher rubbing over the reverse side. Later, both sides of the paper received an impress in turn in black printing ink, by means of a mechanical press. The process of engraving blocks of wood for ordinary letterpress was slow and laborious, so that only works likely to be in reasonable demand could be printed. With the advent of type for separate letters, which could be used over and over again, and be set up far more quickly than by engraving wood-blocks, the art of printing assumed fresh importance and wider scope.

There is considerable doubt as to who invented movable type ; despite Dutch claims, it is reasonable to attribute this to *Gutenberg of Mainz*, and it is known from a Strasbourg lawsuit of 1439 that a certain goldsmith sold Gutenberg printing materials in 1436. In the decade 1440–50 an effective process was established and printing became a practical proposition in Mainz, and by 1458 had been carried to Strasbourg. The early books were not dated, otherwise a greater degree of certainty would attach to conjectures of time. The first book in Italy was printed about 1464, and in the following year a press was set up in the Benedictine monastery of Subiaco. France, Bohemia, Hungary and Poland followed, and the Belgian press at Bruges is of special interest, as England's first printer, William Caxton,



Crown copyright. By courtesy of the Director, The Science Museum, South Kensington

Printing press of the type used by Caxton

worked in partnership there before returning to his native country.

The Broadening Horizon

William Caxton (*c.* 1422–91) was born in the weald of Kent, possibly at Tenterden, and after serving as an apprentice to a mercer in London, he took up residence in the Netherlands and by 1463 occupied the position of Governor of the English Nation in the Low Countries. While at Cologne in 1471 he probably learnt the technical side of printing, and helped to produce at least three books at the Bruges press between 1474 and 1476.

On his return to England in 1476, Caxton established the first English press at the sign of the " Red Pale " near Westminster Abbey, on a site now forming part of Tothill Street. The earliest known product of the English printing

press was an " Indulgence " issued on December 13, 1476. But Caxton did not confine himself to mere printing. He saw the boundless possibilities of the invention, and its superiority over the laborious methods of the monastery scribes, or professional copyists. While still at Bruges he refers to the physical and mental strain which he had suffered : " in the wrytyng of the same my penne is worn, myn hande wery and not stedfast, myn eyen dimmed with overmoche lokyng on the whit paper . . . therefore I have practysed and lerned at my grete charge and dispense to ordeyne this said book in prynte after the manner and forme as ye may here see ". The " said book " was a translation made by Caxton himself of the *Recuyell of the Historyes of Troye*, and was the first book printed in the English language (1474).

Caxton's vision was an indication of the broadening horizon of the fifteenth century. His translations from the French provided a wider selection of literature for the leisure of English readers. His volumes of poetry and romance encouraged interest in such literary achievements as Chaucer's *Canterbury Tales* (written between 1387 and 1400). Caxton's edition of the latter was the first printing of an English classic. In this way he not only acted as printer, but also as editor and author, thereby anticipating the role of the good publisher, who should be concerned not only with the production of a well-printed book, but also with the quality of its contents.

With the increase in the number of books, there was a tendency for the old method of spreading information verbally to be superseded, especially in those European areas where there were recognized routes of communication. But although much knowledge of the Far East had been collected by travellers such as Marco Polo, regions to the west of Europe remained unknown, so information concerning the earth's surface was incomplete. Books could not be circulated in advance of discovery, and while the horizon of knowledge was being broadened by the invention of printing, the horizon of unknown continents was being enlarged by fifteenth-century voyages of exploration.

For men of the earlier civilizations, the sun had set toward the Mediterranean; for the Greeks, toward Italy; for the Romans, toward Spain; but for the Portuguese, toward an apparently unbounded ocean. Throughout the fifteenth century, sailors of this "Land's End" of Europe were ushering in an age of discovery, which by the end of the century had so enlarged the possibilities of Mediterranean civilization that the new age can best be described as the *Atlantic Period.* In 1419 the Portuguese had discovered Madeira; in 1434 they had turned Cape Bojador on the north-west coast of Africa and reached the Tropic of Cancer; in 1445 they had pushed farther south to Cape Verde.

It is easy to under-estimate such achievements, unless the superstitious background of the time is realized. For example, it was generally assumed that human life in the last-mentioned zone was impossible, so that any expedition thither placed the whole of a ship's crew in jeopardy from the start. True, the idea of sailing round Africa to the East was not new; it may have been achieved by the Phoenicians, and it certainly was attempted from Genoa at the end of the thirteenth century, but the Portuguese, having learned from the shipyards of the Italian port, held the key to ocean exploration in the fifteenth century. They led the way in attempts to reach the East by sea — now a matter of some urgency as the land routes had been blocked by the fall of the Tartar Empire, and the Moslem power again stood between Europe and the coveted oriental products.

Christopher Columbus

Few men have achieved greater fame than *Christopher Columbus* (*c.* 1451–1506). The original form of the English name, Columbus, whether Colombo, Colomo, Colom or Colón, need not detain us. The matter has been fully dealt with in a book *Christopher Columbus* (1939), by Salvador de Madariaga, together with the case for the Christian explorer's Jewish origin. There is doubt as to the date of

birth (evidence points to 1451) but more agreement with regard to the place, namely Genoa, and that the family's occupation was wool-weaving. Christopher's brother Bartholomew, perhaps ten years younger, settled in Lisbon, and busied himself with the production of maps for the use of mariners, and it was to Lisbon also that Christopher came, but in a more dramatic and sailor-like manner. For, having heard the call of the sea from the age of ten, and become proficient in navigation, he seems to have been involved in 1476 in a piratical battle off Cape St. Vincent, in which the ship on which he was sailing was set on fire, and he had to swim to the shores of Portugal with the help of an oar. To the highly imaginative and religious soul of the future discoverer, the saving of his life would be registered as a divine summons to use hand, mind and heart for the exploration of his Creator's world.

Columbus could not have come to a better country; something of its record in exploration and adventure has already been told, showing the important contribution that the Portuguese made towards the broadening horizon. Yet it was not to Portugal that Columbus owed the financing of his expedition. The story is too long to tell in detail, but at any rate a part of it is of scientific interest. Toscanelli, a physicist and mathematician of Florence who was contemporary with Leonardo da Vinci, had communicated to the Portuguese in 1474 a map and instructions for travelling to the East by sailing westwards: " and how many leagues you will have to cross to reach those regions most fertile in all kinds of spices and jewels and precious stones; and think it not marvellous that I call West the land of spices, while it is usually said that spices come from the East, for whoever navigates westward in the lower hemisphere shall always find the said paths West and whoever travels Eastward by land in the higher hemisphere shall always find the same land East ".

Unfortunately, though Toscanelli was right in principle, some of his assumptions were known to be wrong by the more experienced cosmographers of Portugal, and his letter and

plan were shelved. By 1480 Columbus probably knew of Toscanelli's scheme, but was unsuccessful in persuading the Portuguese Court to finance an expedition. In desperation he surreptitiously copied parts of the map, made extensive notes, and set out in 1484 with his son Diego, aged five, to the lands of Castille in Spain, where in 1486 he was allowed to place his plans before King Ferdinand and Queen Isabella.

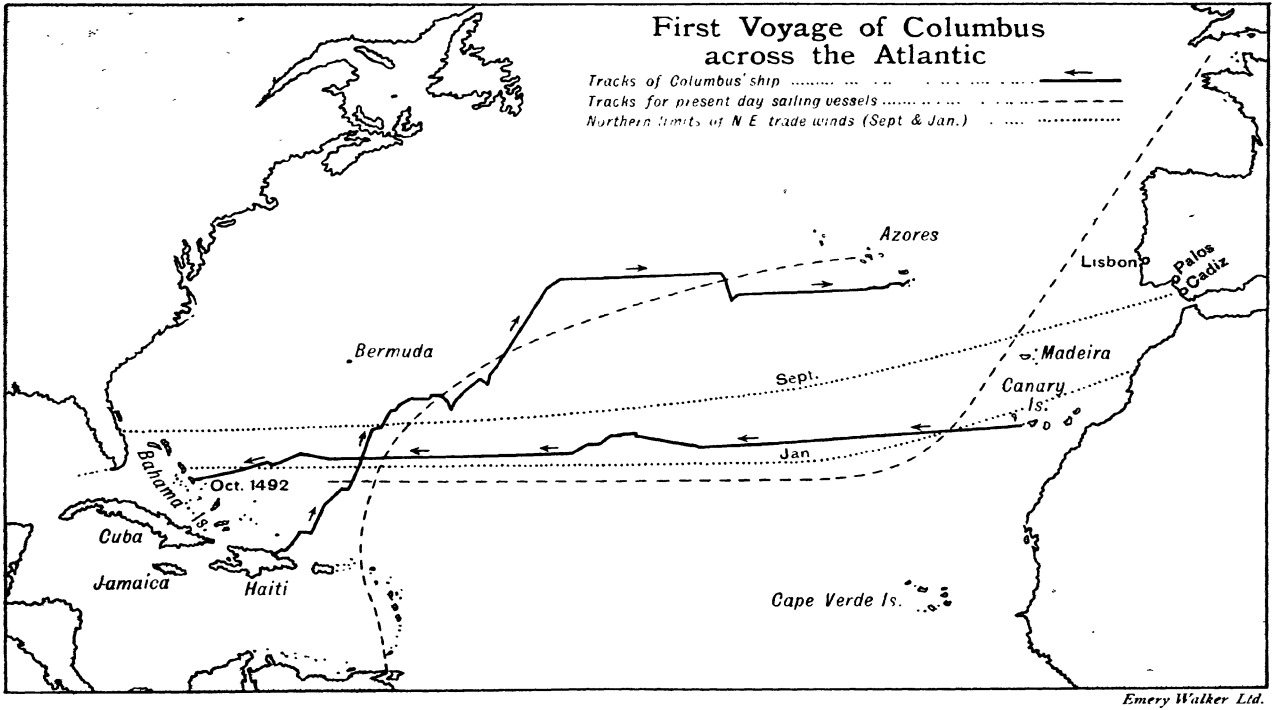
There were many difficulties to be overcome before Columbus finally set sail from Palos on August 3, 1492, in the *Santa Maria*, with two other tiny ships. Evidence is not wanting that Columbus may be regarded as a " Converso ", that is, of Jewish origin but converted to Christianity; it is at least a coincidence that he chose to weigh anchor on the day after the ships containing the Jews, who had been expelled from Spain, set sail. Once on the high seas further difficulties were encountered, this time at the hands of Nature, and of the human element as represented by his crews. True, he had in his wallet a letter from the King and Queen of Spain to the Grand Khan, together with a passport in diplomatic Latin ; he also had supreme confidence in himself, that by sailing west he would vindicate Toscanelli's claim and reach the eastern lands ; yet, even so, there still remained those two unknown factors — Nature, and human nature.

The magnitude of the task that faced Columbus is not easily appreciated in these days of accurate navigation and safe, luxurious and swift ocean travel. To him the voyage westward, though based on Toscanelli's scientific approach, was one of unknown hazard, taking the small fleet farther and farther away from any known land. The faith which Columbus possessed could not be shared by the seamen ; in fact to them Nature was showing herself hostile to the expedition. For example, on September 13 it was noticed that the magnetic needles pointed to the north-west, a fact which can be explained by the modern schoolboy in terms of magnetic variation. But not so by the navigators of those days who, though they knew the compass pointed

slightly east of true north, could only feel that their faith in the needle, as a sure guide, rested on a false foundation. The entry in Columbus's journal for September 17 is significant: they "found the needles deviating north-west quite a fourth of the wind, and the sailors were frightened and downcast and they would not say why". Columbus assured them, erroneously, that the Pole Star moved like others, and it was fortunate for him that at daybreak the needles were found "true" again.

Nature's secrets are not easily wrested from her, and in the light of the scientific knowledge of the fifteenth century Columbus's tenacity and skill are all the more outstanding. To him, God was in the prevailing easterly wind, to the sailors it was the devil: their conspiracy to throw him overboard was successfully dealt with, and on October 7 course was altered to follow the flight of birds to the south-west. On October 11 the crew of the leading ship picked up "a reed and a stick, and another stick carved, as it seemed, with iron tools, and some grass which grows on land, and a tablet of wood. They all breathed on seeing these signs and felt great joy." Two hours before midnight Columbus saw a light on land, and called two men to confirm it; one did, the other did not. Two hours after midnight, the leading ship gave the pre-arranged signals — the gunshot and hoisting the flag — for land had been sighted, and later, as the caravels moved toward the shore, crags, tall grass and unfamiliar trees confirmed the reality of a long-cherished dream.

On that historic day, Friday, October 12, 1492, when Columbus and his followers went ashore on what is now known as Watling, or San Salvador, Island in the Bahamas, the New World greeted the Old, and a new era had dawned. There is not time to tell of Columbus's subsequent voyages, of the Royal recognition of his discovery, and of his ultimate return as a prisoner at the hands of jealous men, and of his death in 1506. His place in the background of science is assured. It is not due merely to his discovery of America, so called from a Florentine merchant, Amerigo Vespucci,



From the point of view of seamanship, it is worth while comparing Columbus's route with that of modern sailing vessels crossing the mid-Atlantic; he made full use of the North-East Trade Winds

who claimed to have taken part in an expedition westwards from Cadiz in 1497. The Vikings had made a more northerly crossing before him, and it is possible that the Danes with Portuguese representatives on board coasted along the St. Lawrence in 1472–73. It is not because he stands at the threshold of a new period of civilization, which we have called " Atlantic " — others have occupied a similar position; for example, the despotic rulers of the East at the threshold of the Classical civilization of the Mediterranean. Columbus's claim to a place in the story of science rests rather on his attitude to theory, which for him had to be *tested.* Looked at from this point of view, his first voyage was in the nature of a great experiment. He was convinced of the soundness of Toscanelli's belief, but that was not enough. He appealed to Nature in the spirit of scientific inquiry, and despite human doubts, and though he did not reach the East or discover a North-West passage, some of her secrets were revealed, and the existence of a New World established. At times his success was threatened by the weakness and obstinacy of human nature, but this did not shake his faith in the great experiment on which he had embarked.

In 1498 Vasco da Gama had reached India by sailing round the Cape of Good Hope, and voyaging eastward. But belief in a westerly passage persisted, and at the beginning of the sixteenth century the scientific spirit of exploration, so characteristic of Columbus, found expression in *Magellan* (1480–1521). This explorer believed there was a way round South America to the East, and despite almost insuperable difficulties from the weather and from mutineers, he was successful in discovering it, thus proving by experiment what he had held firmly in theory. Magellan actually found the islands of the East by sailing towards the west from Spain, and rounding South America through the strait which now bears his name. From the tempestuous seas of those regions the expedition ultimately reached more friendly latitudes, and gave the name *Mar Pacifico* to the sea which, though rolling majestically, showed no sign of storm — the *Pacific Ocean* as we know it.

THE MEDITERRANEAN PERIOD–MEDIEVAL

ACTION		KNOWLEDGE	VISION	
A.D.				A.D.
500		BOETHIUS	St. Benedict	500
	Justinian			
600			St. Augustine of Canterbury	600
	The "Hegira"		Muhammad	
700				700
		ALCUIN OF YORK		
800	Charlemagne			800
900	Alfred			900
		ARABIC SCIENCE		
1000				1000
			Carthusian Monks	
		THE ALCHEMISTS	Cistercian Monks	
1100	Crusades		Medieval Universities	1100
	Teutonic Knights			
1200			St. Francis of Assisi	1200
			Magna Carta	
		ROGER BACON	St. Dominic	
1300	The Tartars	MARCO POLO		1300
	Hundred Years War			
	The Black Death		St. Thomas Aquinas	
			Petrarch	
1400			Chaucer	1400
		CAXTON		
1500				1500
		COLUMBUS		

Magellan was killed afterwards by hostile natives who inhabited one of the small islands of the Malay Archipelago. Only one boat, the *Victoria*, of his former fleet of five survived the hazards of that three years voyage (1519–22); but it had the distinction of being the first ship known to have sailed around the world, thus providing substantial evidence in support of the scientific belief that the earth is round. The *Victoria*, of only eighty-five tons, is typical of medieval travel by sea, and is a reminder of the dangers which beset the most resolute commander, whether due to the uncertainty of the elements or the fickleness of the crew.

At the end of the Atlantic Period we shall find the same two unknown factors, Nature and human nature, and though the conquest of Nature had then reached the stage of ushering in a World Period, the selfishness and lack of vision of human nature came near to wrecking the whole fabric of civilization.

CHAPTER XI: THE WIDER OUTLOOK

The Renaissance

THE danger of associating definite dates with periods in history has already been mentioned, and it exists especially if an attempt is made to limit the beginning or end of that gradual change in the character of the Old World civilization known as the Renaissance. The change took place in different countries at different times, and was due to natural development, not artificial arrangement. The increase in trade that had taken place toward the end of the Middle Ages resulted in the Italian trading centres, and especially the ports, being in close touch with the Near and Far East; this meant a spread of oriental ideas as well as merchandise throughout Europe. With developing commerce and consequent increase in wealth, merchants found themselves in possession of leisure. So for the first time since the fall of Rome men had reasonable opportunity of acquiring knowledge without entering the Church.

Through most of the Middle Ages life had consisted of a struggle for food, and many had resigned themselves to an existence of hope, with the promise of fulfilment after death. The rich and varied life of Italy in the fifteenth century finally changed the old atmosphere of simplicity and resignation to one of leisure and possibility, in which the influence of the East, and the learning of the Classical period, challenged the minds of such as now had the time and inclination to think. As early as Petrarch (1304–74), who was of Florentine origin, and travelled between the cities of Avignon, Milan, Venice and Padua, the change was felt and expressed. Petrarch sought the inspiration of the classics, both Greek and Latin, yet was also conscious of the

medieval ideal that life was only important as seen through death. He renounced the world, and almost at the same time enjoyed it. He preached liberty and independence, but sought the patronage of great men. In him we see the beginnings of the spirit of the Renaissance, which ultimately led to the final break with accepted authority, and in his hesitancy we are reminded also of the difficulty of attempting to fix a date when the new era began.

The influence of the Renaissance was evident in the treatment and use of languages such as English, French and Italian, and the production of a literature based on them. It was seen in the revival of learning, and the introduction of the critical spirit of inquiry. The printing press enabled the results to be made permanent and widely known, and the influence on education was lasting. A professorship of Greek had been established in Florence by 1400, and this language was introduced into the curriculum of schools. Smaller classes were advocated, and relations between boys and masters were aimed at which were not based on force. In art there were two changes which took place in the motive of the artist, apart from the improvement in materials and the theory of perspective. The first was the demand from nobles and merchants for the decoration of places other than churches, so that subjects need no longer be religious ; the second followed from the first, and allowed the subject to speak for itself, rather than being made to represent a preconceived idea.

To sum up the change associated with the Renaissance, two men who lived at the end of the fifteenth century may be mentioned. One was a type of what had been, and the other of what was to be. They met in Florence in 1491, the former a Dominican friar, Savonarola, and the latter Lorenzo de Medici. Savonarola implored the people of Florence to throw away their books and jewels, and by repentance prepare for the disaster about to overtake Italy. Lorenzo, on the other hand, maintained that man's aim should be the development of all his powers to the highest degree. He believed in combining contemplation with

action, and living so as to enjoy the whole of life. A modern author has written of these two: "Lorenzo went very near to the achievement of his aim because he was in sympathy with his age. Savonarola failed because he was an anachronism."

Into that new age, which geographically had moved westwards from the limits of the Mediterranean to the expanse of the Atlantic, came the pioneers of our modern life, the men of the fifteenth and sixteenth centuries, the scholars, the artists, the explorers, the poets and the scientists; and as a tribute to their outlook, Nature herself seemed to foreshadow their achievements in the person of one genius, Leonardo da Vinci, who in himself transformed the narrowness of medieval tradition into the broader spirit of the Renaissance.

Leonardo da Vinci

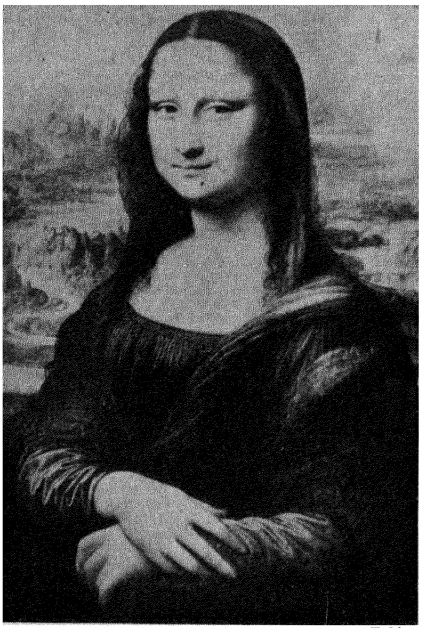
From the complex background of European life and thought there emerged in the second half of the fifteenth century a man in whom the very atmosphere of the Renaissance seems to have been concentrated. The many interests of *Leonardo da Vinci* (1452–1519) reveal the sensitiveness of the artist, and the insight of the man of science: his wide outlook was characteristic of the new intellectual awakening that was already making itself felt. His life consisted of four phases which may conveniently be studied in relation to the cities in which he lived. The first, until he was thirty, centres around Florence; the second, until he was forty-eight, around Milan; the third, until he was sixty-four, in Rome and Florence; and the last three years of his life were spent in France.

Leonardo was born in the small hill-town of Vinci near Florence; his father came from a long line of lawyers, though his mother was of peasant origin. At an early age he developed a talent for music, modelling, drawing and arithmetic. Later his aptitude for painting revealed itself to such an extent that Leonardo's father entrusted him with



LEONARDO DA VINCI
From a self-portrait in the Royal Palace, Turin

the decoration of a round wooden shield, which it was customary to hang on the walls of any house of importance. The work was based on a collection the boy had made of " lizards, snakes, crickets, centipedes, moths, scorpions and bats ", and consisted of a combination of the more terrifying features of these animals. The result portrayed on the shield was a monster emerging from its den " with smoking nostrils and flaming eyes ", and was so illuminated that after Leonardo's father had been duly alarmed, he considered his son's talent worthy of special training. The boy was sent to Florence, where as a pupil of a goldsmith, Verrochio, he



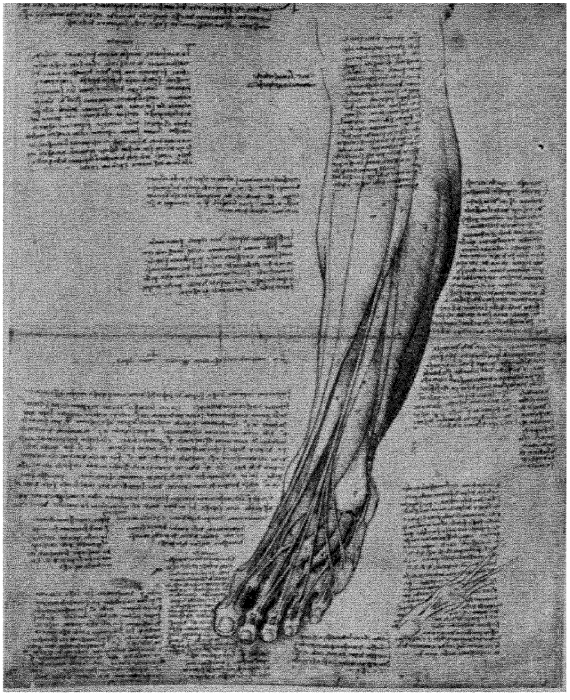
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The Mona Lisa, by Leonardo da Vinci.
" One of the most beautiful and finished portraits in the world "
(*Oxford Companion to English Literature*)

came into contact with a brilliant group of young painters.

The Renaissance period included an awakening of the scientific spirit, and in the workshop at Florence one of the subjects of keen discussion was the effect on art of the theory and laws of " perspective " which had recently been put forward. Leonardo's painting was of such quality that, at the age of twenty, he was enrolled as a member of the Florentine Guild of Painters, and five years later he was commissioned by the City Council to paint an altar-piece for one of the chapels in the Old Palace. It was evidently not realized how slow Leonardo could be in the execution of his work, for although money was paid on account, he did not produce the picture, and five years later the commission was transferred to another artist.





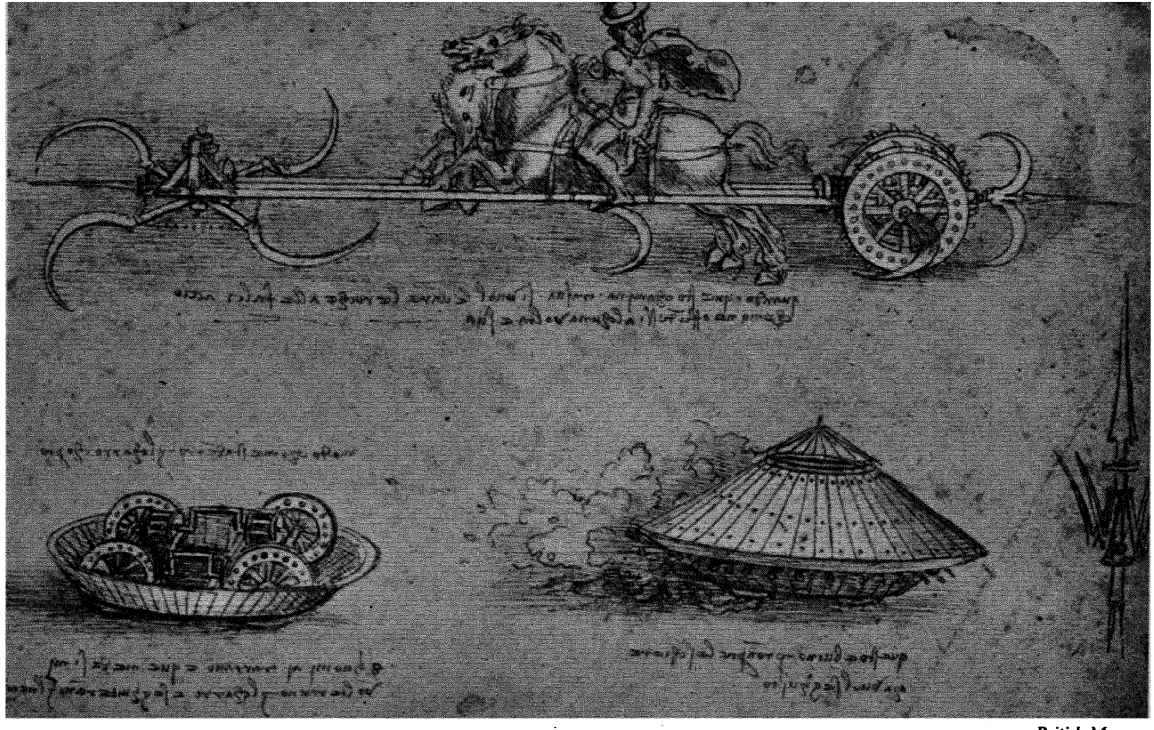
By kind permission of the Librarian, Windsor Castle

Drawings by Leonardo. On the left, **sketches for Sforza Statue** (see p. 121). On the right is a drawing of the Human Leg with manuscript notes which demonstrate his anatomical knowledge

Towards the close of his close association with Florence, when Leonardo was twenty-nine years old, he had produced very little important work, but had attained considerable fame. One other incident of this time may be recorded before passing to the next phase of his life. Despite the experience of the City Council, the monks of a rich monastery commissioned Leonardo to paint a large altar-piece, and being determined that the picture should radiate brightness and give an impression of richness, they supplied the artist with expensive ultramarine and gold. A subsequent comment written by Leonardo reveals the scientific and artistic combination so characteristic of this remarkable man: "Bright colours captivate the crowd, but the true artist seeks to delight the judicious rather than the vulgar. His aim, his pride is not to dazzle with colour but to perform a miracle — to use the play of light and shadow in such a manner that things which are really flat [that is, painted representations] shall appear to be round. To sacrifice shadows to mere splendour of colour is to behave like a babbler who cares more for high-sounding language than for the significance of what he is saying."

In 1481 the optimistic monks sent Leonardo a cask of red wine, presumably with the hope of stimulating his artistic spirit, but they too were disappointed and had to cancel the commission.

In the following year Leonardo moved to Milan, which may be described as the Italian gateway into Europe. Here, under the patronage of the wealthy Duke of Milan, he undertook work, not only as a sculptor, painter and musician, but also as an engineer and authority on town-planning. There is a modern ring in his description of military skill. "I have a method of making bridges that shall be light, strong and easy to transport, others, again, which cannot be destroyed by fire or battle. Also methods of burning or otherwise destroying the bridges of the enemy. I am able to lay mines noiselessly, and even, if required, under a trench or a river. I will also make covered chariots, immune from attack, which will be able to pass into the ranks of the



British Museum

Engines of war proposed and sketched by Leonardo

enemy, despite the opposing artillery, and will be indestructible by even the largest body of men. Behind these the infantry could follow unhurt and unhindered."

His devices for prosecuting a naval battle may have included some form of torpedo. The use of poison gas seems to have been contemplated. Irrigation, canals, street-lighting, decoration, steamboats, flying machines, all came within the scope of his versatile mind.

Leonardo had written to the Duke that he was ready to undertake " the construction of the Bronze Horse which is to be the immortal glory of the prince your father and of the illustrious House of Sforza ". Work on this (p. 118) and on his most ambitious achievement, the fresco entitled " The Last Supper ", was carried out intermittently over a period of years. Apparently the Duke's patience was exhausted in 1489, when he invited other artists to undertake work on the Horse.

The big fresco of " The Last Supper " was painted well above the floor, and an eyewitness describes the progress of the work as follows : " Leonardo used to go early in the morning — I myself have more than once seen him do so — and climb the scaffolding, and there, from sunrise to sunset, forgetting to eat or drink, he would paint without ceasing. On the other hand, he would sometimes spend the next two, three or four days doing nothing to it, but staying for an hour or two each day and just looking critically at the figures and considering his work. And again I have seen him, if the humour took him so, leave the Corte Vecchio at mid-day, when he was working there at the clay-model of that stupendous Horse which you know about, and going straight to the monastery, mount the scaffolding, take up his brush, give one or two touches to a figure, and then, quite suddenly, come down again and go off somewhere else."

In 1498 " The Last Supper " was finished, but was foredoomed to ultimate destruction. Despite advice to the contrary, Leonardo had painted in oils (so that he could make corrections) on, as he claimed, a suitably prepared background, but the dampness of the monastery wall,

which was on the verge of a marsh, soon made itself felt, and within forty years the masterpiece was blurred. Napoleon's soldiers some three hundred years later used the room for stabling and threw their missiles at the remains of the painting. Even the clay model of the Horse met a similar fate. The French had occupied Milan, and in 1501 Gascon archers practised their skill where previously Leonardo had spent so many hundreds of hours. The Duke of Milan was a prisoner in France, and Leonardo stayed on for a while in Milan, hoping to redeem his losses at the hands of the French. Eventually he returned to Florence, when Michelangelo was twenty-four and Raphael eighteen. At this time Leonardo's interests turned from art to science, and the third period of his life was spent chiefly at Rome and Florence.

For two years Leonardo served the infamous son of an infamous Pope as engineer-in-chief. Cesare Borgia intended to succeed his father Alexander VI in the papacy, and was absolutely unscrupulous in the methods by which he endeavoured to achieve his object. Macchiavelli comes into Leonardo's life at this time. The hero of Macchiavelli's book *The Prince* was his master Cesare Borgia, and the book exalts success above morality; so much so that the unscrupulous nature of its author has been perpetuated in the English word "Macchiavellism", which is the doctrine that in "upholding order in a State, the ruler should hold himself bound by no scruple". In a decree to his officers and subjects, Cesare Borgia describes Leonardo as his "well-beloved servant, architect and engineer-in-chief, whom we have appointed to inspect strongholds and fortresses in our dominions, to the end that according to their need and to his counsel we may be enabled to provide for their necessities . . . it being our will that in the carrying out of any works, in our dominions, every engineer will be bound to confer with him and to follow his advice". Leonardo, however, did not lend himself to the machinations of his new patron, and while Cesare Borgia, as a man of action, was enticing his victims to their doom or spoiling a city, Leonardo, the

man of knowledge, was searching for the works of Archimedes, or observing the peaceful flights of birds. To Leonardo there must have come an element of relief when Borgia's father died suddenly, and all hope of his master's succeeding to the papacy vanished with the election of another Pope.

We need not linger on the disagreements between Leonardo and Michelangelo, but some of the bitterness of the younger man may possibly be explained on political grounds. At any rate both artists were commissioned to paint a battle-picture on opposite walls of a public building, in order to spur on the Florentines who were besieging Pisa in the summer of 1503. Leonardo was ordered to investigate the practicability of reducing the town by deflecting the river Arno, and was dispatched in haste in a coach-and-six from Florence to Pisa. But there is no record of further development. During this time intermittent work was done on the portrait of the Neapolitan Lady, " Mona Lisa " (p. 117). Subsequent years were spent at Milan and Rome, and though his prestige as a painter did not lessen, Leonardo's knowledge of human anatomy was increased by his interest in hospital patients and human dissection (p. 118). While at Rome, Leonardo's fame was eclipsed by his rival Michelangelo, and he was unpopular with the Pope. Early in 1515 he was apparently in Milan again, and when that city was taken by the French king, Francis I, who entered the city in triumph, Leonardo probably produced the most elaborate of his toys — a mechanical lion which paced round the hall, stopped in front of the king, and opened its breast, from which fell a mass of lilies, the emblem of the Bourbons.

The concluding years of Leonardo's life were spent in France as the court artist of Francis, and though by 1517 his right hand was paralysed, he continued to draw and write using his left. Among the engineering schemes in which he was interested was one for joining the rivers Loire and Saône. While working on his last picture, " Saint John the Baptist ", paralysis had taken its hold, but his earlier passion for art still remained, together with his later interest in more practical affairs ; so until his death in

1519 there was revealed the twofold nature of one who, in himself, joined medieval to modern, and linked the heritage of the past with the promise of the future.

The Wider Outlook

" If we had to choose one figure to stand for all time as the incarnation of the true spirit of the Renaissance, we should point to the majestic form of Leonardo da Vinci." In these words Sir William Dampier sums up the uniqueness of this remarkable man. Some men of genius may be remembered by the quantity as well as the quality of their work ; others like Thomas Gray have entered the realm of the immortals with only a small volume to their credit. Of Gray it has been said that few published so little to so much effect. As a painter Leonardo da Vinci produced little, but that little was distinguished and finely done. His note-books were a strange collection of mathematical calculations, drawings, and ideas on life and painting, which reveal his versatility. The significance of Leonardo's life lies, however, not so much in its achievement in art or in science, as in his attitude, which embraced both in a spirit of scientific inquiry and recognition of human values. Prof. A. N. Whitehead has described culture as activity of thought and receptiveness to beauty and humane feeling ; this definition undoubtedly includes the culture of Leonardo. His knowledge, which was considerable, was actively employed, and his sensitiveness to beauty and human feeling found expression in work which has been universally recognized.

The account of his life already given shows his interest in science rather than in the discussion of other people's ideas : " Whoever appeals to authority applies not his intellect but his memory ". These words reveal the bias of his mind towards experiment rather than tradition. To him knowledge of the ancients was useful as a starting point, but in itself not conclusive. It is fortunate that although he left behind practically no formal record of his work, the

well-known "note-books" have been preserved and edited. Some of the originals are now in the Royal Library at Windsor. It is from these note-books that the full significance of Leonardo's contribution to science may be realized. The following brief description of his achievements in various branches of science shows the width of his interests.

In general physics and mechanics, Leonardo keenly sought after records of Archimedes' work, no doubt because that great mathematician dealt with things as they are, instead of discussing what they ought to be. Others also had keen interests in such practical approaches, and Leonardo was fortunate in his friends and patrons. His investigations on water at rest and in motion, as well as the principle of the lever, are closely associated with the basic principles formulated by Archimedes. Leonardo understood the principle of inertia, and realized the impossibility of perpetual motion which would be a source of power. He investigated waves on water ; and in air, as sound ; and recognized that light suggests a wave-theory too. In astronomy he was the first to explain the partial illumination of the dark part of the moon's surface, by the sun's light reflected from the earth. He hints also that the sun's motion is only apparent.

Leonardo made careful study of corals and shells from mountains, and foreshadowed geological theory by maintaining that parts of the earth's surface now visible must at some time have been under the sea. He recognized also the deposition of debris by rivers, and the actual gain of land surface from the sea : " in time the Po will lay dry land in the Adriatic in the same way as it has already deposited a great part of Lombardy ".

His work in art was based not only on the principles of perspective but also on a close study of human anatomy. His meticulous care led to such detailed observations that he progressed in physiology so far that he largely anticipated the researches of Harvey with regard to the circulation of the blood. He discarded the popular view that the eye threw out rays which touched objects it wished to examine,

and actually constructed a model to show how an image was formed on the retina. There is something prophetic also in his attempts to construct a flying machine : " Dissect the bat ", he wrote, " study it carefully, and on this model construct the machine ".

Such was the wider outlook associated with Leonardo da Vinci. At times the papacy seemed ready to accept these broader views, but not for long ; had it been otherwise, Europe might have known a different story. As it was, the new ideas were to gain ground but slowly, and in the teeth of opposition which found practical expression in the Inquisition. In Leonardo the battle was joined between " deduction " and " induction ". The former method deducing what *should happen* from the assumptions of traditional beliefs, and without the constant check of observation ; the latter dealing with what *does happen* and recognizing a uniformity underlying the expression of scientific laws, thereby explaining the observed results of experiment.

The complex nature of scientific inquiry leads inevitably to the age of the specialist. Perhaps in this twentieth century there is need to remind ourselves of that wider outlook and broader background which will for ever be associated with the name of Leonardo da Vinci.

CHAPTER XII: NEW THEORIES OF THE UNIVERSE

The Reformation

THE year 1520 is remembered, especially among Protestants, for its association with *Martin Luther*. On June 15 of that year, the Pope declared him a heretic, and on December 10 Luther publicly burnt the Bull of Excommunication; in the same year he issued three famous treatises, the first to the laity, urging them to take in hand the reformation of the Church, the second to the theologians, concerning the captivity of the Church, and the third to the Pope entitled *On the Freedom of a Christian*. There is, however, no particular year or incident which may be regarded as the beginning of that religious awakening known as the Reformation, and which culminated in the incidents mentioned above.

The intellectual interests that had been stirred by the revival of learning with its appeal to Classical thought, resulted in the spread of humanism throughout northern Europe. This movement, which began in Italy, laid emphasis on man rather than on the supernatural, and thus broke through the medieval tradition of scholastic theology and philosophy. It has been described as the parent of all modern developments whether intellectual, scientific or social. In particular, *Erasmus* (1467–1536) realized that the civilizing influences of knowledge might be used to combat the evils of the day, and sought to apply the new learning for the well-being of the common man. If his efforts had been favourably received, the reform of the Roman Church might have taken place from within. It was inevitable that the wider outlook of the Renaissance should have a profound effect on men's attitude to arbitrary authority, and though the Reformation and its causes are

too complex to review briefly, some reference to the objects of the Reformers is desirable.

Three such objects may be traced. First, it was essential to re-establish Church discipline, which had in many directions become lax; secondly, a reform of doctrine was considered long overdue; and thirdly, a lessening of dogmatic control, and an increase in the individual's right of private judgment, based on the Scriptures, were desired. So far as the background of science is concerned, the last object is of special interest: it grew from the awakening spirit of inquiry which we have already observed, both before and during the lifetime of Leonardo da Vinci. The dignity of man's reason began to stand out against blind appeal to traditional authority. Even though it may be argued that belief in an infallible Church was replaced, at the Reformation, by belief in an infallible Bible, the significance of such a change is that men's trust in the old formularies had been shaken. It was only a matter of time for the spirit of genuine inquiry to guide men to a broader view of the universe, a deeper appreciation of the secrets of Nature, and a wider outlook which would embrace the whole of life, physical, mental and spiritual.

While the Reformation was still in progress, the first great change in the world of science, following the Renaissance, came from within the Roman Church.

Copernicus

Belief in the motion of the earth, which is such a commonplace of the modern world, owes its acceptance to the work of *Nicolaus Copernicus* (1473–1543). There is general agreement with regard to the spelling of the word "Copernican", as applied to the theory of the universe in which the planets are regarded as moving round the sun; whereas there is considerable difference apparent in the spelling of the name of the astronomer who put forward the theory. This is partly due to an old and scholarly custom whereby

native spelling was modified by the adoption of a Latinized form. In this way the astronomer himself altered his original names Niklas Koppernigk (this is the most frequent form of the surname) to Nicolaus Copernicus, which he employed chiefly on his published works. Another spelling, adopted for official use, was Coppernic, and in later life Copernic.

Copernicus' father was a wealthy merchant of Cracow who afterwards migrated to Thorn (modern Torun), also on the Vistula, where Nicolaus was born in 1473. In the fifteenth century the inhabitants of both towns were mainly German, and the surname of the family suggests an ancestry associated with the copper-mining industry of Silesia. Copernicus' mother came from a well-to-do German family which had provided the town of Thorn with many of its responsible officials ; the future astronomer Nicolaus was the youngest of two brothers and two sisters. At the age of ten, his father died and the boy's education was arranged by his maternal uncle, the future Bishop of Ermland, a diocese of Prussia.

Copernicus attended school in Thorn, and in 1491 proceeded to the University of Cracow, which had become outstanding among the northern universities of Europe, particularly in mathematics and astronomy, and had been influenced by the humanistic teaching from Italy. While at Cracow it is likely that Copernicus became accustomed to the use of astronomical instruments. After three years at the university, he returned to Thorn, and his uncle tried to secure his election to a canonry at the cathedral town of Frauenburg, on the coast between Elbing and Königsberg. The election was not successful, and Copernicus continued his studies, this time at the famous law school at Bologna, where he came into close touch with the university professor of astronomy, and made further observations. In 1500 he spent a year in Rome teaching mathematics privately, and continuing astronomical work, which included observations of a lunar eclipse, afterwards used in his theory of the moon's motion.

In 1497 Copernicus had been elected, in his absence, to

a canonry of Frauenburg, and his brother similarly in 1499 ; in 1501 the brothers returned to Ermland to ask for further leave of absence to continue their studies. Copernicus went to Padua and completed his legal course, and probably there learned Greek. In 1503 he took his doctorate in canon law at Ferrara, and returning to Padua started the study of medicine.

This story of varied interests and different universities is in contrast to the specialized courses at one and the same university in modern times. However, the breadth of training formed a good background for the development and formulation of a new theory of the universe. Although as a churchman Copernicus would not be expected to practise surgery, he became medical adviser to his uncle, which involved living at Heilsberg Castle, the episcopal residence, until the bishop's death in 1512. During these years much work was done on his new system of the planets ; he also published his own Latin translation of certain Greek Epistles.

It was not only on the academic side that Copernicus revealed breadth of interest, but also in practical affairs and in the discharge of public duties associated with the diocese of Ermland. These included matters temporal as well as spiritual ; and the political situation with which he had to deal called forth outstanding qualities of leadership and resourcefulness. The principality of Ermland tried to maintain its independence between two powerful and mutually hostile neighbours, Poland and East Prussia. Another source of political unrest arose from the desire of the German population of West Prussia for complete independence from the Poles, who wished to incorporate this province in their own kingdom.

The story of the emergence of East Prussia is too long to narrate in detail. Possibly the most important achievement of the German people during the Middle Ages was the colonization of the plain which lies between the Elbe and the Niemen, embracing parts of modern Prussia, East Prussia and Poland. The land was sparsely populated by Slavonic tribes, and in the words of an ecclesiastical proclamation by

the bishops and princes of Saxony : " their land is very rich in flesh, honey, grain, birds, and abounding in all produce of fertility of the earth when cultivated so that none can be compared with it. So say they who know. Wherefore O Saxons, Franks, Lotharingians, men of Flanders most famous, here you can both save your souls and if it please you acquire the best of land to live in."

Slowly the little fishing villages along the bleak Baltic coast grew into prosperous ports, and there were also important inland centres ; ultimately the powerful Hanseatic League linked these together, deriving its name from the individual " Hans " (house), or Guild Hall, centre of trading activity of each town. By the fourteenth century this League had reached the height of its power, and German merchants became wealthy as carriers of merchandise such as wool, cloth, corn and wine ; these " Easterlings " were well-known figures in London, and played such an important part in the foreign trade of England as to cause their name, in its shortened form " sterling ", to be given to the standard coin of the British realm.

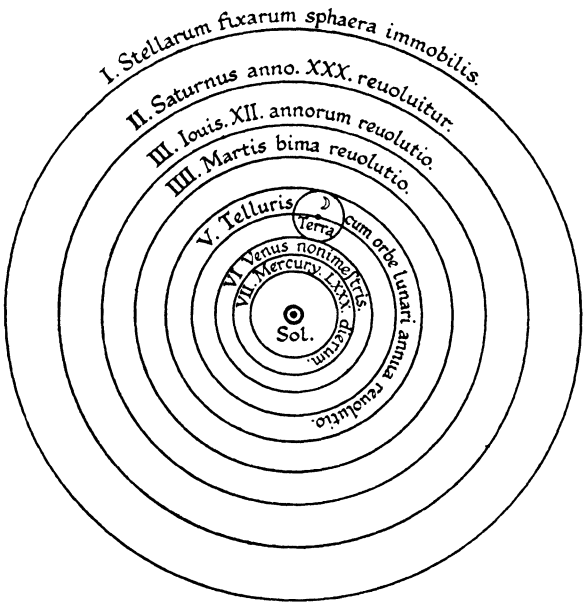
Nor can the part played by the Teutonic Knights be ignored : these were established originally as a German Order in connection with the Third Crusade at the end of the twelfth century, though they finally abandoned the Holy Land a century later. Early in the thirteenth century, some of the Order were called in by a Polish duke to aid him in protecting his duchy from a group of Baltic pagan tribes, who formed the original Prussians, and were akin to the Letts and Lithuanians. In return for their help the Knights were granted land, and, spreading Christianity with fire and sword, they ultimately appropriated the name of " Prussians " and established themselves in the modern territory of East Prussia. By 1309 they had also conquered the Prussian area to the west, thereby linking their own territory to Germany, and cutting Poland off from the mouth of the Vistula, and access to the sea. Such a position meant hostility then, and has done at intervals ever since. Ultimately a Polish-Lithuanian force, together with a Czech

corps, defeated the Teutonic Knights at Tannenberg in 1410; but their influence could not be suppressed. A hundred years later we find a Hohenzollern as their Grand Master, and as a modern historian writes, "from the failure of the Crusades the way was paved for the Kingdom of Prussia, and the late imperial dynasty of Germany".

Through this atmosphere of hostility and distrust, it fell to Copernicus to guide the principality of Ermland during the actual outbreak of war between Poland and East Prussia. His diocese was raided by the plundering bands of Teutonic Knights, and, as we have already noted, Copernicus proved more than equal to his responsibilities. After an armistice in 1521 he represented Ermland at the peace conference. At this time the debasement of the Prussian coinage, aggravated by the war, called for urgent measures, and it was Copernicus who drew up recommendations for remedying the position. He advocated State control of the minting of coins, instead of each city or district having its own currency; he gave minimum proportions of precious metals in an alloy, and urged the necessity of withdrawing the old coinage to prevent the new from being bought up and melted down. We are reminded of a later and even more distinguished natural philosopher, Sir Isaac Newton, who was appointed Master of the Mint in London in 1699.

The political atmosphere with which Copernicus had to deal became less involved when the Hohenzollern Grand Master of the Teutonic Knights agreed in 1525 to being a Duke *in* Prussia rather than the Duke *of* Prussia, and accepted the suzerainty of the King of Poland. Copernicus' religious sympathies seem to have been orthodox in his opposition to Luther, but he was anxious to resolve the differences of outlook, and so avoid the disruption of the Church.

Copernicus' views with regard to a heliocentric theory (Greek *helios*, sun) were developed gradually, and the lessening of his responsibilities in his diocese gave the necessary leisure. In 1539 Rheticus, a young Protestant professor of mathematics at Wittenberg, travelled to Frauenburg to hear more about the new system from Copernicus himself. He



The heliocentric theory of Copernicus.
From *De Revolutionibus Orbium Celestium*

was cordially received, and for ten weeks the older man guided the keen young teacher of twenty-five into the intricacies of his theory. Rheticus drew up a report which had the approval of Copernicus, and in 1540 this earliest published account of the Copernican system was made known to the world.

Copernicus' interests centred more round the development of his theory than the observations on which it was based, most of his own practical work being done at Frauenburg. After years of patient investigation, and possibly when he realized that he would not live much longer, Copernicus sanctioned the publication of his life's work, the *De Revolutionibus Orbium Celestium*. The printing was finished in the winter of 1542–43, and though Copernicus was suffering from a paralytic stroke, he was sufficiently conscious to see and handle an advance copy of his completed

work, which arrived on the day of his death, May 24, 1543.

There is no need to describe the contents of the six books which make up the *De Revolutionibus*, except as an indication of the scope of Copernicus' work. General arguments are set forward to support the heliocentric point of view, and he gives the modern explanation of the seasons, dealing with the diurnal and annual motions of the earth. The precession of the equinoxes, the theory of the moon's motion, and finally the motions of the known planets are all investigated.

But the significance of his work in the story of science is not merely that his theory replaced the Ptolemaic or geocentric system (pp. 51 ff.), but that the implications of the heliocentric system had far-reaching effects on traditional thought and belief. Though there had been various suggestions, even from Classical times, that the earth moved, the more obvious, and as it appeared common-sense, notion that the earth was fixed at the centre of the universe, had become a fundamental belief in the philosophy of the Schoolmen. It was regarded as an essential part of Christian thought, and though the papacy of Copernicus' time did not condemn the new teaching, by 1616 it was treated as " false and altogether opposed to Holy Scripture " ; indeed, it was not until 1822 that the heliocentric theory received the formal sanction of the papacy. The attitude of the Reformers as represented by Luther in his *Table Talk* supported the geocentric theory : " Heaven's motions are threefold, the first is, that the whole firmament moves swiftly round, every moment thousands of leagues, which, doubtless is done by some angel ".

It is easy for us to condemn, and even ridicule, but the leaders of every age should be judged against the intellectual background of the age. In placing the earth as one of a series of planets moving round the sun, instead of the centre of the whole universe, Copernicus was challenging a belief that seemed fundamental to the very existence and dignity of man. It is not surprising that he hesitated to make his theory known, or that an anonymous note was inserted into the *De Revolutionibus* before publication, to the effect that

the principles laid down were merely abstract hypotheses, convenient for the purposes of calculation.

Observational Astronomy

Although the Copernican system was so revolutionary in its description of the earth's motion round the sun, it relied on the old idea of epicycles and eccentrics in order to explain the apparent motions of the planets. Thus Copernicus as well as Ptolemy could subscribe to Milton's description in *Paradise Lost* (Book VIII, ll. 82-84) of

> The sphere
> With centric and eccentric scribbled o'er,
> Cycle and epicycle, orb in orb.

Before these hypothetical circular motions could be replaced by the elliptical orbits of Kepler, it was necessary to test the theory which incorporated them, at the bar of experiment. Tables were prepared to give the positions and motions of the heavenly bodies, and reasonable accuracy claimed for them ; these Prussian Tables (their publication in 1551 was at the expense of the Duke of Prussia) were an improvement on previous ones, but certain serious discrepancies between prediction and observation made it desirable that more observations should be made.

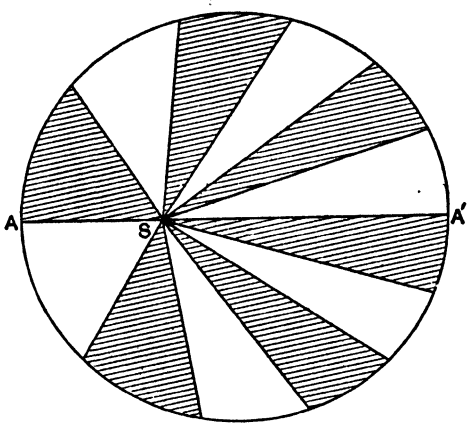
An observatory at Cassel, built in 1561, was the first to have a revolving roof, now a common feature of observatories; important observations made there revealed further errors in the Prussian Tables. The use of pendulum clocks for accurate timing was also an innovation, but the work at Cassel was overshadowed by the records compiled by *Tycho Brahe* (1546–1601) of Copenhagen. A curious sidelight on literary matters of that period is found in this astronomer's reluctance to publish his work, which was largely due to a belief that it was unworthy of the dignity of a Danish nobleman to write books. Among Brahe's achievements was the construction of a large quadrant, radius

nineteen feet, the rim of which was graduated to minutes of arc ; and a great celestial globe, five feet in diameter, on which he marked the positions of the stars from his observations. In 1576 the King of Denmark gave Brahe the small island of Hveen in the Sound, and endowed the observatory, which became famous as Uraniborg (the Castle of the Heavens). At the end of the century the astronomer left Denmark for Germany, and in the winter of 1597–98, while at Hamburg, issued a catalogue of one thousand stars. In 1599 he was installed in a castle near Prague and, fortunately for the world of science, he attracted a young enthusiast, John Kepler, to whom he bequeathed the extensive records which he had accumulated.

Kepler

The parents of *John Kepler* (1571–1630) were Protestants, though Weil, in Wurtemberg, where their son was born, was predominantly Roman Catholic. The father's views, however, could not have been very pronounced, as he enlisted in the Duke of Alva's army which was engaged during 1567–73 in attempting to suppress the rising of the Protestant Netherlands against the persecutions of Roman Catholic Spain. After a childhood marked by illnesses, Kepler ultimately graduated at the University of Tübingen, where the professor of mathematics gave lectures on traditional lines in public, but in private was prepared to give instruction on the Copernican system. Before Tycho Brahe's death, Kepler had been assigned the task of observing Mars, for the planetary tables that the former was preparing. From such observations it became increasingly evident that the Prussian Tables were not reliable, and despite Kepler's attempt to build up fresh combinations of circles to explain the observed motion of the planet, he came to the conclusion that the circular hypothesis must be abandoned, and that the path of Mars was some sort of oval.

At first an egg-shaped curve was assumed for the orbit



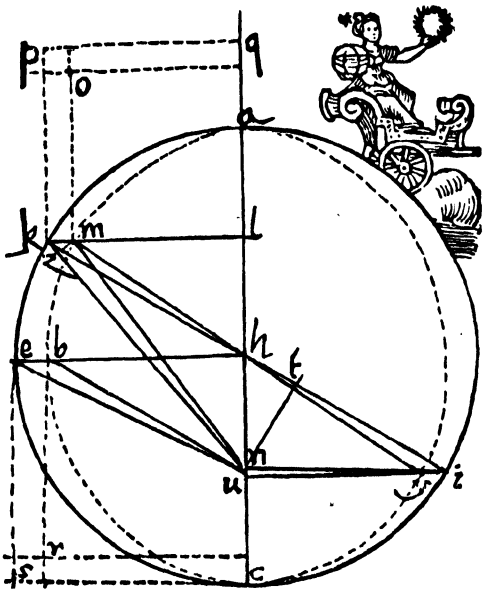
From Berry, "A Short History of Astronomy", by courtesy of Messrs. John Murray

Path of a planet is an ellipse with the sun, *S*, at one focus and major axis *AA'*. If the area of the diagram is divided into equal portions, the successive points on the orbit are the planet's positions at equal intervals of time

of Mars, but the unequal curvature of the ends had to be replaced by the simplest known oval curve, the ellipse, a curve which is symmetrical about both its axes. This satisfied the conditions of the problem, provided the sun was regarded as being situated at one of the two foci of the ellipse. Further investigation showed that if successive positions of the planet are marked at equal intervals of time, the line joining the sun to the planet sweeps out equal areas. This is illustrated by the alternately shaded areas of the diagram above.

The discovery of this last truth so delighted Kepler, that in his book, *Commentaries on the Motions of Mars*, published in 1609, there appeared a figure of victory at the corner of the diagram establishing the last stage of his proof (p. 138).

Between 1618 and 1621 Kepler published three books, an *Epitome of the Copernican Astronomy*, the *Harmony of the World* and a treatise on *Comets*. The second was the most important, and as its title suggests, shows the mystic temperament of Kepler, who still clung to the old idea of the "music of the spheres". This desire to discover numbers which could

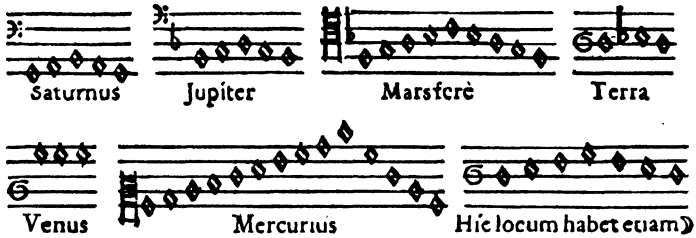


From Berry, "A Short History of Astronomy", by courtesy of Messrs. John Murray

Diagram used by Kepler to establish his Laws of Planetary Motion. The dotted curve represents the path of the planet

be associated with the motions of the heavenly bodies led to his discovery of another law of planetary motion, namely, that the squares of the times of revolution of any two planets (including the earth) about the sun are proportional to the cubes of their mean distances from the sun. The place that speculation played in Kepler's mind with regard to the relation between the proportions of the solar system and various musical scales is evident throughout the *Harmony of the World* and is illustrated in the facsimile on the opposite page.

The voluminous writings of Kepler, which contain so many wild speculations in addition to serious contributions to the cause of science, have led to a variety of opinion as to his merits. But even his search after the mathematical harmonies which he believed to be in the mind of the Creator, produced numerical results which were of far-



From Berry, " A Short History of Astronomy ", by courtesy of Messrs. John Murray

The " Music of the Spheres " from Kepler's *Harmony of the World*

reaching effect. The three summaries, which have survived as " Kepler's Laws ", may, in conclusion, be briefly restated :

(1) The planets travel in paths which are ellipses with the sun at one focus.

(2) The areas swept out in any orbit by the straight line joining the centres of the sun and a planet are proportional to the times.

(3) The squares of the periodic times which the different planets take to describe their orbits are proportional to the cubes of their mean distances from the sun.

In these short statements is contained the result of contemporary astronomical work and also of centuries of observation. The beginnings of the new theory of the universe, associated with the names of Copernicus and Kepler, led to the deeper insight of Galileo and the broader generalizations of Newton. The implications of the new outlook were at first realized only by a few, and were obscured by the political atmosphere and religious wars which followed the Reformation. But the leaven of the new spirit of inquiry was at work, and the seventeenth century saw the inevitable break with tradition.

CHAPTER XIII : THE BREAK WITH TRADITION

Galileo

GALILEO GALILEI (1564–1642) came of a noble Florentine family whose surname was Galilei, and though his father was not in a position to give his son any appreciable financial start in life, he seems to have endowed him with his own spirit of free inquiry. The following quotation from the introduction to one of his father's books might equally refer to the son : " It appears to me that they who in proof of any assertion rely simply on the weight of authority, without adducing any argument in support of it, act very absurdly. I, on the contrary, wish to be allowed freely to question and freely to answer without any sort of adulation, as well becomes those who are sincerely in search of truth."

Up to the age of twelve or thirteen Galileo received his education at Pisa, the city of his birth, attending school and being helped at home with his Greek and Latin lessons. Thence he was sent to the monastery at Vallombrosa near Florence, where he followed a literary education, as befitted a well-born youth of those days. In 1579 his father, chiefly for financial reasons, withdrew him to learn the trade of a cloth-dealer. The variety of Galileo's interests and accomplishments finally influenced his father to decide on his medical training at the University of Pisa, where he soon showed signs of questioning the statements of such authorities as Plato, Aristotle and St. Thomas Aquinas.

In 1581 Galileo is reported to have made his first discovery, basing it on observations of the swinging lamp in Pisa Cathedral. He noted that when the lamp had been pulled out of position by the verger, for the purpose of lighting, it swung backwards and forwards in the same time, even when the size of the swings became much smaller ;

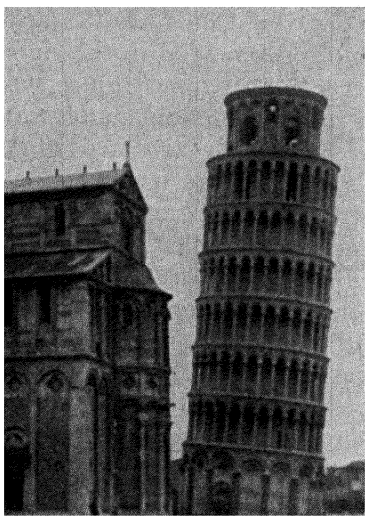
the timing was checked by reference to the beats of his own pulse. From this property of the pendulum, Galileo devised an instrument which physicians could easily use for comparing the pulse of a patient with the normal pulse-rate. The adjustment to suit the individual was made by altering the length of the string tied to the mass or " bob " of the pendulum, thereby varying its time of swing.

During the winter of 1582–83, the Court of Tuscany visited Pisa according to custom, and included in the suite was an able mathematician, Ricci, with whom Galileo became friendly. How the latter's interest in mathematics was aroused is not certain, but the commonly accepted story is not unlikely. Part of Ricci's duty was to teach mathematics to the pages who attended the Grand Duke of Tuscany. Calling on Ricci one day, Galileo found him giving a lesson to his youthful audience on Euclid ; so, hiding behind the door, he listened. On many other occasions he stood unobserved with book in hand, absorbing the mathematician's demonstrations, until he summoned courage to approach Ricci directly and seek his aid. When Galileo's father heard of this preference for Euclid rather than for Hippocrates and Galen, he tried to persuade his son from what he considered an unprofitable study. Afterwards, about 1585, Galileo was withdrawn from the University of Pisa, partly no doubt for financial reasons. He continued his studies at home, passing from the geometry of Euclid to the mechanics of Archimedes, to whom he was destined to become such a distinguished successor.

It was about this time that Galileo constructed the so-called " hydrostatic balance ", in which a movable counterpoise indicates the apparent alteration in weight when a mass is suspended in a liquid. The problem of Hiero's crown, with which Archimedes was faced, seems to have suggested this method of comparing the specific gravities of various substances. Subsequent work on the centre of gravity of solid bodies earned for Galileo the title of " The Archimedes of his time " and indirectly brought him to the notice of the Grand Duke of Tuscany. Successively disappointed in his

applications for professorships at Bologna, Rome, Padua and Pisa, Galileo decided to seek his fortune eastwards; but as he was about to start, the mathematical professorship at Pisa again fell vacant, and this time he was successful.

During Galileo's tenure of office, one incident occurred which is of special importance because of its appeal to experiment to disprove accepted belief. Theories of the universe, such as that of Copernicus, could not be demonstrated to the multitude. Galileo's views led him to believe that if different masses were dropped simultaneously from the same height, they would reach the ground at the same time. A simple experiment of this type could be appreciated by all. If the result disagreed with the traditional belief of the time, then a break with tradition seemed inevitable. The famous Leaning Tower near the eastern end of the Cathedral at Pisa probably provided the suitable height and platform from which to drop the masses, and before the assembled university professors and students Galileo allowed a heavy shot and a light shot to fall together. They reached the ground simultaneously. Had Aristotle witnessed such an experiment there is little doubt that he would have accepted the evidence of his eyes, but not so his medieval disciples. With the exception of the new professor of philosophy, the whole of the teaching staff as well as the heads of the University turned against Galileo, maintaining, in spite of the result of the experiment, that the 10 lb. mass would reach the ground in a



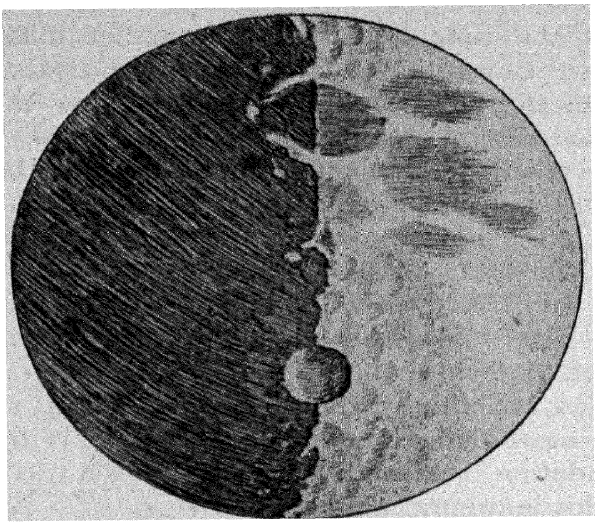
Leaning Tower at Pisa, and east end of the Cathedral

fraction of the time taken by the smaller mass, quoting Aristotle as their authority. It seems, however, that Aristotle had really referred to motion in a resisting medium, so his medieval disciples were doubly wrong; they had misinterpreted their master and also refused to believe the evidence of their eyes.

By 1592 the hostility became intolerable, and this, together with the very slight remuneration of the post, forced Galileo to return to Florence. His financial embarrassment may be realized from the fact that when he set out from Florence in order to obtain the coveted professorship of mathematics at Padua, which had been vacant since 1588, his belongings only weighed about 100 lb. With letters of recommendation from influential persons, he was successful, and gave his inaugural address on December 7, 1592. This was so outstanding, both in knowledge and delivery, that it is referred to in a book on astronomy published by Tycho Brahe six years later.

At Padua Galileo's work covered a wide field, embracing mechanics, geometry, a little magnetism, astronomy and instrument-making. The demands for one of his instruments, a geometrical and military compass so ruled that it could be used for various calculations and constructions, came from all over Europe, and led to Galileo setting up a workshop in his own house. The modern mercury thermometer is a descendant of Galileo's air thermometer of 1602; mercury was first used in 1670, the Fahrenheit scale adopted in 1724, that of Réaumur in 1730 and the centigrade scale in 1742.

The first telescope was developed by Hans Lippershey, an optician of Middelburg, whose assistant had noticed accidentally that two spectacle lenses, held in a certain position, had the effect of enlarging the appearance of objects, but showing them upside down. Galileo improved on this, so that his Galilean telescope showed an object the right way up; successive telescopes which he constructed improved the magnification to such an extent that he was able to observe not only the surface of the moon, but also



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One of Galileo's drawings of the Moon. From the *Siderius Nuncius*



Reproduced by courtesy of the Director, Institut d'Astrophysique, Paris

A modern photograph of the Moon, taken at the Astrophysical Institute, Paris

four of Jupiter's satellites, and ultimately the peculiar appearance of Saturn, which in 1656 was first described as a ring by Huygens.

Galileo's reputation as a teacher brought many distinguished political visitors to Padua, and in addition his friendships included outstanding men of science. It is a significant coincidence that William Harvey, who was also destined to be the forerunner of a new approach to a branch of science, was a student of medicine at Padua during 1598–1602.

It was not so much the observations and experiments which Galileo made that caused the break with tradition as his *attitude* to them. For him the facts based on them were treated as facts, and not related to some preconceived idea, as we saw in the case of Kepler's *Harmony of the Spheres*. The facts of observation and experiment might, or might not, fit into an acknowledged scheme of the universe; but the important thing, in Galileo's opinion, was to accept the facts and build the theory to fit them. If he was unable to produce the latter, he declared it better " to pronounce that wise, ingenious and modest sentence, ' I know it not ' ".

Galileo's most important and original contribution to progress was in connection with motion, and it has been justly said that his work was the foundation of the experimental and mathematical science of dynamics. Here again this involved a break with tradition. The Schoolmen, basing their thought on Aristotle, were chiefly interested in the ultimate cause of things, and analysed motion into such vague ideas as action, efficient cause, end and natural place. Galileo was concerned with *how* motion occurred, not *why* it should occur, and so gave mathematical framework to the ideas of distance and time. On one hand he formed a link with the mathematical outlook of Kepler, and on the other with Newton, who gave expression to the ideas of force, mass and motion in his three laws of motion, and in his theory of universal gravitation.

The Inquisition

In 1610 Galileo wrote to Kepler, and the following extracts reveal the intellectual inertia against which he had to contend : " You are the first and almost the only person who, after a cursory investigation, has given entire credit to my statements. . . . We will not trouble ourselves about the abuse of the multitude, for against Jupiter even giants, to say nothing of pigmies, fight in vain. Let Jupiter stand in the heavens and let the sycophants bark at him as they will. . . . I think, my Kepler, we will laugh at the extraordinary stupidity of the multitude. What do you say of the leading philosophers here to whom I have offered a thousand times of my own accord to show my studies, but who, with the lazy obstinacy of a serpent who has eaten his fill, have never consented to look at the planets, or moon, or telescope? Verily, just as serpents close their ears, so do men close their eyes to the light of truth. To such people philosophy is a kind of book, like the Aeneid or the Odyssey, where the truth is to be sought, not in the Universe or in nature, but (I use their own words) by comparing texts ! " Even a Florentine astronomer could write in 1611, " Moreover, these satellites of Jupiter are invisible to the naked eye, and therefore can exercise no influence on the earth, and therefore would be useless, and therefore do not exist ".

The break with tradition had inevitably taken place, and though Galileo was offered, and accepted, the position of First Mathematician of the University of Pisa in 1610, trouble began to loom ahead. He had left Padua, which was on the free soil of Republican Venice, for the markedly ecclesiastical atmosphere of Tuscany. The religious order of the " Society of Jesus " (the Jesuits) was organized at Montmartre, Paris, in 1534 by St. Ignatius of Loyola, who had been a soldier, and who based his organization on military discipline and rank, with the dominant purpose of foreign missions. Such a society was naturally used to combat Protestantism, and to support the " Counter-Reformation "

movement which had sprung up within the Roman Catholic Church. In 1542 the Jesuits had established a school in Padua, and their increasing influence in public policy led to a decree by the Venetian Senate in 1591 that no Jesuit should be allowed to give instruction at Padua in any of the sciences taught in the University. In 1606 the Pope placed the Republic under an interdict, and the Senate replied by expelling the Jesuits.

The discovery of the phases of Venus gave support to the Copernican theory, and brought fame to Galileo. In 1611 he was received by the Pope, and when he departed from Rome he left behind many sincere friends and admirers, but in addition some jealous enemies. The ecclesiastical tribunal for the suppression of heresy, known as the Inquisition, or the Holy Office, dates from the twelfth century, and later became particularly active against the Protestants. The opinions of Galileo were brought to the notice of the Holy Office in Rome in 1615 and a secret inquiry instituted. In order to combat these intrigues Galileo himself set out for Rome before the end of the year. Early in 1616 he was admonished, and ordered to relinquish the Copernican theory; a few days later Copernicus' book, *De Revolutionibus*, was suspended until corrected.

There is not space to pursue in detail the activities of Galileo in the years following his first appearance before the Inquisition, but in 1632 was published his *Dialogues*, which formed the basis of a discussion on the relative merits of the Ptolemaic and Copernican systems. The Jesuits brought charges against the author, and ultimately in 1632 Galileo was once more before the Inquisition, and after a trial of ten months was pronounced guilty. He signed a formal abjuration of his beliefs and was condemned to " the formal prison of this Holy Office for a period determinable at Our pleasure ".

Galileo was now seventy years old, and suffering from the ill-health that had followed him for many years. In view of popular belief to the contrary, it is fair to state that there is no evidence that Galileo was tortured, or that, on

rising from his knees after the abjuration, he muttered " it moves nevertheless ". His " imprisonment " was allowed to consist of residence in a villa of the Grand Duke of Tuscany, where many years before he had shown Jupiter's moons and other celestial objects to amazed Cardinals. Later he was allowed to live at Siena and eventually in his own villa at Arcetri, being granted leave also to visit Florence.

Among his many visitors was Milton, then in his twenty-ninth year, who assured Galileo that his *Dialogues* were being eagerly read in England. The information must have been particularly gratifying to the aged astronomer, who had become completely blind a few months previously, at the end of 1637. Within fifteen years Milton himself was blind, and the closing line of the sonnet which he composed " On His Blindness ", well describes the restricted life which befell both scientist and poet :

They also serve who only stand and wait.

Torricelli (1608–47), best known for his invention of the mercurial barometer, had been inspired by *The Dialogues*, and proved a faithful amanuensis in the last months of Galileo's life.

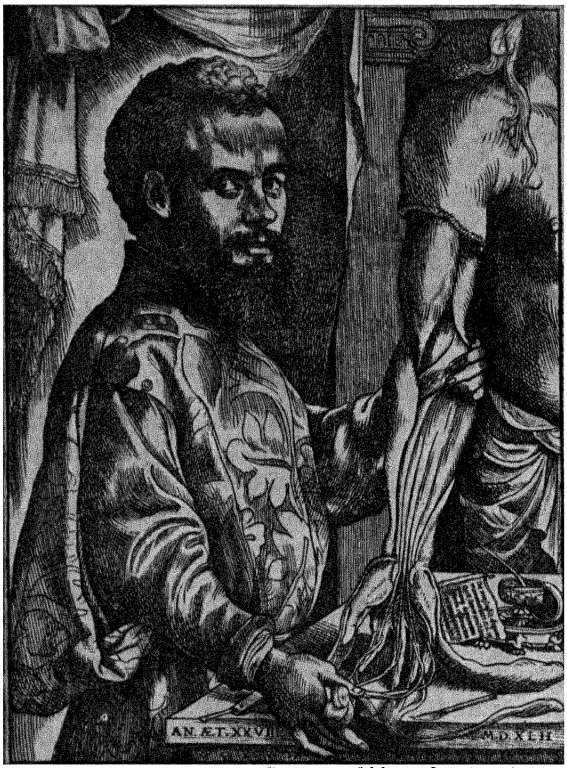
Right to the end in 1642, Galileo was actively engaged on various theories and projects, the very last being a plan for a pendulum clock. The Grand Duke of Tuscany was constant in his attentions during the closing months of the astronomer's life, visiting him and sending him supplies of his choicest wines and other delicacies, for, as he used to say, " I have only one Galileo ".

After three hundred years of scientific progress made possible by the foundations which Galileo laid, these words assume a new significance ; for us also there is " only one Galileo ". " As we read his writings, we instinctively feel at home ; we know that we have reached the method of physical science which still is in use today " ; so writes Sir William Dampier. " In a very real sense Galileo is the first of the moderns."

Awakening in Medical Science

The influence of the Renaissance on medical science was greatly increased by the invention of the printing press. The return to classical learning made accurate translations of Galen's works possible, and the distribution of printed copies throughout Europe towards the end of the fifteenth century kindled a wide interest in them. Dissection had chiefly been undertaken to support Galen's views, and students regarded it rather as an aid to memory. As Prof. C. Singer writes : " The dissection in fact was supposed to illustrate Galen, rather than Galen to explain the dissection ". By the end of the century, work such as that of Leonardo da Vinci was contributing to a knowledge of the structure and functions of the various parts of the body, and before the middle of the sixteenth century there was open discussion of Galen's theories at the universities. The awakening in medical science had begun.

The year 1543, which saw the publication of Copernicus' *De Revolutionibus*, was also the year in which Vesalius' *The Fabric of the Human Body* was printed. The production was a finely illustrated large folio volume, and forms one of the landmarks of the history of science, being a detailed record of a large number of discoveries and investigations made by the author. *Vesalius* (1514–64), a Belgian, became a professor at the University of Padua when he was only twenty-four years old. His successful teaching attracted hundreds of students, for whom in 1538 he published a " guide " which consisted of six fine plates with full descriptions. Vesalius' work was, however, based on Galen, and although he realized difficulties in reconciling his observations with accepted theory, he did not offer anything better in its place. *The Fabric of the Human Body* became the standard text-book ; but at the age of twenty-nine its author decided to give up research and become a court physician. A new edition of his book in 1555, however, stated that he was unable to find experimental support for Galen's physiology.



By courtesy of Messrs. G. Bell & Sons, Ltd.

Vesalius, aged 27. From a reproduction of an engraving in his *Fabric of the Human Body*

Contributions began to be made to the knowledge of the relation of the blood to the heart ; one came from an unexpected source, namely, a theological book, *The Restitution of Christianity*, by Servetus, a theologian (and medical practitioner at Vienne, near Lyons) who disputed both Roman Catholic and Protestant views. He believed that the study of physiology would lead to a knowledge of God, and though he was still under the influence of Galen and Aristotle, he came very near to the idea of the circulation of the blood, using the phrase that the blood is driven from

the right ventricle through a long passage in the lungs. Unfortunately, entering into correspondence with Calvin, he sent him a manuscript copy of his book in 1546, which was published in a modified form in 1553. The sequel shows, at its worst, the religious bitterness and hatred of those days. Servetus was tried and burnt alive at Geneva, under the Protestant influence of Calvin; he was also tried in his absence by the Roman Catholic authorities at Vienne and they too sentenced him to be burnt alive; but as this had already been done, his effigy was burnt instead. Is there not something of grandeur in the spirit of this seeker after truth who, at the risk of death, dared to break with tradition? Realizing that his life was threatened he wrote to a friend, " I know of a truth that this work will be my death " ; yet he persisted in the anonymous publication of his book, with the result already described.

It may have been from one of the few surviving copies of *The Restitution of Christianity* (there is one now in the National Library at Paris which bears the marks of fire) that some of Servetus' ideas became known. The true nature of the circulatory system, however, was not appreciated even by *Fabricius*, who taught anatomy at Padua during 1555–1619 and who published a book in 1574 *On the Valves of the Veins.*

Padua was the leading medical school of the day, and towards the end of the sixteenth century, while Fabricius was at the height of his fame, a young Cambridge graduate, William Harvey, studied there; and it is to him that the world owes the discovery of the circulation of the blood.

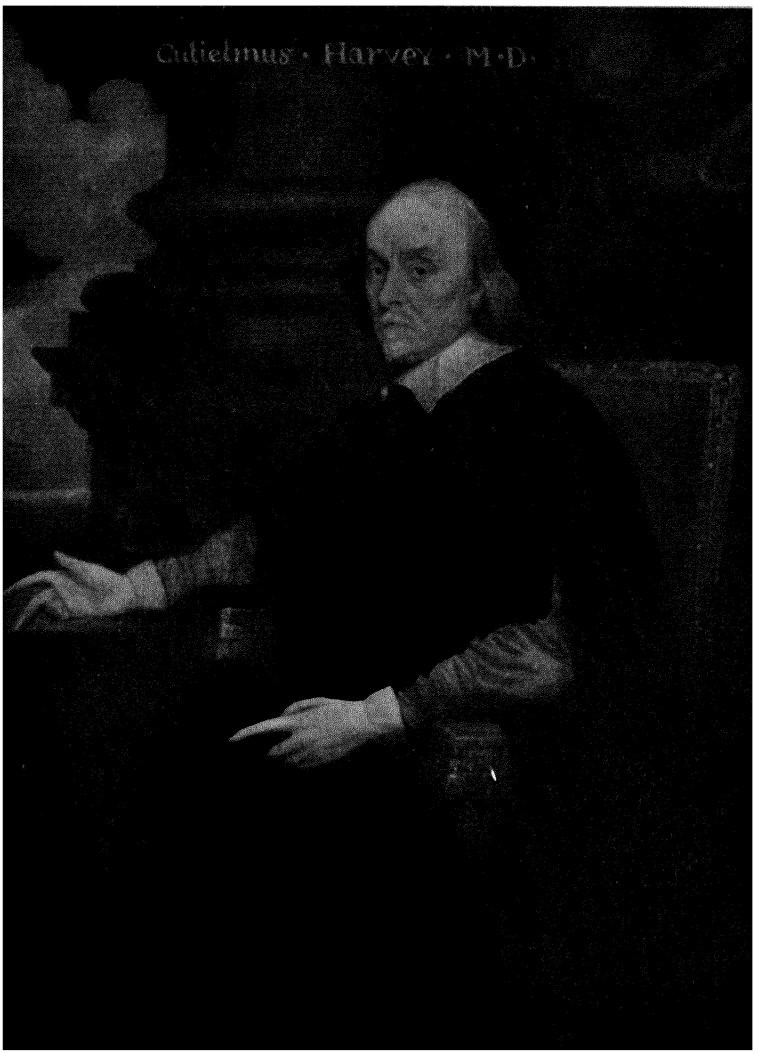
Harvey

William Harvey (1578–1657) was born at Folkestone. At the age of ten he was sent to the King's School, Canterbury, and six years later he entered Gonville and Caius College, Cambridge. Originally founded in 1348 and known as Gonville Hall, this College had a strong link with the

University of Padua, for in 1557 it was refounded by Dr. John Caius (pronounced "Keys") who had studied under Vesalius at Padua. Caius had been instrumental in encouraging traditions of Greek learning and Italian anatomy which were to have such a strong influence on Harvey as an undergraduate. In 1597 he took his degree at Cambridge and went to Padua; in later life he gladly acknowledged the debt he owed to Fabricius. In 1602 he was made a doctor of medicine at Padua, and on returning to England a similar honour was awarded by Cambridge, his "Alma Mater".

In the same year Harvey took up medical practice in London, and in 1609 was elected physician to St. Bartholomew's Hospital. Following the usual custom, he would subscribe to "The Charge of the Physician", from which the following extract gives an idea of seventeenth-century hospital routine: ". . . one day in the week at the least through the year or oftener as need shall require you shall come to this hospital and cause the Hospitaller, Matron, or Porter to call before you in the Hall of this Hospital such and so many of the poor harboured in this Hospital as shall need the counsel and advice of the Physician. And you are here required and desired by us, in God His most Holy name, that you endeavour yourself to do the best of your knowledge in the profession of Physic to the poor then present, or any other of the poor at any time of the week which shall be sent home to you by the Hospitaller or Matron for your counsel, writing in a book appointed for that purpose such medicines with their compounds and necessaries as appertaineth to the Apothecary of this house to be provided and made ready for to be ministered unto the poor, every one in particular, according to his disease. You shall not for favour, lucre, or gain, appoint or write anything for the poor but such good and wholesome things as you shall think with your best advice will do the poor good, without any affection or respect to be had to the Apothecary. And you shall take no gift or reward of any of the poor of this house for your counsel."

In 1615 Harvey was chosen as lecturer at the College



N.P.G.

WILLIAM HARVEY

Reproduced, from the painting by Cornelius Janssen, by kind permission of the Royal College of Physicians

of Physicians in London, and the written lecture notes which he used in the following year prove that, by then, he had realized the essential points in the circulation of the blood. The notes are in a curious mixture of Latin and English, and they can be deciphered only with difficulty because they are so badly written (a practice which is said to persist among physicians even today!). Among other information we learn that by 1616 Harvey had dissected more than eighty different kinds of animals. The evidence for his belief in the circulation of the blood may be summarized by means of the following extracts :

" The blood is constantly passed through the lungs into the aorta as by two clacks of a water bellows to raise water."

". . . there is a transit of blood from the arteries to the veins."

". . . a perpetual motion of the blood in a circle is brought about by the beat of the heart."

The phrase " two clacks of a water bellows " apparently defied translation into Latin : the " clack " was a form of valve used on pumps, and Harvey doubtless refers first to the valves between the auricle and the ventricle which prevent blood that has once entered the ventricle from getting back into the auricle, and second to the valve at the beginning of the pulmonary artery which prevents blood once driven into that vessel from the ventricle from getting back again into the ventricle.

The publication in 1628 at Frankfort-on-Main of *An Anatomical Dissertation concerning the Motion of the Heart and Blood in Animals* enabled Harvey's views to reach a wider public. Comparing his work with that of Servetus, who came so near to Harvey's discovery, Prof. C. Singer writes : " The two men are poles asunder when it comes to verification. Servetus is content with a statement, the other passes cautiously from observation to inference, from inference to verification in an orderly and stately sequence." In Harvey, the break with tradition is rendered less abrupt by his skilful limitation of the problem. He achieves his object,

namely, the discovery of the mechanical explanation of the heart's movement, and refuses to be led away into speculation concerning the various " spirits " and " innate heat " which had the authority of Galen or Aristotle. Harvey's position is best summarized in his own words : " Whether or not the heart, besides propelling the blood, giving it movement and distributing it to the body, adds anything else to it — heat, spirit, perfection — must be decided on other grounds. So much may suffice at this time, when it is shown that by the action of the heart the blood is transfused through the ventricles from the veins to the arteries, and distributed by them to all parts of the body."

Harvey lived through a period of considerable change both in his own country and in Europe. He was ten years old when the Spanish Armada was defeated in 1588, and he grew up in the atmosphere of Shakespeare's plays and the later part of the Elizabethan age. He was closely associated with the Stuart kings, being appointed physician to James I in 1618. He witnessed the catastrophe of the Thirty Years War, brought about by the Jesuit persecution throughout central Europe, especially in Bohemia. This war inflicted on the German peasants untold hardship and starvation, in which whole villages died out. At the time of the Great Rebellion in England, Harvey accompanied his master Charles I and refers to his own lot in the following terms : " Whilst in attendance on the King during our late troubles . . . certain rapacious hands not only stripped my house of all its furniture, but what is a subject of far greater regret to me, my enemies abstracted from my museum the fruits of many years of toil. Whence it has come to pass that many observations, particularly on the generation of insects, have perished with detriment, I venture to say, to the republic of letters."

At the battle of Edgehill in 1642, Harvey looked after the two young princes, and so it is said, they sat under a hedge, Harvey reading a book, but later ministering to the wounded. After the defeat of the King in 1646, Harvey practically retired into private life. In 1654 he was unani-

mously elected president of the Royal College of Physicians, but graciously declined the position, in view of his years and health, asking that the retiring president might be re-elected. But his vigour of mind remained. In his eightieth year, and within six weeks of his death at Roehampton in 1657, he replied to a letter from a Haarlem physician who had sent him an interesting specimen, and the following extract shows how far removed he was from the trammels of mere tradition unsupported by observation and experiment: "Nature is nowhere accustomed more openly to display her secret mysteries than in cases where she shows tracings of her workings apart from the beaten path; nor is there any better way to advance the proper practice of medicine than to give our minds to the discovery of the usual law of nature, by careful investigation of cases of rarer forms of disease."

There is one fact concerning the circulation of the blood that Harvey was not able to discover with the instruments at his disposal. He realized that the blood did pass from arteries to veins, but for this belief he had no support from observation. In order to show it a microscope was necessary, and though Galileo had demonstrated the use of such an instrument in 1610, nothing of value was revealed in microscopic work until after Harvey's death. What had been missing in Harvey's demonstrations was supplied by *Malpighi* (1628–94), professor of medicine at the University of Bologna, who showed great skill in minute anatomy. Nearly all Malpighi's works were published in London, by and at the expense of the Royal Society, which had been founded in 1662. His first publication (1661), however, as would be expected, emanated from Bologna; in this he described how, by using a microscope for the examination of the surface of a frog's lung, he realized that the connection between arteries and veins consisted of a network of "tubules". Malpighi was thus the first man to see the passage of blood through the tiny, thin-walled vessels connecting arteries and veins, and now known as blood capillaries.

THE ATLANTIC PERIOD – RENAISSANCE

ACTION	KNOWLEDGE	VISION
A.D. 1500		A.D. 1500
Cesare Borgia	LEONARDO DA VINCI	Savonarola Lorenzo de Medici Michael Angelo Martin Luther Erasmus
Hanseatic League		
	COPERNICUS	
		St. Ignatius of Loyola
	SERVETUS	
	VESALIUS	
	TYCHO BRAHE	
Spanish Armada		
	KEPLER	
		Shakespeare
1600		1600
	GALILEO	
Thirty Years War		
	TORRICELLI	
	HARVEY	
Charles I		
		Milton
	MALPIGHI	

The brilliant results of Galileo and Harvey in their respective spheres may be regarded as the climax of the Scientific Renaissance. These two pioneers stand at the threshold of the modern period. Having weathered the storms of controversy and tradition, they were able to hand on a broader view of man's universe, and a deeper appreciation of man's body. There were still difficulties and prejudices ahead, but Galileo and Harvey had set the course of future scientific inquiry, and, fortunately for the world, there were others ready to take over the helm.

CHAPTER XIV : A FRESH BEGINNING IN NATURAL PHILOSOPHY

The Royal Society

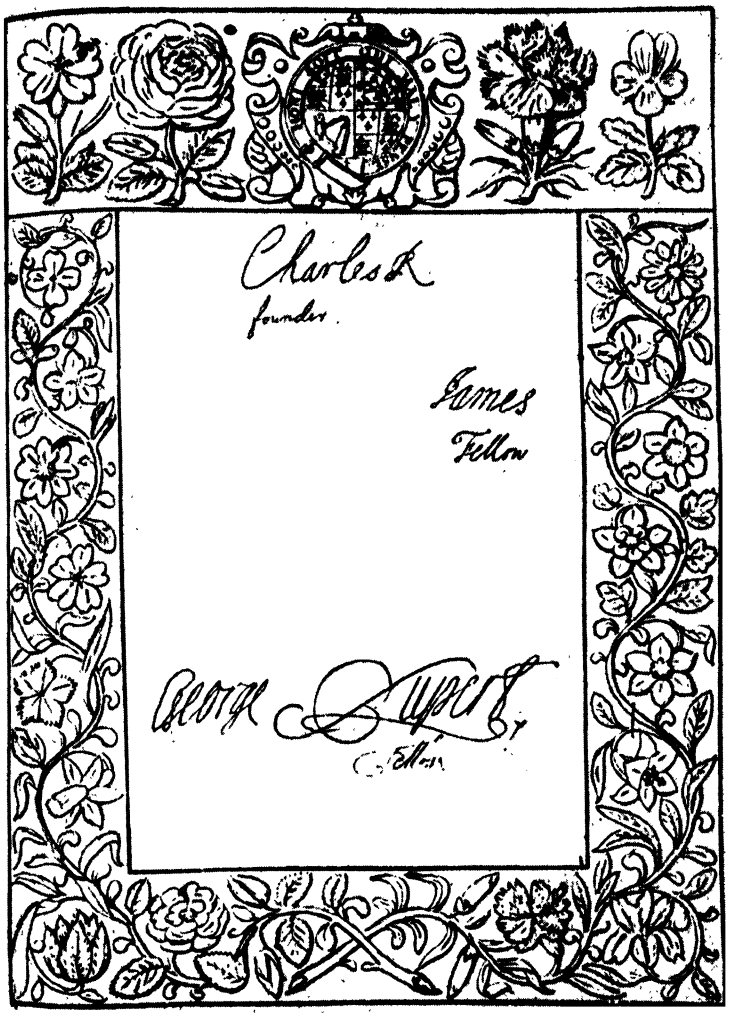
THE work of Galileo and Harvey constituted a challenge to succeeding generations. In any age, whether such a challenge is accepted depends on the men and women which that age is capable of producing. A similar challenge was implied in the brilliant achievements of the Greek thinkers, but their successors were not, to any great extent, creative ; and some four centuries elapsed after the death of Archimedes, until Ptolemy and Galen formulated their systems of knowledge concerning the universe and the human body. But even these were collections of accepted beliefs more than original contributions to science. Then for about twelve hundred years the theories were accepted as authoritative, and remained unchallenged until the scientific renaissance. The intervening centuries had not produced men capable of accepting the challenge of the Greek pioneers of scientific inquiry. Then, in the seventeenth century, the challenge arose again, this time from the break with tradition made inevitable by the wider outlook which had culminated in the historic researches of Galileo and Harvey.

By the end of the sixteenth century, Francis Bacon (1561–1626), Lord Chancellor of England, had expressed the growing desire "to extend more widely the limits of the power and the greatness of man". By the middle of the seventeenth century, Bacon's writings had appealed to many men of learning, particularly those of his own University of Cambridge. Later, some of these men, with others of like interests, began to meet in London to exchange views and discuss problems of the new experimental philo-

sophy. The Society which was thus built up was called the "Invisible College" by Robert Boyle, who as an experimenter had especially been influenced by Bacon. Despite the upheaval of Civil War, some sort of continuity seems to have been preserved, for in 1660, after the Restoration, the meetings were resumed in London, and it was decided to found a Society of Experimental Philosophy. The next step was the granting of a Royal Charter by Charles II in 1662, and the *Royal Society* so founded was destined to play an outstanding part in the development of science, not only in the land of its origin, but throughout the world.

For some twenty years enthusiasts had been meeting, frequently under great difficulties, to promote the study of "natural philosophy", especially in relation to observation and experiment. The challenge of Galileo and Harvey had been accepted by their own generation, for, in the words of the Royal Charter, the Society's object was "improving Natural Knowledge by experiment". In this concise phrase is contained also the charter of all scientific progress. For the *natural*, as opposed to the supernatural and superstitious, must be the underlying assumption, and *observation and experiment* the final test, of any theory. Sir Walter Scott maintained that belief in witchcraft decreased appreciably after the Royal Society had begun to investigate this and other alleged supernatural phenomena. For some years the terms "Member" and "Fellow" of the Royal Society were used indiscriminately, but now the former is reserved for foreign members; admission to the Society is by election by its Fellows. To be elected a Fellow of the Royal Society is now one of the highest honours in Britain that can be bestowed on a man of science by his fellow-countrymen; it carries with it the right to use the letters "F.R.S." after his name. Foreign members are also elected, and the honour is reserved for very outstanding men of science of foreign countries.

Among the first members of the Council of the Royal Society was the Hon. Robert Boyle (1627–91), an Irishman who is said to have been described, after the manner of his



By kind permission of the President and Council of the Royal Society

First decorated page of the Charter Book of the Royal Society, showing the signatures of Charles II (founder), his brother James (afterwards James II), George (Prince of Denmark and afterwards consort of Queen Anne) and Prince Rupert

country, as " the Father of Chemistry and Uncle of the Earl of Cork ". His name is recalled in " Boyle's Law " which states that the volume of a gas varies inversely as its pressure, provided the temperature remains constant. To Boyle also is due the chemical conception of an element, which he regarded as a homogeneous substance incapable of decomposition into simpler components. Another well-known name is that of Sir Christopher Wren (1632–1723), who, in addition to his achievements in architecture, was a mathematician and professor of astronomy at Oxford. His attitude to building reflects the spirit of the age ; just as science was returning to the Greek method of inquiry, so Wren made use of the classic lines of architecture, and broke with the Gothic tradition. (The term " Gothic " has no geographical significance ; this type of architecture dates from the twelfth century at St. Denis' Abbey, near Paris, an area never occupied by the Goths. The description " Gothic " was used in the sixteenth century as a term of reproach, based on the traditional behaviour of the Goths.) Whether in the well-proportioned majesty of St. Paul's Cathedral, the city churches in London, or the quiet of Neville's Court and Trinity College Library at Cambridge, Wren's work diffuses a silent exhortation to clear thinking, sincerity and harmony.

In its early days the Royal Society included men of letters, and it certainly does not seem incongruous that for two years it was presided over by that versatile diarist, Samuel Pepys (1633–1703), who was elected president in 1684. Nor does it lessen the dignity of such a distinguished society to be satirized by Samuel Butler (1612–80) in *The Elephant in the Moon* :

> Their learned speculations
> And all their constant occupations.
> To measure wind, and weigh the air,
> And turn a circle to a square.

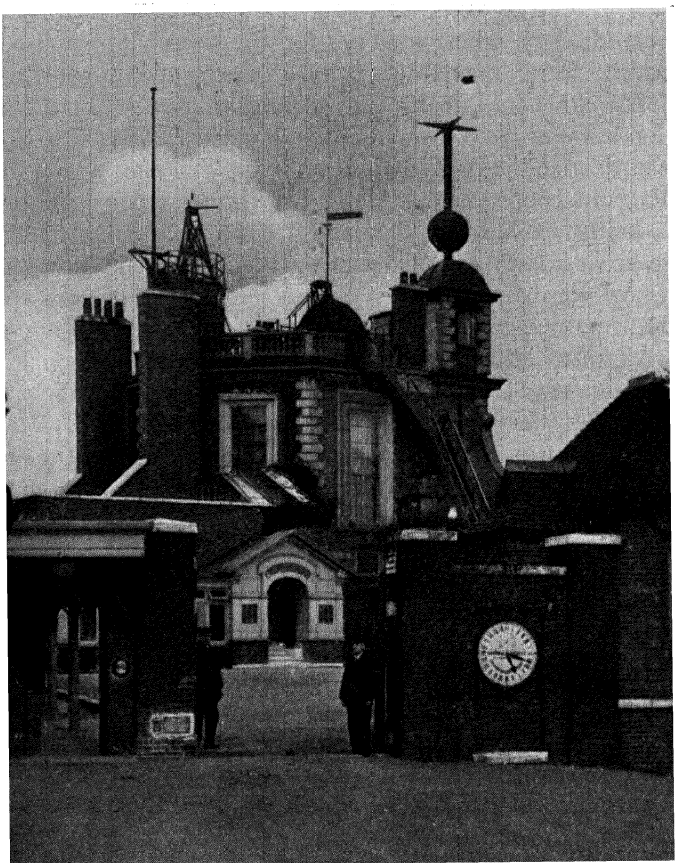
" The Elephant in the Moon ", as seen by the astronomer, turns out to be a mouse which has got into the telescope!

It was not only in England, however, that the challenge

of the scientific renaissance was accepted. As might be expected, the earliest societies for the discussion of the new learning were formed in Italy. Much of central Europe unfortunately had been plunged into an abysm of barbarism and misery as a result of the Thirty Years War (1618–48). But in France the Académie Royale des Sciences was founded at Paris in 1666, and by the end of the year correspondence was being exchanged between it and the Royal Society. One great advantage of the latter has been its independence of State control, a fact which has, in comparatively recent times, enabled the Royal Society to take the lead in promoting innovations in international scientific relationships.

A few years after signing the Charter of the Royal Society, Charles II was associated with the beginnings of another scientific institution, namely the *Royal Observatory, Greenwich*, founded in 1675 to meet a practical navigational need. In this year a committee had been appointed to report on a method of finding longitude at sea which had been offered to the Government by a Frenchman. It was mainly due to *John Flamsteed* (1646–1720), a native of Derbyshire, that the committee recommended that the offer be declined. It also sent a memorial to the King urging the setting up of a national observatory in order to provide more accurate knowledge of the positions of the heavenly bodies. In this way it was hoped to aid the increasing numbers of English navigators in their task of finding longitude at sea. Charles II approved the plan, and Flamsteed was appointed the first Astronomer Royal. Despite the meagreness of his salary — £100 a year — and the fact that he had to provide his own instruments, and an assistant, Flamsteed produced a catalogue of three thousand stars, which was more extensive than that of Tycho Brahe and which, through its increased accuracy, laid the foundation of careful observation for which the Observatory has become world-famed.

It is a tribute to the influence of Flamsteed and his successors on astronomical and nautical science that in 1884 the meridian of longitude passing through the Royal Observatory was adopted by international agreement as the zero



By courtesy of the Astronomer Royal

Gateway and Flamsteed House at the Royal Observatory, Greenwich

meridian from which longitude is measured up to 180° East or West of Greenwich. The other measurement necessary to fix any position on the earth's surface is of course the parallel of latitude, using the equator as zero and measuring up to 90° North or South of it.

The accompanying photograph shows Flamsteed House and the old building of the Royal Observatory, designed by Wren and erected in 1675. The long windows are in the

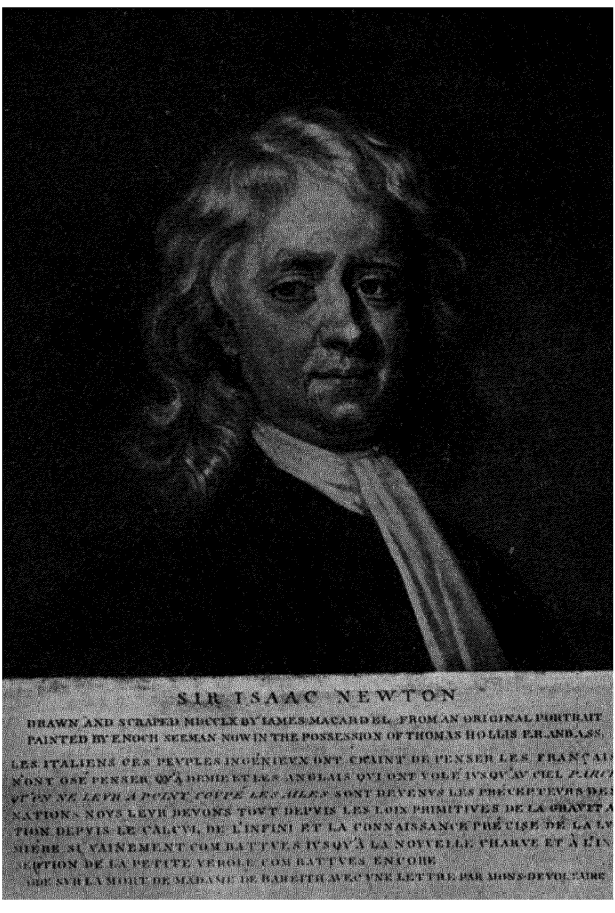
Octagon Room, where the first observations at the Royal Observatory were made by Flamsteed with his sextants. The floor beneath the Octagon Room is the official residence of the Astronomer Royal. Successive Astronomers Royal, from Flamsteed on, have lived there. On the roof the " time-ball " slides down the staff at the instant of noon daily, and to the right of the entrance gates is the Shepherd 24-hour electric clock. The entrance gateway was destroyed by a bomb during the Second World War and the 24-hour clock was damaged.

To the present Astronomer Royal, Sir H. Spencer Jones, has fallen the task of superintending the move of the Observatory from Greenwich Park to Herstmonceux Castle, Sussex. The growth of London eastwards along both banks of the Thames had made the atmosphere of Greenwich unsuitable for observations, and the brightness of the sky due to street-lighting and illuminated advertisement signs also interfered with the use of the telescopes. The chimneys at a near-by electric power station were indeed shortened to reduce interference by smoke and hot gases. So long ago as 1923, the development of local electricity undertakings for trams and trains made it necessary to move that portion of the Observatory's work which dealt with magnetic observations to Abinger, in Surrey. These changes are a reminder of the competing claims of modern civilization and of scientific research, without which the former would not have attained its present standard.

On its new site, the Observatory will be known as the Royal Greenwich Observatory.

Isaac Newton

Through the many and varied achievements of its Fellows, the Royal Society has constantly placed successive generations under an obligation, but to one of its Presidents the whole world stands a debtor. *Isaac Newton* (1642–1727) is unique, for he did more than take up the challenge of



Portrait of Newton by Enoch Seeman in the dining-room of Trinity Lodge, Cambridge; engraved by MacArdel, 1760. Reproduced from an engraving in the possession of the Royal Institution, London

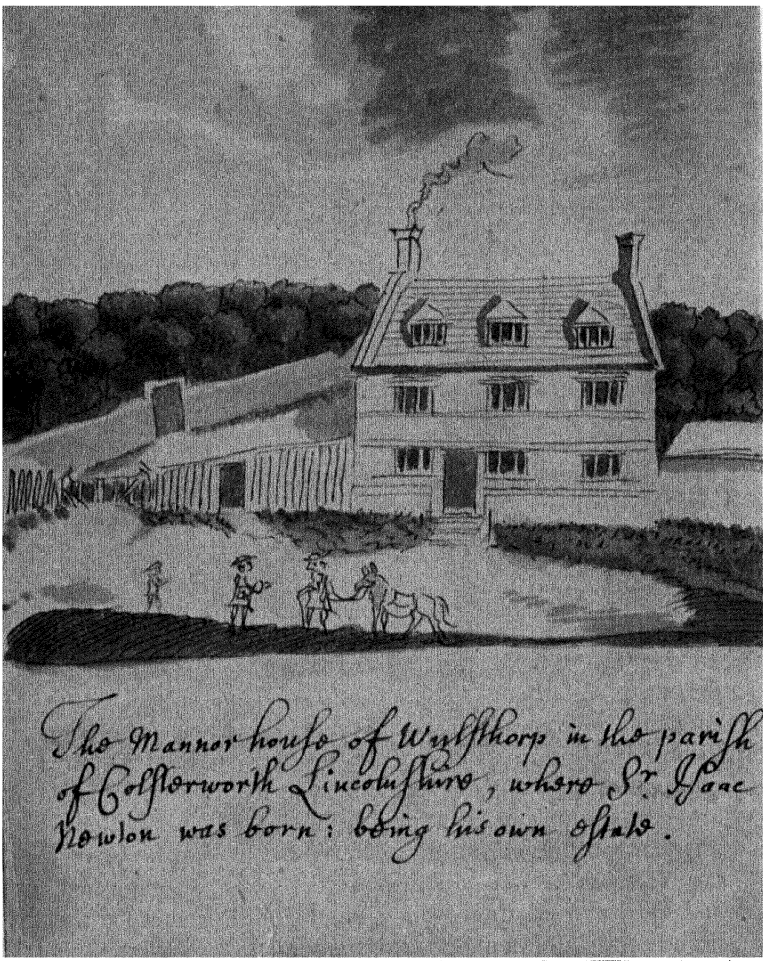
Galileo and Harvey ; he gave to mankind a fresh start in natural philosophy.

The year 1642, which saw the beginning of the armed struggle between Charles I and Parliament, may especially be remembered in the story of science as the year of Galileo's death and Newton's birth, for during the lives of these two men the great transition took place from medieval to modern scientific achievement. At Woolsthorpe Manor House (p. 168), about six miles south of Grantham, a tablet over the mantelpiece of the room in which Isaac Newton was born, pays tribute to his greatness, in the couplet of a contemporary poet (Pope, 1688–1744) :

> Nature and Nature's laws lay hid in night :
> God said, " Let Newton be ", and all was light.

Sheltered from the turmoil of civil war, Newton's childhood was spent in Woolsthorpe, a small hamlet with the river Witham running between it and the Great North Road. The health of Newton's mother was seriously impaired by the shock of her husband's death, shortly before the birth of her son, and this had a corresponding effect on the infant, so that Newton started life under a twofold handicap. At the age of twelve he was sent to the King's School at Grantham, lodging with an " apothecary " and his wife, on a site now occupied by an extension of the George Hotel in the High Street. His early school days were uneventful, until apparently a bully who had kicked him, so aroused Newton's indignation that he not only administered physical retribution, but also determined to beat his adversary in work as well. This feat was easily accomplished, and the victor continued his triumphs until he reached the proud position of being head of the school.

For many of the incidents of Newton's life, especially the earlier part of it, the modern biographer is indebted to *Memoirs of Sir Isaac Newton's Life*, by William Stukeley, M.D., F.R.S., published in 1752, the author being a fellow-countryman and friend of Newton after their meeting at the Royal Society in 1718. Stukeley collected considerable



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Facsimile of Stukeley's Sketch, from his *Memoirs of Sir Isaac Newton's Life*

information locally, and the story of the " mouse miller " is typical of the mechanical bent of Newton's mind while still at school. Stukeley reminds us that at this time " A windmill is a sort of rarity in this country, abounding so much with rivers and brooks ; for which reason they use water-mills ". During the building of a new windmill near Grantham, Newton paid such attention to the details of construction that he made an accurate model of it in wood, which worked when placed on the roof of his lodging. " But Isaac was not content with this bare imitation. . . . He put a mouse into it, which work'd it as naturally as the wind. This he used to style his mouse miller, and complained jokingly what a thief he was, for he eat up all the corn put into the mill." There were various speculations as to how the mouse turned the mill. " However it was a piece of diversion to not a little part of the town and country, to pay a visit to Isaac's mouse miller, and the farmer readily supplyd him with handfuls of corn on Market days."

The " water-clock " controlled by water dropping from a cistern also belongs to this period, and also the sun-dial. On September 3, 1658, the day of Oliver Cromwell's death, a great tempest apparently swept the country ; Newton was taking part in a jumping contest, and though not ordinarily outstanding in this sport, he used his intellect to good effect ; as Stukeley narrates, " yet observing the gusts of the wind, took so proper an advantage of them as surprisingly to outleap the rest of the boys ".

Newton's mother recalled her son from Grantham in order to take charge of the family estates ; possibly this occurred when he was in his fifteenth year, and as may be expected he proved totally unfitted for that sort of responsibility. " But these employments ill suited with Sir Isaac's taste. When he was order'd into the field to tend on a flock of sheep, he was sitting under a tree, with a book in his hand ; or busying himself with a knife, cutting models and inventions in wood. At other times he would get to a spring head or running stream, which this charming country abounds with. There he made little wheels, such as they use in water-mills,

some over-shot, as they call them, some under-shot, with proper dams, sluices and many hydrostatic experiments. In the meantime the sheep under his care were stray'd into the corn fields ; which must occasion great outcry and damage, to be repaid by his mother. Nor would Isaac so much as remember his dinner-time, so intent was he in philosophical meditation." Stukeley mentions many other incidents, presumably founded on fact, which suggest that Newton conformed to the traditional notion that genius and absent-mindedness are related.

In 1658 Newton was allowed to return to Grantham, and spent three years preparing for Cambridge. Although outstanding at school, he by no means held a similar position in his early days at Trinity College, which he entered in 1661 as a " sizar " (at that time this implied the performance of certain menial duties in return for tuition and food). As late as 1664, when competing for a scholarship, the examiners, though recommending him for an award, commented on his poor knowledge of geometry ! The Cambridge days, however, soon yielded that indication of genius which ultimately gave to the University its mathematical renown, which it still holds. Within a few months of his taking the degree of B.A. in 1665, Newton was quietly developing ideas on the binomial theorem, method of fluxions (his form of the differential calculus), colours, and experiments with a prism, but he kept his researches to himself.

The incidence of the bubonic plague of 1665 enforced Newton's retirement the following year from Cambridge to the ancestral home at Woolsthorpe. Without a college library at hand, and without the apparatus for extending his work on optics, Newton was forced to meditation on other problems, and it is to this period that is ascribed the traditional " apple " incident. The idea of the earth's gravitation was not new, and Galileo had already disproved the accepted belief that the speed at which a body falls depends on its mass ; but to Newton is due the actual formulation of the problem itself, which is always the most important step in any solution. There were two points at

issue: first, to determine how the gravitational pull would vary with the distance from the body, and second, to see whether the gravitational phenomena observed at the earth's surface (like the falling of the apple) would also account for the motion of the moon. Newton was able to confirm his belief that the gravitational pull is inversely proportional to the square of the distance, by applying it to the third of Kepler's laws of planetary motion. From this, based on the assumption of the essential unity of the universe, he passed to the application of the inverse square law to the moon's motion, in order to test the theory.

Considerable controversy has centred round the delay of about twenty years which occurred in announcing the law of gravitation. As a result of the many investigations made at the time of the bicentenary, in 1927, of Newton's death, it appears that the chief reason was due to the caution with which Newton treated his discovery, and to the serious difficulties, which at first he was not able to overcome, such as whether the total attraction of a sphere could be regarded as concentrated at its centre. There were three Englishmen also especially interested in gravitation: Robert Hooke, whose name is associated with the law concerning elasticity, Sir Christopher Wren, mathematician and architect, and Edmund Halley the astronomer. His own inability to prove the inverse square law led Sir Christopher to say that he would give either Halley or Hooke two months in which to bring to him a convincing demonstration of the principle; and a book of the value of forty shillings to whichever of them did it. Halley went to Cambridge, and consulted Newton, with the result that the latter's work was at last made known in 1684.

The story of the publication of Newton's great work, the *Principia*, is also of interest. On May 19, 1686, the Royal Society resolved that " Mr. Newton's ' Philosophiæ Naturalis Principia Mathematica ' be printed forthwith in quarto, in a fair letter ". The Society's funds, however, had been so depleted by the publication of a book on *Fishes* that even the salaries of its staff were in arrear. Fortunately, one of

PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J S. NEWTON, Trin. Coll. Cantab. Soc.* Matheſeos Profeſſore *Lucaſiano,* & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,

Juſſu *Societatis Regiæ* ac Typis *Joſephi Streater.* Proſtat apud plures Bibliopolas. *Anno* MDCLXXXVII.

By courtesy of Prof. E. N. da C. Andrade, F.R.S.

Title-page of the first edition of the *Principia*

the Fellows saved the situation ; Halley, whose father was a prosperous soap-boiler and London merchant, probably used part of his paternal allowance in financing the printing of the *Principia*, which had been licensed by the president, Samuel Pepys, on the authority of the Council. The *Principia* sold quickly, copies became scarce and prices high. It is said that a Scotsman copied the whole book out by hand, in consequence !

In the *Principia*, which was written in Latin, the learned language of the day, Newton gives a clear statement of the *Laws of Motion*, deduced from the dynamical experiments of Galileo. The first two may briefly be summarized thus : (1) absence of force implies uniform motion in a straight line, while (2) rate of change of motion is determined by force. The third law is the well-known statement that (3) action and reaction between two bodies are equal and opposite. After establishing the gravitation of Jupiter, Saturn, the Sun and the Earth, Newton proceeds to his *Law of Universal Gravitation*, that the force between two bodies is proportional to the product of their masses, and inversely proportional to the square of the distance between them.

It is not without interest that one of the most striking vindications of the Newtonian mechanics is associated with *Halley* (1656–1742) who made possible the publication of the *Principia*. In 1682 a great comet appeared, and Halley made careful observations of its path ; after the publication of the *Principia*, the possibility was realized of a comet describing an ellipse with a very long axis through the sun, and Halley set out to gain all the information available concerning the appearances of previous comets. Basing his calculations on Newton's work, he maintained that the comet of 1682 had visited the region of the earth previously in 1607, and again in 1531, and he confidently predicted that it would reappear at the end of 1758 or the beginning of 1759. Realizing that he would not live to see its return, Halley expressed the hope that if the comet did come back as predicted, " impartial posterity will not refuse to acknowledge that this was first discovered by an Englishman ". The comet returned, and has done so at the predicted inter-

vals, in 1835 and 1910; also it is known as Halley's Comet.

Apart from his work on gravitation and the laws of motion, Newton is remembered by his investigations concerning *colour*, and the "spectrum" produced when white light is allowed to pass through a prism. Although it is now realized that the seven colours — violet, indigo, blue, green, yellow, orange and red — of which he considered white light to be composed, should be replaced by a multiplicity of colours of various wave-lengths, there is something prophetic in his insistence on the corpuscular theory of light as opposed to Huygens' wave-theory. The difficulty of imagining that tiny corpuscles could travel with the velocity of light was urged as an argument against the corpuscular theory, but the idea does not seem so impossible in view of the modern atomic theory of electrons moving with that velocity. In 1671 Newton presented a "reflecting telescope" which he had made to the Royal Society, and was elected a Fellow in January of the following year; in 1703 he was elected president. His work on *Opticks* was published in English in 1704, whereas the *Principia* had been written in Latin.

Newton's wide researches in *pure mathematics* chiefly had a practical bias, and despite the unfortunate dispute concerning whether he or Leibniz was the first to discover the methods of the calculus, there is no doubt as to the tremendous contribution that Newton made to mathematics in his "method of fluxions". A committee appointed by the Royal Society reported in 1712 in favour of Newton as the "first inventor". To Leibniz at any rate belongs the distinction of devising a notation which has proved invaluable in its application to the problems of applied science.

After the flight of the Roman Catholic James II, in 1688, Parliament was summoned in the following January to recognize the Protestant William and Mary. Among its members was Isaac Newton, representing the University of Cambridge, and the following description is taken from Macaulay: "Among the crowd of silent members appeared the majestic forehead and pensive face of Isaac Newton . . . he sate there, in his modest greatness, the unobtrusive but

unflinching friend of civil and religious freedom". Newton's Whig sympathies led him to support the new royal house, and foster loyalty to William and Mary. In 1701 he was again elected M.P. for the University of Cambridge, and remained its representative until the dissolution after the death of William III. The following extract from Stukeley's *Memoirs* gives an account of his knighthood, and refers to his last and unsuccessful candidature for Parliament: "In April 1705 Sir Isaac Newton came to Cambridg, to offer himself a candidate to represent the University in parliament. In 16th. of that month Queen Ann was pleased to visit the University of Cambridg, from Newmarket, whither a deputation of the heads of the Colleges had been, to invite her. . . . The whole University lined both sides of the way from Emanuel college, where the Queen enter'd the Town, to the public Schools. Her Majesty dined at Trinity college where she knighted Sir Isaac, and afterward, went to Evening Service at King's college chapel: which I always lookd upon as the most magnificant building in the world." Newton was defeated by the Tory element, then in the ascendant at the University, and did not again seek re-election.

In 1696 Newton was appointed Warden of the Mint, having been specially selected to deal with the debased silver coinage due to cheap alloys and the prevalent habit of clipping. In the words of Macaulay, "The ability, the industry and the strict uprightness of the great philosopher, speedily produced a complete revolution throughout the department which was under his direction". In 1699 Newton was appointed Master of the Mint, a high office which he held to the end of his life.

Newton's calm and scientific judgment never deserted him, and in his eighty-fifth year, a fortnight before his death, he felt well enough to preside at a meeting of the Royal Society, though he had been confined to his house at Kensington for some months previously. On his return he became seriously ill, and patiently suffered great pain during those last days.

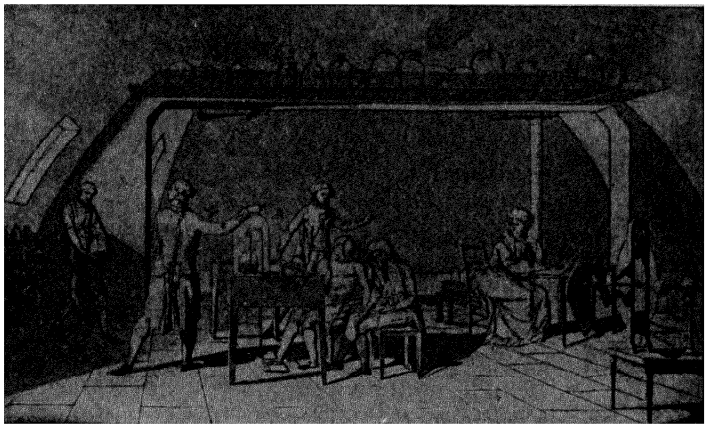
It is not an exaggeration to say that most of the amenities of everyday life, which we take as a matter of course, on

land, on sea and in the air, could not have come into being without a recognition of those principles made known to the world by the genius of Isaac Newton. Yet his own estimate reveals a humility which is all the more striking, because of the magnitude of his achievements : " I do not know what I may appear to the world ; but to myself I seem to have been only a boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me ".

Lavoisier : the Birth of Modern Chemistry

To appreciate the beginnings of modern chemistry, and the significance of Lavoisier's work, it is necessary to understand current ideas concerning combustion. It seemed common knowledge to men of the seventeenth century that when a substance was burnt something escaped from it, and though this " something " had been identified with sulphur, a new name was given to it by Stahl (1660–1734), who was physician to the King of Prussia. The escaping something he called " phlogiston " (Greek *phlogizō*, set on fire) ; it was the material of fire, not fire itself. One of the difficulties which beset the " phlogiston " theory was the fact that metals when heated *increase* in weight. Various explanations were offered, including " negative " weight which was attributed to " phlogiston ", a conception comparable to Aristotle's idea of " lightness " as property of matter itself.

While chemistry relied on qualitative surmises rather than on quantitative analysis, little progress could be expected. But an age which was permeated by the mathematical implications of Newton's work, could not long remain oblivious to numerical data in other fields. It fell to the lot of a French chemist, *Lavoisier* (1743–94), to dispel speculation by appealing to the balance (the accurate form of scales used in scientific work), thereby laying the foundations of modern chemistry.



Lavoisier's experiments on respiration. The subject is breathing oxygen from a jar; Madame Lavoisier, who assisted her husband, is at the desk on the right

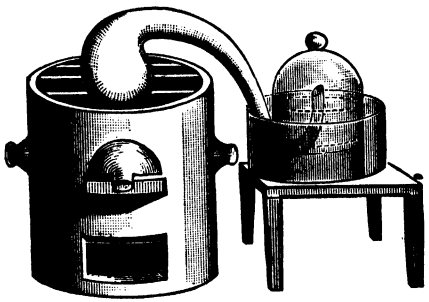
Lavoisier was born at Paris in 1743, into a well-to-do family; following the death of his mother five years later, he and his sister were cared for by their maternal grandmother, whose wealth enabled full advantage to be taken educationally of the obviously high intelligence of the future chemist. It was, however, with a view to his attaining eminence in the legal profession that the young Lavoisier was trained, so that at the age of twenty-one he was a fully-qualified lawyer. He spent much of his leisure attending lectures at the "Jardin du Roi" or "Le Jardin des Plantes" which had been founded in Paris in 1627 as a site for the cultivation of medicinal plants. By the middle of the eighteenth century the "Jardin" had become famous for the lectures of Rouelle (1703–70), who as demonstrator in chemistry attracted and inspired Parisian society with a love of the science. Fortunately, Lavoisier had access to notes on the lectures which had been made by Diderot (who was responsible for the famous French *Encyclopédie* published between 1751 and 1780), and was therefore able to concentrate on the experiments themselves.

Lavoisier's father had been interested in science, and the

son had already shown himself gifted in mathematics, having at the age of twenty won a medal and money prize for solving a problem set by the French Government; so it is not surprising that the lawyer succumbed to the lure of chemical experiments, such as he had watched with so much interest at the "Jardin". In 1768 he was elected a member of the Académie Royale des Sciences. Soon afterwards he joined the hated *Ferme Générale*, a group of financiers who collected the indirect taxes in France, a step which led eventually to his condemnation and death. In 1775 he was appointed executive officer of a small committee in charge of the nitre and gunpowder factories of France. In the chemical researches to which he devoted himself he was greatly assisted by his wife, who engraved several plates for the *Elementary Treatise on Chemistry* which Lavoisier published in 1789, the year of the French Revolution.

Most of Lavoisier's chemical investigations were carried out in the laboratory of the Arsenal at Paris. The importance of his work centres round his insistence on quantitative methods in the formulation of chemical ideas. Through him a final blow was dealt to the "phlogiston" theory, which was held by Continental and English chemists. Among the latter was *Priestley* (1733–1804), a Leeds Unitarian minister with a taste for chemical experiments who had discovered, in August 1774, a gas which we now know as oxygen. Priestley believed it was air with phlogiston removed, and accordingly called it "dephlogisticated air". He also realized that this gas supported life better than ordinary air, and afterwards suggested that it might be used in the treatment of diseases of the lungs. On visiting Paris in October 1774, Priestley dined with M. and Mme. Lavoisier and told them of his discovery, and that the "dephlogisticated air" enabled a candle to burn more brightly.

Lavoisier repeated Priestley's experiment, but the mass of quantitative results which he was accumulating enabled him to give a far more satisfactory explanation. Lavoisier maintained that the red powder of burnt mercury which Priestley had heated actually gave off the "dephlogisticated



Lavoisier's apparatus for heating mercury in a limited volume of air

air" which he, Lavoisier, called "oxygen". By the unanswerable evidence of the balance, Lavoisier proved that the loss of weight of the red powder at the end was exactly equal to the weight of the oxygen given off. He was also able to explain the red powder itself, which had been originally formed by the heating of mercury in air (we now refer to this powder as mercuric oxide) ; for the loss in weight of the air was equal to the gain in weight of the mercury. In other words, Lavoisier had come to an entirely *new theory of combustion*, according to which the oxygen of the air had combined with the metal, and so caused the increase in weight. By leaving out of account the mystical " phlogiston " and trusting to quantitative evidence, Lavoisier confirmed the *law of the conservation of matter* (matter is neither created nor destroyed during any physical or chemical change), and so brought into chemistry those principles and methods which Galileo and Newton had used to such advantage in solving problems of the physical universe.

Such a fresh beginning in the approach to chemistry was accompanied, not unnaturally, by the urgent necessity of introducing a nomenclature based on scientific principles. To this also Lavoisier contributed ; and it is to him and his disciples that chemistry owes the replacement of lengthy and ambiguous phrases to describe a substance, by the comparatively simple chemical names which we recognize today. For example " carbonate of potash " (in modern laboratories

potassium carbonate) was a decided improvement on van Helmont's " alcahest " or " nitre fixed by itself ", to quote only two of the eight titles by which this substance was previously known.

Lavoisier's achievements in science did not compensate, in the scales of revolutionary France, for the fact that he had been a *fermier* of taxes before the Revolution; although it seems that he carried out his duties honestly and endeavoured to improve the system. The only charge that was brought against him in 1794 was that " of adding to tobacco water and other ingredients detrimental to the health of the citizens ". The president of the Tribunal claimed that the Republic had no need of men of learning. A year earlier Christianity had been abolished. So having abandoned the guidance of *knowledge*, and the leaven of *vision*, the Republic had to rely on the men of *action*, and *they* sent the " greatest chemist of all time " to the guillotine.

Linnaeus : the Classification of Living Things

Most of the learned societies which deal with one special aspect of science include in their titles some reference to the branch concerned ; for example, the Royal Astronomical Society. The Linnaean Society of London, however, whose members are especially interested in botany and zoology, takes its name from *Carl Linnaeus* (1707–78), an eighteenth-century Swedish biologist who, by 1762, had made the Uppsala Botanic Garden the finest and best known in Europe. After the death of Linnaeus, his books and extensive collections ultimately came into British hands, and the Linnaean Society of London was founded in 1788 to preserve them, and also to encourage interest in natural science.

Linnaeus' father was a clergyman and a keen gardener, and from quite early days his son Carl was brought up amid the extensive display of foreign plants which had been collected in the rectory garden. He had his own plot, and learnt much from his father concerning the names and habits of various plants. Carl was educated at Vaxjo in the

south of Sweden, and in 1727 became a medical student at the University of Lund, which is situated a few miles inland from the Sound.

In the following year, however, Linnaeus transferred to the University of Uppsala, and a part of his medical training included a visit to Stockholm to watch the dissection of a human body. The journeys there and back so strained Linnaeus' financial resources that he lacked the bare necessities of life, and Celsius, a Swedish astronomer at Uppsala, took him into his own home. The interests of Celsius (1701–44) were not confined to astronomy, as it is to him that we owe the division of the thermometric scale, between the boiling-point of water and its freezing-point, into 100 parts, as in the modern centigrade thermometer. But Celsius' scale was graduated downwards, treating the boiling-point as zero, thereby avoiding negative readings for temperatures below freezing, which would obviously be a convenience in a northerly country like Sweden.

Linnaeus' financial position gradually improved as his reputation as a lecturer spread. During May–October 1730 he made a journey to Lapland, travelling in all about 5000 miles and suffering considerable hardship. The extensive collections with which he returned proved invaluable. By 1734 he finished his medical training, but owing to a custom prevalent in Sweden at that time, he would only be allowed to practise when he had obtained a doctor's degree in another country. In the following year, after a fortnight's residence in Holland, he successfully obtained a doctorate at Harderwijk, on the shore of the Zuider Zee.

In 1741 Linnaeus was appointed professor of botany at Uppsala. The number of students at the University rose from five hundred to fifteen hundred, and his fame spread to such distant countries as India, America and Japan. At the end of twenty years he received the highest honour that his country could bestow, being appointed a member of the Swedish House of Nobles and assuming the name of von Linné. The latter years of his life were marked by increasing ill-health, and he relinquished his professorship

some fifteen years before his death in 1778.

In the early days of biology, Aristotle realized the importance of classification, and had the generations which succeeded him been imbued with the same spirit of inquiry, instead of regarding his writings as final and authoritative, the story of science would have been very different. After Aristotle's day, a great deal of exploration had taken place, and by the fifteenth century specimens could be collected from the east as far as China and from the west as far as America. By the eighteenth century the need for scientific classification had become urgent. There were various attempts at this, but it was Linnaeus who made a fresh start in classification by grouping "species" into "genera", "genera" into "orders" and "orders" into "classes". Though considerable modification has taken place, we still use these four important groups, namely, class, order, genus and species.

The contribution to science by which Linnaeus will always be remembered is the method of defining every known living thing by two Latin names; that is, a system of *binomial nomenclature*. The first name is that of the "genus", and the second that of the "species". The simplicity of the scheme was as strong a point in its favour in biology, as was the simplicity of Lavoisier's reforms in naming chemical substances. The use of Latin words is a reminder of the international nature of science, and has the great advantage that the same living thing is known by the same name in different countries. By *The International Rules for Botanical Nomenclature* published at Jena in 1906, biologists of the world gave the necessary authority for the use of Linnaeus' method.

The stimulating effect of Linnaeus' love of wild life is seen in the various societies bearing his name which have sprung up throughout the civilized world. In his appeal to Nature as it is, rather than speculation on what it should be, Linnaeus carried on the spirit of the scientific renaissance. With Newton and Lavoisier he accepted the challenge of Galileo and Harvey, and so helped mankind to make a fresh beginning in natural philosophy.

CHAPTER XV: INVENTION AND INDUSTRY

The New Age

AN incident in the life of Newton, when he was forty-four years old, brings into relief the implications of the Renaissance, which had been slowly unfolding throughout Europe for over two hundred years. James II, who had succeeded his brother Charles II on the latter's death in 1685, made no secret of his Roman Catholic sympathies. Following the rebellion of the Protestant Duke of Monmouth, Judge Jeffreys was appointed Lord Chancellor, and when the Court of High Commission (so unpopular in Charles I's reign) was revived by James II, Jeffreys became its president. A dispute had arisen between the King and the University of Cambridge, and the latter had taken its stand on the main point at issue, namely that no Royal mandate could override the existing law without the consent of Parliament. In 1687 the Vice-Chancellor, accompanied by eight representatives of the Senate, was ordered to appear before the Court of High Commission. The Vice-Chancellor was soon reduced to silence (and ultimately deprived of his office, as well as of his position as Master of Magdalene College), and the eight representatives, who included Isaac Newton, were forbidden to say anything in defence, and were ordered out of court, with an insult.

Two names have become household words from among those who took part in this sinister incident — Newton and Jeffreys. The former went back to his rooms at Cambridge to continue the proof-reading of his *Principia*, which has proved one of the world's greatest contributions to knowledge; the latter, who attempted to override the spirit of democracy and freedom by the arbitrary use of authority, stands out from the pages of history for his other activities as an infamous

example of the cruelty and inhumanity of the bully. On one hand the painstaking and unobtrusive work of the seeker after truth, leading to a reverence for knowledge and a respect for freedom; on the other, the careless and blatant tyranny of opportunism, based on discredited authority, and contempt of human feeling.

It is not possible to follow in detail the course of events influenced by the great issues of the Renaissance. In *science* we have already traced the challenge made to traditional authority, and how that challenge was accepted. In *religion* the upheaval of the Reformation was followed by bitter wars of controversy and persecution, which had profound effects in the political sphere. Not only was this evident in the sixteenth century, but it also resulted ultimately in some European countries retaining their Roman Catholic tradition, and others championing the cause of Protestantism. For example, by the middle of the eighteenth century the struggle of Frederick the Great (King of Prussia from 1740 to 1784) with Austria culminated in the Seven Years War (1756–63), in which the Protestant powers of Britain and Prussia were arrayed against Roman Catholic Austria and France, together with Russia of the Greek Orthodox Church. (The separation within the Catholic Church which took place in 1054 resulted in the formation of the Roman Catholic Church in the West, and the Greek Orthodox Church in the East; both were anti-Protestant.)

In *constitutional matters* the spirit of the Renaissance was felt in England in the rebellion which made Cromwell a Protector, and later in the bloodless revolution which placed William of Orange and Mary on the throne of England in 1689, within two years of the appearance of Newton before the Court of High Commission authorized by James II. In France a hundred years later, the revolt against arbitrary authority found expression in the storming of the Bastille (July 14, 1789), the formation of the Republic and the revival of the phrase "Liberty, Equality, Fraternity". Nor would it be right to ignore the religious movement that was inspired by John Wesley (1703–91) and which was con-

cerned with the individual's right to personal religious experience, without the interference and arbitrary authority of the priest. The spirit of religious fervour which followed, called Methodism, played an important part in saving England from the horrors of the French Revolution.

Apart from the relation of the individual to authority which was such an outstanding factor during the Renaissance, there was another aspect of human activity which had an important bearing on the peace of the world. The spirit of *adventure and exploration* which, toward the end of the fifteenth century, culminated in an Atlantic period of civilization, was also responsible for the formation of settlements far distant from the original homelands. The rivalry between European powers might thus easily become hostility where the representatives of those powers were neighbours on foreign soil. The conveyance of merchandise from the settlement to the home country was another bait which frequently held great treasure for an envious enemy, whether pirate or a recognized State. The " Spanish Main " afforded plenty of opportunity for such unofficial warfare. Later, an inevitable struggle arose for dominance in such distant places as America and India, where many of the European powers were involved.

In North America, New England had been founded by the Pilgrim Fathers, following the historic voyage of the *Mayflower* in 1621. Virginia to the south was of earlier date, but they were joined by the annexation of the intermediate land of the New Netherlands. This was made possible by the Naval War between England and Holland during 1665–67. New Amsterdam became New York, in honour of Charles II's brother, the Duke of York, afterwards James II. Farther north and nearly a century later, the French were defeated by Wolfe at Quebec in 1759. In India they experienced a similar fate in the decisive battle of Plassey (on the northern tip of the Ganges delta) at the hands of Clive and the East India Company in 1757. A little later, the implications of arbitrary authority as opposed to mutual co-operation were seen in the outbreak of the War of American Independence

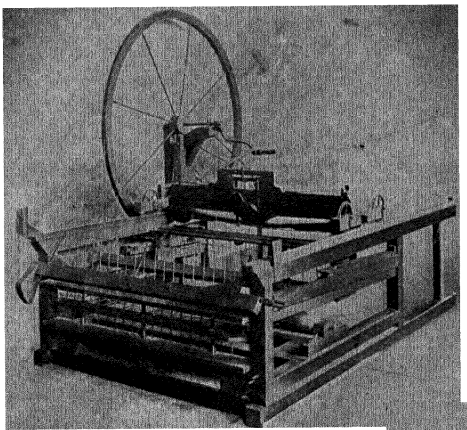
in 1776, which resulted in the American colonies breaking away from the British Crown and forming the United States.

Enough has been written to show the complex political results of the great changes in thought and outlook associated with the Renaissance. There was, however, a further development which was destined to revolutionize the mode of life and standard of living throughout the civilized world. Amid the background already described, the work of such pioneers as Newton, Lavoisier and Linnaeus was quietly carried on, and a fresh beginning made in natural philosophy. It is not surprising therefore that a generation should arise in which the inventive spirit made itself felt in the more ordinary concerns of daily life. This, together with the use of *power*, especially steam power, ushered in a new age and changed the customs and conditions of life, first in England, and later throughout the world. It was during the eighteenth century in particular that invention began to influence industry.

Arkwright: Bringing Power into Industry

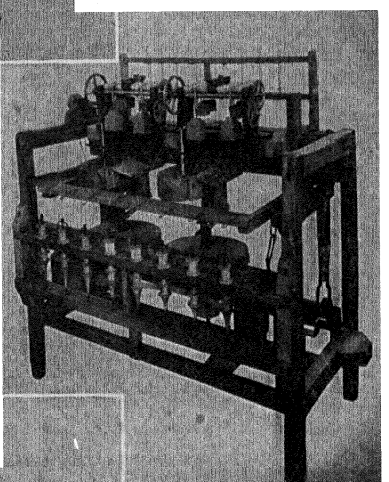
The appointment of *Richard Arkwright* (1732–92) as High Sheriff of Derbyshire in 1783, and his knighthood three years later, marked the culmination of a remarkable career. Born at Preston some fifty years earlier, the future inventor migrated to Bolton, where he carried on the trade of barber and wig-maker. From the age of thirty-five he was more than interested in developing ideas to revolutionize the production of cotton material, and ultimately lost his own business and sank his wife's savings in that endeavour. To understand the significance of his "water frame", it is necessary to trace the improvements in the method of cotton manufacture that took place during the eighteenth century.

The everyday use of such words as "calico" (from Calicut, on the west coast of Madras) and "muslin" (from Mosul, in Iraq) is a reminder of the part that the East played



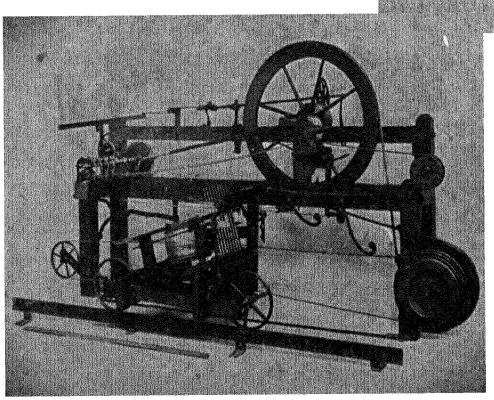
HARGREAVES' SPINNING JENNY

ARKWRIGHT'S WATER FRAME



Three machines fundamental to the development of the cotton industry

Crown copyright. From exhibits in the Science Museum, South Kensington



CROMPTON'S MULE

in the original cultivation and manufacture of cotton. Though the Protestant refugees from Holland introduced the loom into England at the end of the sixteenth century, it was the considerable trade of the East India Company that brought cotton goods into general use. The imitations manufactured in England were inferior to the native product, and the vested interest of the linen and wool manufacturers was so strong that it was made a crime to wear cotton apparel. This restrictive law was modified in 1736, but even then the warp had to be of linen yarn. The impetus thus given to the cotton trade showed itself in the multitude of Lancashire weavers whose cottages, situated in an ideal moist atmosphere, became small independent factories for the production of cloth. The " spinning " duties of an unmarried daughter led to the well-known title of " spinster ".

In 1750 John Kay, a clockmaker of Warrington, invented the " flying shuttle " which, by its automatic return, halved the labour involved. The time thus saved increased the demand for " weft ", and this in its turn led to improved devices for spinning the cotton yarn. In 1770 James Hargreaves of Blackburn patented the " spinning jenny ", a frame with eight spindles side by side, enabling that number of threads to be spun at once instead of the single thread of the old distaff or spinning-wheel.

Following on this, in 1771 Arkwright operated a machine actuated by water power, and known as the " water frame ". It included suitably rough pairs of rollers rotating at appropriate speeds, in order to strengthen the yarn before it was spun, and it had been demonstrated secretly in the house of a grammar school master at Preston. Eventually a factory was set up in Nottingham, and the power provided by horses. Later a warm spring (which did not freeze in winter) near the river Derwent provided the necessary water power, which gave its name to the invention. In 1779 Crompton combined the two principles of Hargreaves and Arkwright into one hybrid machine, the " spinning mule " ; and in 1785 a clergyman named Cartwright introduced the " power loom " to include weaving as well as spinning. In the same

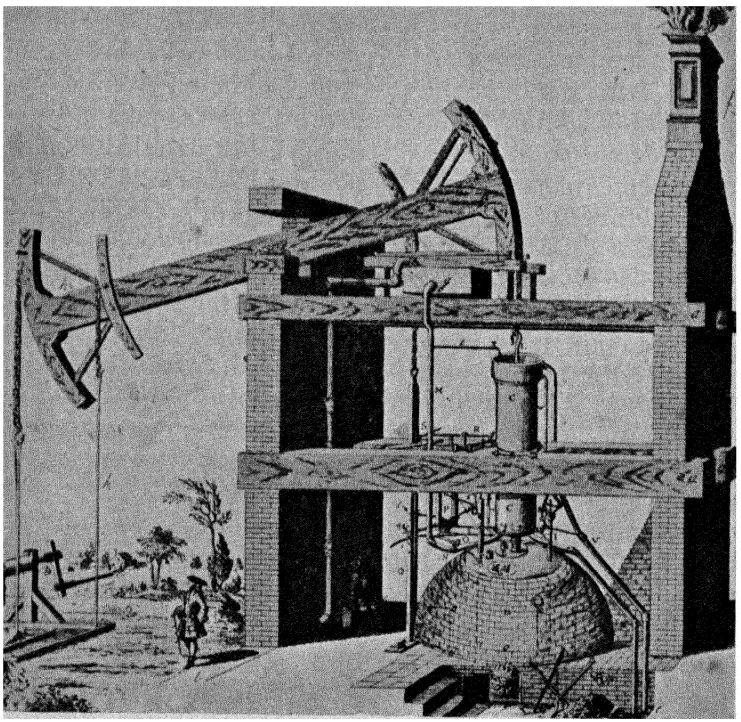
year the steam engine was first used in the manufacture of cotton.

The significance of Arkwright's work lies in his use of *power*. True, many of the inventors of the eighteenth century were of limited education, and did not compare, from the academic point of view, with such distinguished Continental contemporaries as Lavoisier and Linnaeus. Yet their practical insight played an important part in preparing English industry for the advent of steam power. This in its turn had a far-reaching effect on the industrial revolution, which began when the workshop moved from cottage to mill, and culminated in the complex network of factory and machinery of the nineteenth century.

James Watt and the Steam Engine

The inventions just described should be regarded as typical rather than limited to the cotton industry. In fact, the development of the steam engine itself is a series of ingenious improvements, the greatest of which was due to *James Watt* (1736–1819).

As far back as the time of Hero of Alexandria, a mathematician with a very practical turn of mind (date uncertain, about first century A.D.), a model was made, which to some extent foreshadows the reaction steam turbine of modern times, or even the internal combustion jet engine of some modern aeroplanes. Hero used the recoil of steam from a jet to make an arm, carrying the jet, rotate about an axis. But no practical use came of this, and it was not until about the beginning of the eighteenth century that steam engines became commercially useful in industry. This was largely due to the work of *Thomas Newcomen* (1663–1729), a native of Dartmouth, and an ironmonger by trade. It may have been through correspondence with Robert Hooke of the Royal Society that Newcomen was stimulated to combine the three simple notions of the balance, the tendency of condensing steam to produce a vacuum and the piston working



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Beighten's drawing of Newcomen's Engine, 1717

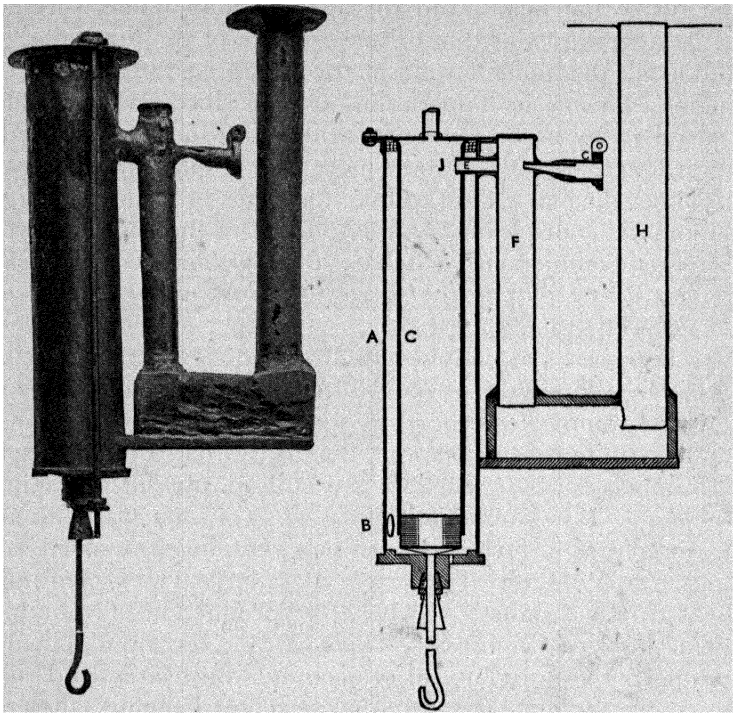
in a cylinder. In any event, Newcomen deserves considerable credit for the skill and ingenuity with which he used these ideas.

The principle is illustrated in the accompanying drawing. Steam was admitted to the cylinder at a pressure only a little above atmospheric, thereby causing the beam (suitably weighted) to overbalance and draw up the piston. Steam was then cut off and sprays of cold water introduced into the cylinder in order to condense the steam in it. The partial vacuum thus produced allowed the pressure of the atmosphere to force the piston down, and so to reverse

the tilt of the beam, and to raise the load. The working stroke therefore was due to the pressure of the atmosphere, and hence the name " atmospheric " is applied to this type of engine. The cycle of operations just described was originally controlled by boy attendants turning taps on and off, and, according to legend, one boy, more bent on play than engine-minding, devised a cord to take the place of his own hands. Automatic control, however, is evident in the engravings of the first commercial models, and Newcomen's valve-gear played a vital part in the successful application of steam to power production.

There were probably several hundred Newcomen engines in use by the middle of the eighteenth century, not only in the coal mines of the north of England and the Midlands, and the tin mines of Cornwall, but also abroad ; and indeed, a number of these engines are still in use for pumping purposes. It is significant that, in view of their wastefulness in the matter of fuel, these engines were only employed, on any large scale, either where low-grade coal was plentiful, as at the coal mines, or where the production of valuable metal justified almost any expense. An essential part of mining is the pumping up of accumulating water, and this was successfully achieved by the Newcomen engines, though the cost of running was excessive. If efficiency could be improved a vast field lay open for the extended use of this new form of power. Such a development was made possible by the inventive genius of James Watt.

Born at Greenock in 1736, Watt grew up in the practical atmosphere of nautical instruments, his father being a good mechanic of scientific taste and unusual skill. James Watt was allowed to amuse himself in his father's workshop, and while he was still young, to have a forge of his own ; when only fourteen years old he made an electrical machine. His subsequent interests seem to have been wide, and included botany, mineralogy, geology, chemistry and natural philosophy in general. In 1754 he lived at Glasgow, but as opportunities were few, he migrated the next year to London, a journey on horseback which, in those times, took nearly



Watt's Steam Engine

fourteen days. He was apprenticed to an instrument-maker near Cornhill. Eventually he returned to Scotland ; and in 1757 he was allowed a room within the precincts of Glasgow College. Here a workshop developed which was visited by various men of science, including Joseph Black (1728–99), a Fellow of the Royal Society of Edinburgh. Black is well known for his discovery in 1755 of " fixed air ", now known as carbon dioxide, and especially for his work on latent heat.

In 1763 Watt was called upon to repair a model of a Newcomen engine, in use at Glasgow College, and so his attention was specially turned to the problem of steam power. He was astonished at the quantity of steam required in com-

parison with the small size of the working cylinder, and soon realized that the large quantity of water injected to condense the steam also chilled the cylinder to such an extent that the next admission of steam had first to re-heat the cylinder, thereby losing considerably in volume and pressure by condensation. Black's work on latent heat proved that a large quantity of heat was required to change water into steam at the same temperature, so that while so much of the steam was being unnecessarily condensed there was naturally a very great loss in efficiency.

It took Watt two years to find the solution, namely, condensing the steam in a separate vessel which was always kept cold, and maintained vacuous by means of an air-pump ; the cylinder itself being surrounded by a steam-jacket to maintain its temperature.

The experimental model which Watt made convinced him of the efficiency of his plan, but the capital involved in making a large engine was beyond his means. Moreover, in 1765 he married, and faced with the necessity of earning a living, he became a surveyor in the construction of canals, a position offering considerable prospect at that time. The first serious attempt to construct a canal through hilly country in England was made about the middle of the eighteenth century and is associated with the name of the Duke of Bridgewater. It was now that Watt's friendship with Black proved a turning point in his career, for in the same year he was introduced by his friend to John Roebuck of the Carron Ironworks, Stirlingshire, who required a powerful and economical pumping plant in connection with proposed coal mines.

By 1767 Roebuck was so satisfied with Watt's proposed " condensing " engine that a partnership was formed with a view to a patent, and Roebuck took over Watt's liabilities of about £1000 (chiefly owed to Black).

Unfortunately, workmanship still defeated the attainment of the desired efficiency, and Roebuck's pits suffered in consequence. Later, his share in the patent was bought out by Matthew Boulton (1728–1809) of Birmingham. The

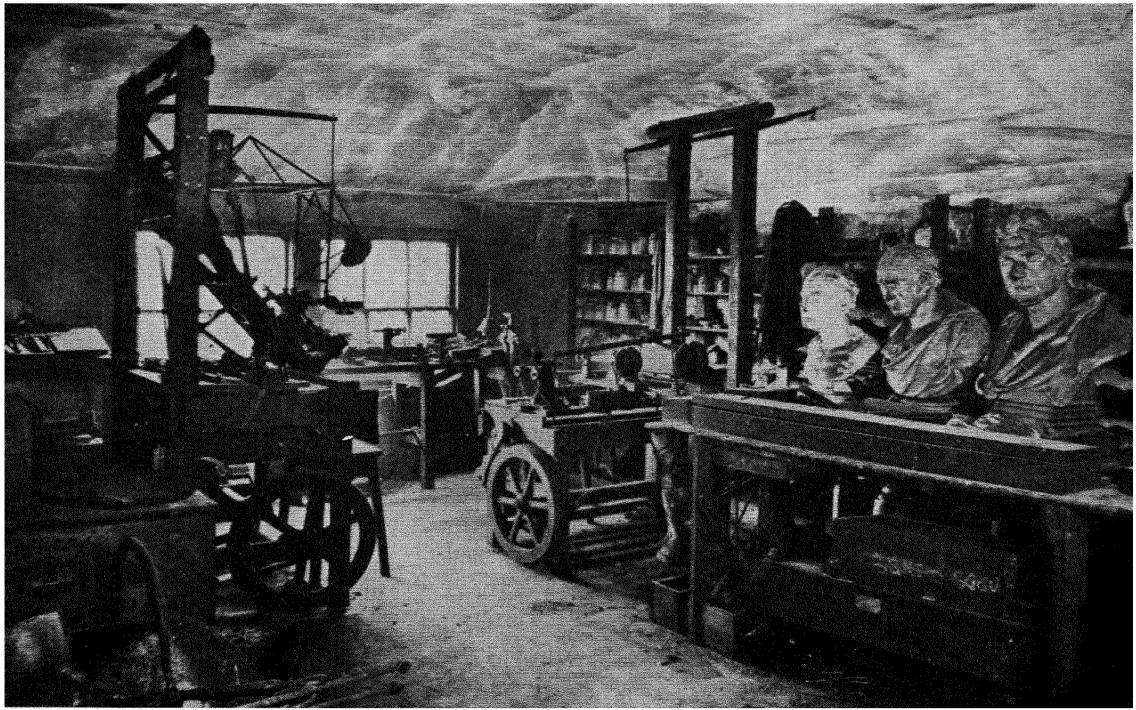
engine was moved to Boulton's Soho Works at Birmingham, and Watt joined the concern in 1775. An improved boring machine enabled a more accurate cylinder to be made, and the condensing engine became established. In 1780 the first Watt engine made for use on the Continent was completed and shipped.

Watt's numerous improvements included the conversion of rectilinear movement of the piston and beam into a rotative movement of a shaft, suitable for driving the numerous mills which were springing up. Another development was the " double-acting " engine, in which live steam was admitted to each side of the piston in turn.

Even after his retirement in 1800, Watt was busy in his workshop at the top of his house at Heathfield Hall, devoting his attention especially to mechanisms for the copying of sculpture. After his death in 1819 this garret was left untouched until 1853.

In 1857 " Heathfield " was let to Mr. Thomas Pemberton, an art critic, whose son describes the formal opening of the garret on the occasion of a visit of Mr. Gibson Watt, a great-nephew of James Watt : " Of course we were all assembled when the key turned in the rusty lock and the two passed through the door. Full two inches deep the dust was on the floor, and their footprints made marks in it as if they were walking in soft snow. In response to earnest entreaties I was allowed to join them, and there I saw everything just as the great inventor had left it."

Dr. Samuel Smiles, who was writing his *Lives of the Engineers*, visited the garret in 1864 or '65. In the accompanying picture may be discerned the two sculpturing machines, one for making a copy of sculpture of equal size, and the other for a copy of reduced size. These are improvements, as Watt wrote, on " a machine of the nature of a turning lathe which copies medals and other things in bas-relief ; it is called in France ' tour à médailles ', in England ' the likeness lathe '." The following is an interesting record of the time taken, and is extracted from one of Watt's journals :



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The Garret Workshop of James Watt

BUST OF SAPPHO, January 1811

		Hour
Jan. 28	Making pedestal, 1 hour . . .	1
„ 29	Soaking in a strong coat of oil-varnish and cementing the bust on pedestal . .	1
„ 30	Cutting out the stone, cementing it and the bust to the moveable plates, and fixing the centres	3
„ 31	Roughing the stone with the tearing-drills to within the thickness of a halfpenny of the truth	9
Feb. 1	Going over it with the quarter-inch drill to within the thickness of a thin sixpence .	5
Saturday 2	Doing the face with the 1-8th drill to the truth, from the outer corner of one eye to do. of the other (went too slow) . . .	5
3	Doing her breast with do. . . .	1
Monday 4	Do. one side of the head . . .	4
Tuesday 5	Do. round to within 1-4th of the whole .	4
6	Quite round, finished the shoulders, removed some of the steps or plaits . . .	3
7	Cut the crown of the head, undercut the neck, and cut it off from the centre-piece, repaired the most of it . . .	3
		39

This work was done on the equal machine

In 1924 the contents of the garret were presented to the nation by Major J. M. Gibson Watt, and now occupy their original position in a replica of the room at the Science Museum, South Kensington — a fitting memorial to a great inventor. The inscription on the statue of James Watt in Westminster Abbey begins :

> Not to perpetuate a name
> Which must endure while the peaceful
> arts flourish,
> But to show
> That mankind have learned to honour those
> Who best deserve their gratitude.

These words were written by Lord Brougham, who with George Birkbeck of Glasgow founded the London Mechanics' Institute in 1824, from which the present Birkbeck College,

University of London, has evolved. This epitaph in Westminster Abbey thus indirectly links the pioneer mechanics and inventors of the eighteenth century with their numerous successors in the nineteenth.

One other inventor should be mentioned. In 1777 a young engineer, *William Murdoch* (1754–1839), had entered the service of Boulton and Watt, and was employed for many years in supervising the numerous engines made for the Cornish mines. Murdoch invented *gas-lighting* and used it in his house at Redruth in 1792. Despite the opposition to the use of such a product from coal — Sir Walter Scott ridiculed the idea of "lighting London with smoke" — Murdoch persisted in his project and was permitted to illuminate the Soho Works with his "smoke" on the occasion of the Treaty of Amiens (1802) between Britain and France. The glowing account in the *Birmingham Gazette* of that time concludes with the following somewhat human note: "Every house in the neighbourhood was also splendidly illuminated, and all the workmen belonging to the manufactory were regaled at public-houses".

Murdoch's numerous inventions included the hydraulic lift and the first model locomotive steam carriage. The latter arose from a necessity which proved to be the mother of invention. Murdoch had great difficulty in obtaining transport to take him the round of the Cornish mines, so he investigated the possibility of road steam locomotion. After five years' experimenting, the model was successfully working and Boulton and Watt's agent reported to the firm in August 1786: "William Murdoch desires me to inform you that he has made a small engine of ¾ inch diameter and 1½ inch stroke, that he has apply'd to a small carriage which answers amazingly". A copy of the model may be seen in the Science Museum at South Kensington.

The original machine struck terror into at least one soul, as the following incident testifies. Desiring to test the machine secretly out of doors, Murdoch took it in the dark to a quiet road on the outskirts of Redruth. A biographer vividly describes what happened in the following

words: "Responding to his call, the offspring of his invention quickly got up steam and, with puny puffs and snorts, went fizzing along the highway. Meeting it in the grim darkness a belated clergyman returning to Redruth yelled with terror, for he believed he was at last face to face with that Evil One of whom he was accustomed to make such uncomplimentary remarks in the pulpit. The meeting might not be a pleasant one! Luckily Murdoch was quickly at hand to relieve the good man's fears."

It is strange that Watt himself displayed no enthusiasm for the future of steam locomotion, and dissuaded Murdoch from perfecting his invention. It was due to a later engineer that the commercial use of this form of traction was developed with such far-reaching results.

George Stephenson: Development of the Railway

When once the invention of an efficient steam engine was established, it could only be a matter of time and ingenuity before its application to transport was realized. It is therefore because of its importance in the background of science that prominence should be given to the work of *George Stephenson* (1781–1848). His is another example of the man who, with only slight educational opportunities, but with almost limitless enthusiasm and capacity for hard work, took a leading part in the development of fast-moving transport which has now spread throughout the world. George Stephenson was born in 1781 at Wylam amid the poor surroundings of a mining district a few miles to the west of Newcastle. He came, however, of a family of Tyneside mechanics, a typical product of the latter end of the eighteenth century in their zeal for self-improvement.

Stephenson had no school advantages, and while quite young he started work as a cowherd, then in charge of a colliery horse, and at the age of fourteen as assistant to his father, whose work consisted of shovelling coals into the furnace of a Watt pumping engine. Stephenson taught himself

to read at the age of seventeen, and his scant leisure was devoted to night school and experiments on steam traction. By 1813 Hedley had built the "Puffing Billy" used at Wylam Colliery. Stephenson's employers authorized him to supervise the construction of a steam locomotive on similar lines, and in this he took an active part as a mechanic. The result was a heavy, slow-moving engine, the maximum speed of which was four miles an hour; its coal consumption was so excessive that it was cheaper to continue with the old system of hauling trucks of coal by means of horses.

Turnpike roads were much older than the coal mines and had not been constructed with the object of serving the latter. Also the increasing network of canals could not link up with individual pit-heads, so that the need for another form of transport was greatest in the mining areas. Railroads, along which wagons were hauled by horses, were already in use. Stephenson finally persuaded the directors of the proposed Stockton and Darlington railroad to adopt steam instead of animal traction for their coaches. Thus the *first railway* was opened in 1825. Despite initial high costs, unreliability and prejudice, time proved that the railway had come to stay, and with its use in other coal-fields, the need for joining up and general expansion became pressing and popular. Considerable capital was subscribed without difficulty, and the railways contributed in no small measure to the industrial revolution that was taking place, and to those changes in social life which altered the face of Britain in the nineteenth century. It is only just over one hundred years since Queen Victoria made her first journey in a railway train, and during the following ten years, by 1852, the principal towns of England were connected by rail.

Large orders for locomotives and iron came from the Continent, and with them the need of increased production. In America the effect of steam locomotion could be seen on an unprecedented scale. The slow-moving caravans which had hitherto been associated with migrations throughout the world were replaced by the fast transport of the railroads as they pushed westwards across North America, opened up

settlements, grazing grounds and hitherto untapped natural resources and brought them into the service of man. Invention had produced undreamt-of possibilities in industry.

Astronomy and Newton's Laws

In this chapter on invention and industry, interest has naturally centred round the more ordinary concerns of daily life, such as the production of cloth, means of transport, or amenities of lighting. Before passing to the source of power dealt with in Chapter XVI, it may not be inappropriate to direct attention to yet another discovery. It was made about the middle of the nineteenth century, when railway transport was being rapidly expanded, and electric generators were making their appearance in industry. The discovery was not concerned directly with man or his immediate environment, nor did it have any obvious effect on his standard of living. It was an unobtrusive piece of research, not without its human interest, but it provided a striking tribute to the accuracy of Newton's conception of the universe.

In 1781 the planet Uranus had been discovered by *Sir William Herschel* (1738–1822), a poor German musician born at Hanover who had migrated to England and become an organist at Bath. With his sister he contributed much to modern physical astronomy, and became the first president of the Royal Astronomical Society (founded as the Astronomical Society of London in 1820). Irregularities, which never exceeded the tiny angle of two minutes of arc, were observed in the motion of Uranus, and basing his work on accepted Newtonian mechanics, a young Cambridge graduate, *J. C. Adams* (1819–92), came to the conclusion that these perturbations were due to the presence of a hitherto unobserved planet, the position of which he determined. Adams communicated his convictions to the Astronomer Royal, who arranged for a search for the unknown planet to be made at the Cambridge Observatory, which possessed at that time the most powerful telescope in England.

The French astronomer *Le Verrier* (1811–77) was also working independently on the same problem, and at a somewhat later date sent his prediction of the new planet to the Berlin Observatory. Within half an hour after the astronomers had begun their search, a new planet (Neptune) was discovered in exact accordance with the prediction, and less than one degree of arc from the point that Le Verrier had indicated. Shortly afterwards it was found that observations made at Cambridge, as a result of Adams' predictions, had also recorded the new planet. In this unexpected way additional evidence was forthcoming in 1846 in support of Newton's ideas of force and motion.

The discovery of Neptune seems far removed from either invention or industry, yet the Newtonian theory on which that discovery was based is also the foundation of modern navigation and hence of modern trade. The predictions contained in the *Nautical Almanac*, prepared years in advance, assume the validity of Newton's mechanics. It is on such tables that the sailor relies as he voyages to the distant places of the earth, and takes with him the products of the inventive mind and tireless energy of an Arkwright, Watt or Stephenson.

CHAPTER XVI: PROGRESS IN ELECTRICAL SCIENCE

The Nineteenth Century

By the end of the eighteenth century, England was fast becoming the workshop of the world. A keen observer of those days might easily have thought that it only remained for the engineer to perfect the steam engine, the business man to increase export trade, and the politician to solve the problem of the conditions and standard of living. But the nineteenth century was to show that although coal and steam had played such an important part in the industrial revolution, another source of power was to emerge, and point the way to cleaner and healthier factories, improved conditions of everyday life, and the rapid and extensive communications which mark the twentieth century as the beginning of a " world period " of civilization. That new source of power was *electricity*. In his preface to *A History of Europe*, H. A. L. Fisher, referring to steam and electricity, writes : " It is possible that two thousand years hence these two scientific inventions may be regarded as constituting the ' Great Divide ' in human history ".

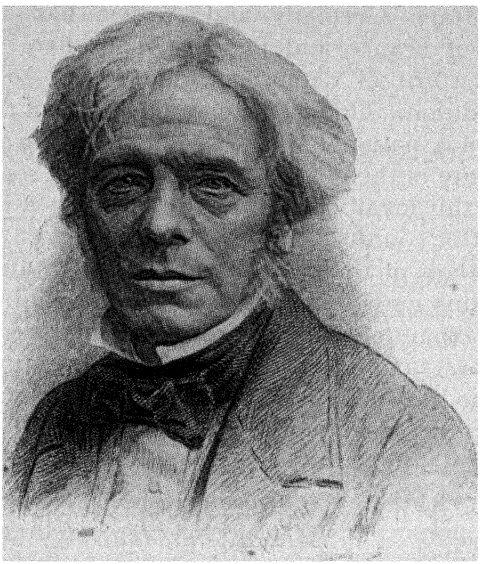
However, before discussing the work of the pioneers who made this *electrical revolution* possible, there is another story of a very different nature, to which reference must be made if we are to understand why progress in electrical science in the nineteenth century culminated in a period of world conflict in the twentieth. About the time when important discoveries in electricity were being made, Europe was recovering from the effects of the *French Revolution*. The spirit of liberty which had shown itself in the War of American Independence, and later in the democratic aspirations of France, encouraged men everywhere to unite against oppression in any form. By the middle of the nineteenth

century, Italy, Germany and Austria had followed the examples of France and Belgium, and there was born in Europe a spirit of democracy determined to break with feudal tradition. One of the characteristics of the latter was the lack of a national spirit, loyalty to his over-lord being the first duty of the peasant ; but those who sought freedom disowned this loyalty, and substituted for it a loyalty based on district or country. So was born *nationalism* ; and during the latter half of the century the various States of Europe became conscious of the implications of nationality. The desire for expansion and possessions led to power and rivalry, to selfishness and to armaments, and eventually to wars beyond the boundaries of any one continent, and ultimately embracing the whole world.

Michael Faraday

During these periods of revolution, of war and preparing for war, men of science were quietly making discoveries which, had they been used constructively, could have altered the story of the first part of the twentieth century. One of the foremost of these, and promising far-reaching benefits for mankind, was the discovery of electrical power. The pioneer work was done by a man who lacked educational and social advantages, but whose enthusiasm and ability enabled him to lay the foundations of modern electrical practice.

While *Michael Faraday* (1791–1867) was still young, his parents moved from the village of Clapham in Yorkshire, to that of Newington in Surrey, which, as Newington Butts, is now well within the London area. His father was a blacksmith, whose shop was situated not far from the present position of the Elephant and Castle tube station. Eventually the family moved north of the Thames, and at thirteen years of age Faraday worked for a bookseller, Ribeau, in Blandford Street, not far from Oxford Circus. After a year, Faraday was apprenticed in bookbinding. In this atmosphere of books his natural bent for science found expression,



MICHAEL FARADAY

and leisure from work was used to increase his knowledge of chemistry, his elder brother financing his attendance at lectures. At this time *Sir Humphry Davy* (1778–1829), the inventor of the miner's safety lamp, was professor of chemistry at the Royal Institution of Great Britain, in Albemarle Street, which had been founded in 1799 for the popularization of scientific research. One of the customers at Ribeau's bookshop had noticed Faraday's interest in science and gave him tickets to four of Davy's lectures. With characteristic care Faraday made notes on these lectures; he bound the notes and sent the volume to Sir Humphry with a request for employment. This resulted in his appointment as a laboratory assistant at the Royal Institution, and in 1813 he went to live there. Here he carried out routine duties such as washing bottles and keeping the laboratory clean, but he quickly showed himself capable of greater responsibility and research; ultimately, in 1825, he was appointed Director of the Laboratory of the Institution, and

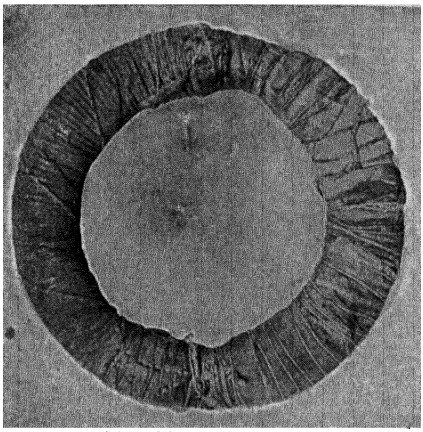
the remainder of his active life was spent at the Royal Institution.

Soon after going to the Royal Institution, Faraday travelled as assistant and companion to Davy during a tour of the Continent. The journey began in 1813, when Britain was at war with France ; it seems strange that the party should be allowed to travel in enemy country, but Napoleon had sanctioned the tour in the interests of science. At Paris they met *Ampère* (1775–1836), the physicist from whose name we get the international unit of electrical current ; at Florence they saw one of Galileo's telescopes, and at Rome they met *Volta* (1745–1827), whose discoveries with regard to the electric battery became so important that his name is perpetuated in the unit of electromotive force, the volt. The tour was concluded in 1815, and we know from his notes that it broadened Faraday's ideas. In the following year he began to lecture on chemistry (see p. 223). In 1824 he was elected a Fellow of the Royal Society.

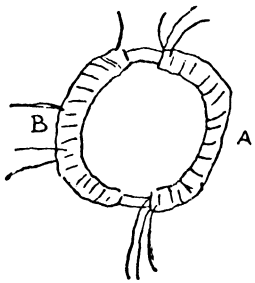
The famous Juvenile Lectures which are still given annually at the Royal Institution were started by him in 1843. Faraday had carefully studied the art of public speaking, and his renown as a lecturer was such that in 1857 the Prince Consort and the Prince of Wales (afterwards King Edward VII) went to hear him at the Royal Institution.

Faraday had been sure in his own mind that there was an intimate connection between electricity and magnetism ; but experimental proof was lacking. His work culminated in 1831 with the discovery that when an electric current is being started or stopped in a closed circuit, a current is caused to flow in a neighbouring but separate closed circuit. This effect is known as *electromagnetic induction.* The centenary was marked by a Faraday Exhibition at the Royal Albert Hall, London, in 1931. It is not too much to say that this discovery is the basis of all the vast developments of modern electrical engineering.

An immediate result of the principle of electromagnetic induction is its application, in the *dynamo*, for generating



Science Museum photograph from the original in the Royal Institution



From "Faraday's Diary", by courtesy of the Royal Institution

A photograph of Faraday's "Ring", the forerunner of the modern transformer and the basis of electric generators and motors; and (right) a copy of the drawing of the "Ring" accompanying Faraday's notes on his experiments

electricity (the word "dynamo" is derived from the Greek word *dynamis*, power). By causing a coil to rotate in a magnetic field, so as to cut the lines of magnetic force, an "induced" current is produced in the coil. The current changes its direction as the coil turns through two right angles, and so an "alternating" current is produced. A "direct" current can be obtained by using a suitable device known as a "commutator". The rotating coil is called the armature, and more powerful results can be obtained by making the armature of several coils of insulated wire.

The *electric motor* is similar to the dynamo in construction, but differs in that an electric current is passed through the armature. In this case, when the plane of the coil carrying the current lies obliquely to the direction of the magnetic field, the coil is acted on by forces which cause it to rotate. By suitable arrangement the rotation of the armature may be maintained, and used for driving machinery.

The *transformer* is another important device in electrical engineering, and is a familiar feature in the distribution

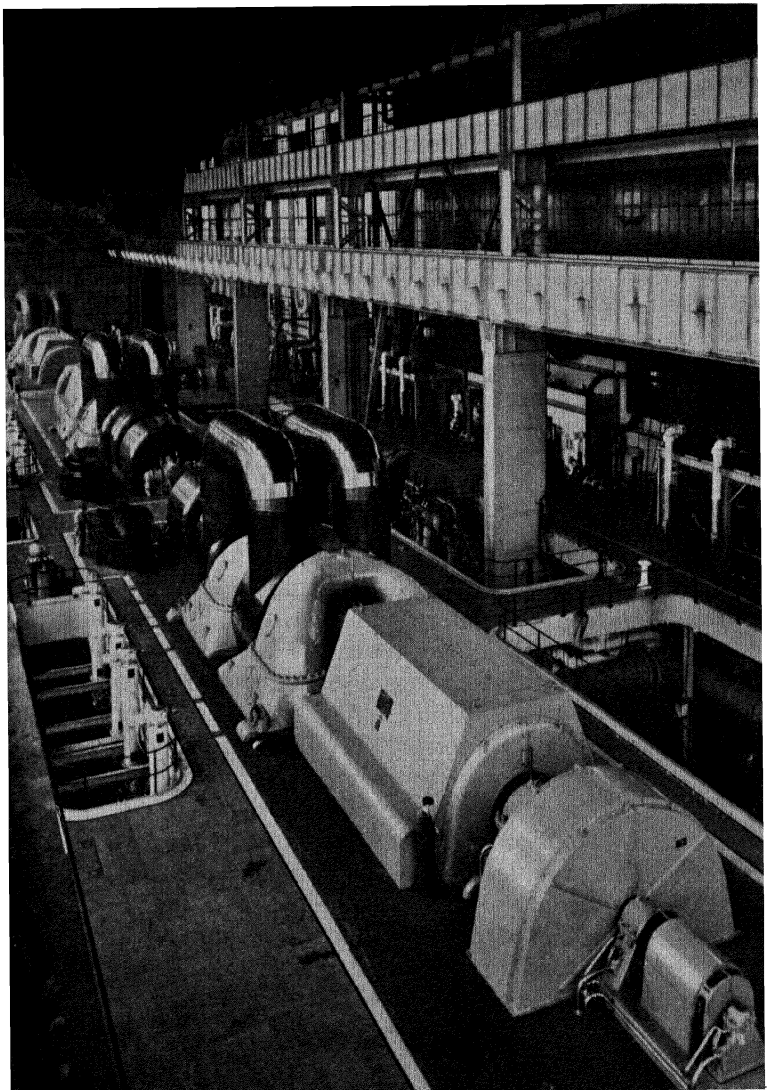
of electrical power throughout the country. By its use high-voltage currents can be economically conveyed from the generating station, and " transformed ", as required, to low-voltage ones suitable for industrial and household purposes. In this connection special interest attaches to the page of Faraday's note-book for August 1831. As may be seen from the accompanying facsimile, two coils of insulated wire are wound round the opposite parts of an iron ring. As a current is started in one coil called the " primary ", the other coil, the " secondary ", is cut by lines of magnetic force, and a momentary current induced in it. By employing an alternating current in the primary, an alternating current is induced in the secondary, and by suitable arrangement of the number of turns of wire in the two coils, the voltage in the primary can be " stepped up " or " stepped down ".

Another important discovery of this period is that of *electrolysis* (Greek *ēlektron*, amber, from which the first effects of electricity were observed; *lusis*, a loosing or setting free), by which is meant the breaking down of a substance by the passage of an electric current through either a solution of it, or the liquid produced when the substance is heated until it melts. The process is much used in modern industry. For example, in electro-plating the current enters the solution or " electrolyte " at the anode (Greek *ana*, up; *hodos*, way), which may be a sheet of copper, and leaves by the cathode (Greek *kata*, down), which in this case is the article to be electro-plated. Copper is deposited on the cathode, and so the article becomes electro-plated with copper. In silver-plating the anode is made of silver, and the electrolyte is a solution of silver cyanide.

In industry a knowledge of quantities and costs is essential and for this purpose Faraday's laws of electrolysis are fundamental:

(1) The mass of a substance liberated is proportional to the quantity of electricity passed.

(2) When the same quantity of electricity is passed through different electrolytes, the masses of substances liberated are proportional to their chemical equivalents.



By courtesy of The British Thomson-Houston Co., Ltd.

The development of Faraday's discovery of electromagnetic induction: a modern electric power station. Barking Power Station of the London Electric Supply Co. Ltd., showing three 75,000-kilowatt turbo-alternators. Note man standing against casing, centre foreground

(The chemical equivalent of a substance is the number of units of mass of the substance that will combine with or displace eight units of mass of oxygen.)

Towards the end of his life Faraday's work was recognized by the Government and he was granted a pension. Queen Victoria also allowed him to occupy a house at Hampton Court; this is still standing and is next to the one in which Sir Christopher Wren lived. Both houses face the large green opposite the main entrance to the palace. Faraday's life was simple and unaffected by his achievements; he was generous towards the poor, and loyal to a little-known Christian sect — the Sandemanians. They were so strict that no excuses were accepted for non-attendance at the Sunday service. It is recorded that Faraday was excommunicated for a time, because he allowed a visit to Queen Victoria to interfere with his duties to the Sandemanians.

In his later years Faraday spent much time improving the lighting system of lighthouses, and even at seventy years of age made journeys to Dungeness to test the new electric lamps he had planned there. On land and sea, and even in the air, our modern civilization depends on electricity, and is a tribute to the patient pioneer work of Michael Faraday.

Clerk Maxwell and the Cavendish Laboratory, Cambridge

No account of the progress of electrical science in the nineteenth century would be complete without some reference to the work of *Clerk Maxwell* (1831–79). At the age of fourteen he wrote a paper on improved methods of drawing ovals of the type seen in Greek friezes, and this unusual achievement was but a foretaste of the extraordinary mathematical skill and insight which were evident during his comparatively short life. Much of his work was a development of the ideas put forward by Faraday of the relation between electricity and magnetism.

Faraday had realized the importance of the medium

across which electric and magnetic forces act, and in 1845 pointed towards a relation between them and light. Clerk Maxwell succeeded in setting Faraday's theories within the framework of mathematical equations, showing that it should be possible to propagate electric waves with the velocity of light, and that light itself is an electromagnetic phenomenon. Such electromagnetic waves were actually first demonstrated by a German scientist, Hertz, in 1887.

Just as the name of Faraday will always stand out as an experimental physicist with exceptional intuition, so that of Clerk Maxwell will be associated with the theory linking electricity, magnetism and the phenomenon of light. It was significant of the awakening interest in science at Cambridge, that Clerk Maxwell was appointed in 1871 to the newly founded professorship of experimental physics. Under his direction the plans of the Cavendish Laboratory were prepared, and by him were laid the foundations of that world-wide reputation for experiment and theory which the Laboratory possesses, and which has been consistently maintained by his distinguished successors. The Directors of the Cavendish Laboratory, and the years during which they held the post, are: Clerk Maxwell, 1871–79; Lord Rayleigh, 1879–84; Sir J. J. Thomson, 1884–1919; Lord Rutherford, 1919–37; Sir Lawrence Bragg, 1938– .

At first sight the somewhat academic atmosphere of a physics laboratory may seem far removed from the practical activities of daily life, but the physical researches toward the end of the nineteenth century have produced inventions which could scarcely have been anticipated by the most optimistic of discoverers. Attention has already been directed to the important part that electromagnetic induction plays in electrical engineering. This industry has, during the past century, spread to almost every aspect of our daily life. Electric lighting and heating, electric trains, household appliances, etc., account for the use of some 24,000,000 tons of coal annually in Great Britain alone.

Equally outstanding are the results of research on electromagnetic waves: their use in "wireless" is familiar, and

during the Second World War the public became accustomed, through its use in the armed forces, to another development, namely " radar ". Known first as radiolocation, this exceedingly efficient apparatus is capable of detecting objects, such as aircraft, by directing short electromagnetic waves toward them until the reflected rays from their surface are received back at the transmitting station. Among the obvious uses of radar in peace-time is navigation in darkness and fog of both aeroplanes and ships. A further application of electromagnetic waves of short wave-length (or high frequency) is to be seen in television, an invention which will undoubtedly be developed as a result of the experience gained during the Second World War.

CHAPTER XVII: A CENTURY OF CHEMISTRY AND CHEMICAL INDUSTRY

THE practice of working with the materials of Nature dates back to the very early stages of civilization. Whether in the extraction of metals or the preparation of ointments and decorative pigments, or the mixing of medicines, man has been carrying out chemical processes and accumulating a wealth of knowledge and experience concerning the composition of substances, and the interactions or changes that can take place between them. There is more than the obvious verbal connection between modern " chemistry " and medieval " alchemy ". The value of alchemy to chemistry lay in its accumulation of experimental data and processes, the necessary prelude to any chemical theory.

Reference has already been made to the work of the Hon. Robert Boyle, and its importance to chemistry cannot be over-estimated. It was due to him that the Aristotelian conception of four elements only, namely, fire, air, earth and water, was shaken, and *The Sceptical Chymist* published in 1661 is witness to his desire to break with tradition that was not supported by experiment. Robert Boyle, as one of the contemporaries of Newton, contributed in no small degree to the brilliant achievements of scientific philosophy associated with the seventeenth century, and through the foundations which he laid, the chemical researches of Lavoisier in the eighteenth were made possible. But like other branches of science, chemistry made outstanding strides in the nineteenth century, led at the beginning of the century by Humphry Davy, whose interest in the subject was largely aroused through the writings of Lavoisier.

Sir Humphry Davy

The name of *Humphry Davy* (1778–1829) has become a household word in connection with the miner's lamp — the Davy Safety Lamp — which has played such an important part in the welfare of those who work underground. Born near Penzance, Davy was educated at the local grammar school and later at Truro; as a schoolboy he showed but little zeal, except for verse translations from the Classics and story-telling. It has been claimed that the granite rocks of Land's End and the serpentine of the Lizard, within such a short distance of Penzance, and also the near-by copper or tin mines, stimulated Davy's interest in chemistry, and that the sea-weeds of those storm-tossed shores were actually the objects of some of his first original researches.

When Davy was sixteen years old, his father died leaving a widow and five children, and with a sense of responsibility as the eldest child there also came an awakening of interest in more practical affairs. Davy was apprenticed to a surgeon-apothecary at Penzance, and laid down for himself a wide range of studies: metaphysics, ethics, mathematics and, in 1797, chemistry.

In 1798 Davy was appointed superintendent of the Pneumatic Institution at Bristol, founded to investigate the medicinal properties of various gases In the following year he made a careful study of the properties of nitrous oxide. The action of this " laughing gas " is aptly described by Robert Southey, the author, who was one of Davy's friends. " My first definite sensation was a dizziness, a fullness in the head, such as to induce a fear of falling. This was momentary. When I took the bag from my mouth, I immediately laughed. The laugh was involuntary, but highly pleasurable, accompanied by a thrill all through me; and a tingling in my toes and fingers, a sensation perfectly new and delightful." The value of nitrous oxide as an anaesthetic is well known, and it is still widely used in dental surgery.

In 1801 Davy left Bristol to become professor of chemistry

at the Royal Institution in London. His experiments on the chemical effects of electric currents led in 1807 to the decomposition of caustic potash, and to his giving the name of " potassium " to the new metal thus produced. Davy's work on the relation between chemical and electrical phenomena produced, in the hands of his even more distinguished pupil Michael Faraday, the laws of electrolysis stated in the preceding chapter.

Davy's experiments covered a wide field, and to him we owe the names of many elements ; for example, barium, calcium and strontium, chlorine, fluorine and iodine. In 1812 he was knighted, and the invention by which he is best known — the safety lamp — was the result of an investigation in 1815 of the causes of explosions in coal mines. Essentially the device consists of an oil lamp having a closed cylinder of wire gauze as a chimney. The dangerous " fire-damp " penetrates inside the gauze and burns there, but the flame is not communicated to the gas outside the gauze because heat is being conducted away continuously by the metallic gauze. Davy included a suitable screen to prevent draughts from causing an explosion. After three months, the colliers were convinced of its trustworthiness, and in March 1816 a general meeting of coal-owners at Newcastle passed on their tribute of thanks. In the language of the time, Davy refused to put " four horses to his carriage " by patenting his invention, and of this J. C. Gregory writes in a centenary biography, " Davy had intended to protect men from death or mutilation; he was satisfied to have succeeded without also protecting the protection ".

At the age of twenty-five Davy had been elected a Fellow of the Royal Society — a signal recognition of his exceptional powers — and seventeen years later he became its president. The Royal Society honoured him with a Rumford Medal (Benjamin Thompson, Count Rumford, founded a chair of chemistry at Harvard College, U.S.A., and founded the Royal Institution in London in 1799), and he was made a baronet on October 20, 1818.

Davy's Continental tour with Faraday during 1813–15

has already been mentioned in Chapter XVI; during 1818–20 he was abroad again — to explain his safety lamp, and to study the papyri found in the ruins of Herculaneum. In March 1828 he began his last Continental journey, and though his health had begun to fail in 1823, his mental keenness persisted. On May 28, 1829, he reached Geneva accompanied by his wife, but he died on the following day.

John Dalton and the Atomic Theory

The accumulation of observed facts is a necessary prelude to the formulation of scientific theory. By the beginning of the nineteenth century, the nature and quantity of experimental evidence were sufficient for chemical beliefs to be reviewed and modified. Whereas Sir Humphry Davy was more engaged in the breaking of new ground in the realm of discovery, particularly with regard to individual elements, it fell to the lot of *John Dalton* (1766–1844) to formulate a comprehensive theory to include the growing mass of experimental data and observed chemical law.

Dalton was born near Cockermouth, in Cumberland, and his parents though limited in financial resources — his father was a weaver — were able to endow their son with those character-forming virtues of single-mindedness and hard work so characteristic of the Society of Friends. According to Dalton himself, he left the village school at the age of eleven. Mensuration, surveying and navigation were included in his studies — an interesting, practical and nautical bias having some relation presumably to the proximity of the sea. A year later, he returned to take over the duties of instructing. One of his pupils has described the difficulties of maintaining discipline when many of the class were as old as their instructor, and frequently challenged him to fight in the graveyard outside. This teaching lasted for two years; then having been employed on the land at intervals for another year, he became, at the age of fifteen, an assistant in a boarding

school at Kendal, and studying, to quote his own words, "Latin, Greek, French and the Mathematics with Natural Philosophy". Dalton's instinct for teaching remained throughout his life. Many years later, a distinguished admirer from Paris travelled to Manchester and found Dalton, then of European fame as a chemist, supervising the work of a small boy, "cyphering" on a slate. To his inquiry whether he was addressing Mr. Dalton came the simple reply: "Yes; wilt thou sit down whilst I put this lad right about his arithmetic?"

The writer of this was born at the Village of Eaglesfield about 2 miles west of Cockermouth, Cumberland. Attended the village school there & in the neighbourhood till 11 years of age, at which period he had gone through a course of Mensuration, Surveying, Navigation, &c, began about 12 to teach the Village School & continued 2 years afterwards; was occasionally employed in husbandry for a year or more; removed to Kendal at 15 years of age as assistant in a boarding school, remained in that capacity for 3 or 4 years, then undertook the same School as a principal & continued it for 8 years, & whilst at Kendal employed his leisure in studying Latin, Greek, French & the Mathematics with Natural Philosophy. removed thence to Manchester in 1793, as Tutor in Mathematics & Natural Philosophy in the New College, was 6 years in that Engagement, & afterwards was employed as private & sometime public Instructor in various branches of Mathematics, Natural Philosophy & Chemistry; chiefly in Manchester, but occasionally by invitation in other places, namely London, Edinburgh, Glasgow, Birmingham & Leeds. &c.

Feb. 19 1833 John Dalton

Facsimile of a letter by Dalton to Miss Catherine Johns outlining his career

The accompanying letter shows that in 1793 Dalton was appointed tutor in mathematics and natural philosophy in New College, Manchester; afterwards, he was employed "as private and sometimes public Instructor in various branches of Mathematics, Natural Philosophy and Chemistry; chiefly in Manchester, but occasionally by invitation in other places, namely London, Edinburgh, Glasgow, Birmingham and Leeds". Of London he writes, "a surprising place and well worth one's while to see once, but the most disagreeable place on earth for one of a contemplative turn to reside in constantly".

It is not surprising, with such a wide background of knowledge and academic interests, that Dalton's contribution to chemistry should be better remembered by his formulation of theory than by his collection of experimental data. This does not mean that he ignored the latter or was merely a theorist, and in this connection it is characteristic of his attention to detail, that from 1787 until the day before his death he kept a daily record of weather and allied phenomena — including some 200,000 separate observations. In fact, a lecture delivered by Dalton in 1810 makes specific reference to this: "Having been long accustomed to make meteorological observations, and to speculate upon the nature and constitution of the atmosphere, it often struck me with wonder how a *compound* atmosphere, or a mixture of two or more elastic fluids, should constitute apparently a homogeneous mass, or one in all mechanical relations agreeing with a simple atmosphere".

With regard to the *Atomic Theory* which bears his name, it may be stated that Dalton introduced the concept of "atoms" (Greek *a*, not; *temnō*, I cut: that is, something which cannot be cut) to explain chemical combination and gaseous volume. This was very different from the speculations of Greek philosophers, who introduced their atomic theory to make the universe intelligible. Dalton's theory was successful in explaining the observed facts of chemical combination and may be briefly described as follows: (1) Chemical elements are composed of minute particles of

matter called atoms, which remain undivided in all chemical changes. (2) There is a definite weight for every kind of atom. Different elements have atoms differing in weight. (3) Chemical combination takes place by the union of the atoms of the elements in simple numerical ratios.

The atomic theory was not published until 1808, when Dalton's *New System of Chemical Philosophy* appeared. Dalton himself would willingly acknowledge the influence of Newton's *Principia* on his work, and it has been justly claimed that the atomic theory holds the same kind of relation to the science of chemistry which the Newtonian system does to that of mechanics.

In 1822 Dalton was elected a Fellow of the Royal Society; in 1816 the French Academy of Sciences made him a *correspondant* for its Section of Chemistry; and in 1830 he was elected a Foreign Associate of the Academy. At the meeting of the British Association at Oxford in 1832, the University conferred on him the honorary degree of D.C.L., and though he would not be able to appreciate the colour of the doctor's scarlet gown, owing to colour-blindness (a defect sometimes known as "Daltonism"), the honours bestowed were a genuine tribute by his contemporaries to the outstanding significance of the atomic theory for chemistry.

In 1833 Dalton received a Civil List pension, and a year later he was presented to King William IV. A slight attack of paralysis occurred in 1837, the year of Queen Victoria's accession, and a further attack in 1844 led to his death at Manchester, the city where so much of his work had been done. The institution in 1853, by the townspeople of Manchester, of Dalton scholarships for original research in chemistry, and tenable at the then recently established Owens College, formed a fitting tribute to the memory of a great man of science.

No description of the atomic theory would be complete without reference to the "hypothesis" of *Avogadro* (1776–1856), an Italian physicist. To appreciate his work the meaning of the term "molecule" (French *molécule*, diminutive of Latin *moles*, mass) must be understood; it is the smallest

mass of a substance capable of independent existence. Avogadro showed that the molecules of an element may consist of one or more atoms, behaving as though they were single particles.

The hypothesis states that " equal volumes of all gases and vapours under the same conditions of temperature and pressure contain identical numbers of molecules ". This recognition that the smallest particle of a substance that could exist independently, might itself be composed of more than one atom, enabled certain chemical combinations to be explained (such as those involved in the various oxides of nitrogen) which had hitherto baffled chemists.

E. J. Holmyard pays a just tribute to the importance of Dalton and Avogadro: " The world has produced chemists of scintillating genius in the nineteenth and twentieth centuries, but their work, marvellous though it be, is but a working-out of the principles laid down by Lavoisier, Dalton and Avogadro ".

Mendeléeff: Classification of the Elements

The work of classification in which Aristotle played such an important part in the early days, became increasingly necessary as science developed into well-defined branches of knowledge. For example, Linnaeus met the demand in biology by introducing the four groups — class, order, genus and species — together with the accompanying system of binomial nomenclature. As soon as chemistry emerged from alchemy, a similar need arose with regard to the large accumulation of chemical data. Boyle realized the need for regarding chemistry as a part of natural philosophy, and he determined to give effect to this " by handling Chymistry, not as a Physician, or an Alchymist, but as a meer Naturalist, and so by applying Chymical Operations to Philosophical purposes". Lavoisier's introduction of the idea of an element as some kind of matter which cannot by any known means be split up into two or more constituents enabled the latter

to draw up a " Table of Simple Substances ", and attention has already been directed to improvement in nomenclature due to Lavoisier and his disciples (p. 179). By the middle of the nineteenth century considerable progress had been made in the classification of the elements, and in the early 'sixties Newlands observed that if elements are arranged in the order of their atomic weights " the eighth element, starting from a given one, is a kind of repetition of the first, like the eighth note in an octave of music ". *J. A. R. Newlands* (1838–98) was an English chemist of Italian descent on his mother's side; he was involved in the Young Italy Movement, and in 1860 took part in Garibaldi's campaign. Newlands' " Law of Octaves " was not received with enthusiasm, and the story that a member of the Chemical Society asked him whether he had ever examined the elements according to the order of their initial letters, at any rate hints that there was considerable initial prejudice.

Probably the best-known name in connection with the classification of the elements is that of *D. I. Mendeléeff* (1834–1907). Born at Tobolsk in Siberia, he was not, as a boy, very studious. At the age of sixteen his studies were continued at St. Petersburg, through considerable sacrifice on the part of his mother. Despite ill-health he graduated with honours in 1855. Owing to the aid which he had received from a scholarship, he was under an obligation to spend eight years in teaching. Mendeléeff was sent to Odessa, but on account of ill-health was allowed to return to St. Petersburg, and in 1863 became a professor there.

Mendeléeff, working on the idea that there must be a connection between the mass and properties of chemical elements, devised the well-known Periodic Table, in which the elements taken in order of mass can be arranged in columns so that each column includes elements of related character. The Table constructed by Mendeléeff contained several vacant spaces, and he did not hesitate to prophesy that new elements would be discovered to occupy those spaces, and also described the properties that the hitherto undiscovered elements should possess. Elements with pro-

perties predicted by Mendeléeff were discovered by other chemists in 1879, 1875 and 1886 respectively, and called scandium, gallium and germanium, after the nationality of their discoverers. The periodic classification of the elements thus received added support from the accurate predictions that were made from it.

It is frequently the case that independent workers arrive at similar results at the same time. During 1869–70 Mendeléeff came to the conclusion that " the properties of the elements are in periodic dependence on their atomic weights ", and almost simultaneously the same result was reached by *Lothar Meyer* (1830–95) in Germany.

The periodic classification has assumed a new meaning in the light of the atomic theory of the twentieth century.

Chemistry and other Branches of Science

There is probably no element more important for the maintenance of life than carbon, and the number of compounds which contain this element are enormous — at present more than 200,000. It is not a matter of surprise therefore that a special subject, *organic chemistry*, deals with these substances. The name is derived from the organisms, plant and animal, which are so largely composed of carbon compounds, most of which, it was originally believed, could only be produced by the agency of plant and animal life.

The preparation of such organic compounds as glycerine, prussic acid, citric acid and oxalic acid dates back to the second half of the eighteenth century; and the work was done by an exceptionally brilliant Swedish experimenter, *Scheele* (1742–86). Lavoisier was among the founders of organic analysis, but it is to *Justus von Liebig* (1803–73) that the speed of modern methods is due. To him also we owe the name " benzol ", now changed to " benzene ", an important constituent of fuel for automobile engines, introduced on account of its " anti-knock " properties.

In the realm of agriculture, it was von Liebig who first,

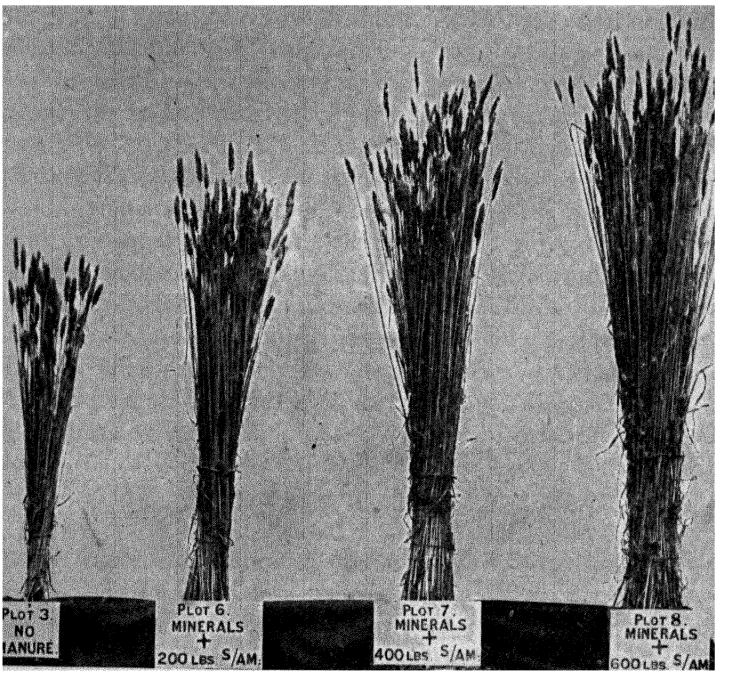


Photo. Rothamsted Experimental Station

Effect of nitrogenous manure on the growth of wheat. " S/AM " indicates sulphate of ammonia, which serves as a source of nitrogen

in 1840, pointed out that plants do not subsist merely on carbon dioxide and the water abstracted from air and soil, but that they have to be fed with elements essential for the building up of their structures — nitrogen, phosphorus and potassium. *Sir William Crookes* (1832–1919), who is well known for his researches on cathode rays, issued a solemn warning in 1898, when he was president of the British Association for the Advancement of Science, by directing attention to a serious threatened world shortage in the supply of wheat, unless some means could be found of providing the soil with the necessary nitrogen. The air, which when freed from moisture and carbon dioxide is roughly a mixture of

4 volumes of nitrogen to 1 volume of oxygen, is the obvious and cheap source of nitrogen, and since 1903 three processes have been used on a large scale for manufacturing nitrogen compounds. The effect on wheat of nitrogenous fertilizer is seen in the accompanying illustration.

From Faraday's work on electrolysis, mentioned in the preceding chapter, it is evident that no division between physics and chemistry can be clearly drawn. It is significant that in 1887 the *Zeitschrift für physikalische Chemie* (*Journal of Physical Chemistry*) was founded by the German chemist, Ostwald, with van 't Hoff, who was regarded by his contemporaries as " the greatest living physical chemist ". Indeed, it is worth noting that Faraday's earliest work was chemical; he discovered benzene and he was the first to liquefy chlorine and several other gases. This association of the two sciences, physics and chemistry, is not incongruous when it is remembered that both deal with the properties of inanimate matter. The nature of solutions comes especially within the purview of physical chemistry, as does also the phenomenon of electrolysis. The experimental 'achievements of the twentieth century have resulted in the greatest of all physico-chemical themes, namely, that of atomic structure with its far-reaching results.

In the last paragraph, physics and chemistry were referred to as sciences which deal with the properties of inanimate matter. But the latter may be so closely associated with living organisms that a special branch of chemistry — *biochemistry* — can conveniently be introduced to deal with this " chemistry of living things " or " physiological chemistry ". As might be expected, organic chemistry plays an important part in the study of biochemistry.

The expenditure of energy in our daily lives raises the question of the sources of bodily energy. The energy which enables a steam engine to haul a train is derived from the combustion of coal, and the energy expended in our daily work comes from the consumption of food, the digestion of which may be looked upon as a " cool form of combustion ", in which the necessary oxygen is obtained from the air which

enters the lungs. There are three classes of food — *proteins*, *carbohydrates* and *fats* — to which must be added certain mineral salts and water. The proteins are composed of carbon, hydrogen, oxygen and nitrogen, generally with some phosphorus and sulphur. The nitrogen is essential in building up flesh and tissues in a growing child and is necessary to replace that excreted by people of all ages. Examples of proteins are lean meat, fish, game, eggs, milk, cheese, peas and beans. Carbohydrates (organic compounds composed of carbon, hydrogen and oxygen, in which the latter two are in the same proportions as in water) and fats are necessary to replace the carbon which is oxidized and breathed out of the body in the form of carbon dioxide. Examples of these foods are potatoes, bread, butter, dripping and salad oil, and they may be described as chiefly energy-producing. Milk contains all the substances required in a food, including vitamins (from the grass eaten by the cow), to which reference will now be made.

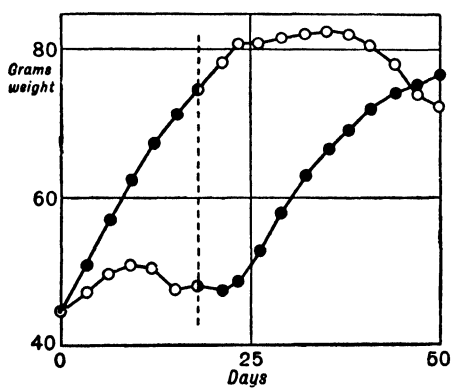
A valuable contribution of biochemistry to the study of health is the knowledge that has accrued concerning *vitamins* (Latin *vita*, life). The chief work was done in the early years of the twentieth century, but the necessity of including certain substances in a diet other than those just mentioned, was recognized by the end of the sixteenth century. In those days, the prevalence of scurvy often meant that a ship's crew were unable to carry out the ordinary routine of seamanship. Herbert Spencer in *The Study of Sociology* (1880) quotes the case of a certain commodore who in 1600 took out the first squadron of the East India Company's ships, and kept the crew of his own ship in perfect health by lemon juice, while the crews of the three accompanying ships were so disabled that he had to send his men on board to set their sails. Pryde, in *Recent Advances in Biochemistry*, mentions an even earlier instance, namely the winter of 1535–36, when a French pioneer in the New World was at Quebec with his men suffering severely from scurvy, and was made acquainted by the Indians with a cure for the disease. This consisted of a decoction of the leaves of an evergreen — probably a

spruce or a cedar found growing in eastern Canada.

Towards the end of the nineteenth century, a similar problem, that of the disease beriberi (or sleeping sickness), arose in the Japanese Navy; and this was solved when a ration of barley was substituted for a portion of the polished rice which constituted the greater part of the existing diet. Subsequent investigation by a medical officer of a prison in Java, Dr. C. Eijkman, pointed to the fact that the beriberi was associated with the absence, in the polished variety, of the outer husk of the rice.

So far back as 1881 it was recognized that artificial mixtures of proteins, fats and carbohydrates, together with salts and water, cannot be used for rearing experimental animals, whereas milk is adequate for this purpose. It was not, however, until *Professor Sir Frederick Gowland Hopkins* (1861–1947) established the fact that milk must contain certain substances, other than the five well-recognized ingredients already mentioned, which are indispensable for growing organisms.

Hopkins' results may be conveniently studied in reference to the following chart, taken from his original paper:



Hopkins' chart showing the effect of adding milk to an artificial diet

The lower curve (up to the eighteenth day) shows the average weight in grams from day to day of eight male rats upon a basal diet excluding milk, whereas the upper curve

THE FOUR BEST-KNOWN VITAMINS

Vitamin	Essential for	Deficiency causes	Occurs in	Remarks
A	Growth	General debility	Milk, butter, suet, yolk of eggs, liver, fish roe, fresh green vegetables	Cod-liver oil contains about 250 times as much vitamin A as butter does. Liver and eggs contain all classes of vitamins
B (there are several vitamins in this group)	Good blood	Anaemia, nervous debility, intestinal troubles	Eggs, liver, kidneys, heart, whole wheat and rice, peas and beans, yeast	
C	General health	Scurvy	Fresh vegetables and raw fruits, oranges, tomatoes, lemons, etc.	Vitamin C is only present in living tissues — not in tinned and bottled fruits
D	General health and growth of bones	Rickets	Milk and butter, cod-liver oil	Vitamin D is similar in its effects to vitamin A, and both are now available in extracts, pellets, etc.

shows the weight of eight similar rats taking 3 c.c. of milk per diem in addition to the same basal diet. On the eighteenth day, marked by a vertical dotted line, extra diet of milk was transferred from one set of rats to the other. The former soon ceased to grow and actually lost weight, while the under-developed rats began to grow rapidly when the milk was added to their dietary.

Gowland Hopkins was professor of biochemistry at the University of Cambridge from 1914 until 1943; he was elected a Fellow of the Royal Society in 1905 and was its president during 1930–35. In 1935 he was appointed to the Order of Merit (O.M.) in recognition of his outstanding achievements in the scientific study of nutrition.

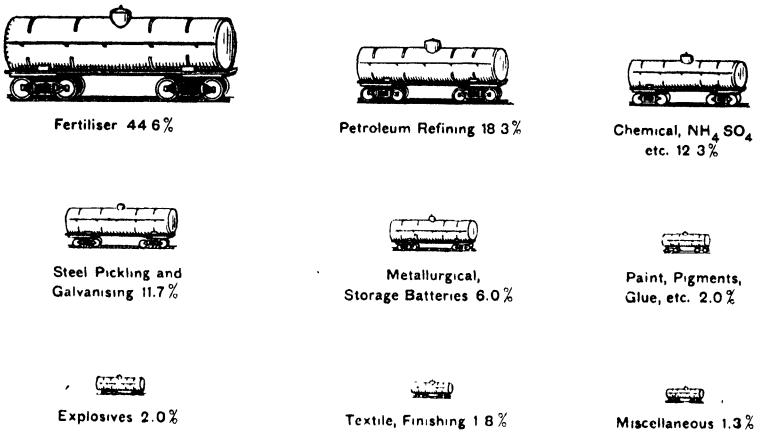
The development of our knowledge of vitamins cannot be pursued further, but attention may be directed to the more important and better known ones, and this can conveniently be done by means of the table on page 226.

This increased knowledge of what is essential for bodily health clearly has an important bearing on the choice of foods, and also on the methods of cooking and preparing food, so that the vitamin content may not be destroyed. Indeed it is claimed that the deliberate selection of foods for import into Great Britain, with the general scheme of food rationing adopted during the Second World War, was largely responsible for the sustained vigour and good health of the population.

Industrial Processes

No survey of science and its background would be complete without some reference to the industrial processes that have been evolved. The story of man reveals various stages in the growth of craftsmanship and in the production of implements designed for his own well-being and control of Nature. The very terms used to denote the early ages — stone, bronze, iron — indicate the practical bent which has characterized his development. The industrial revolution, with the introduction of steam and electrical power, enabled greater use to be made of the increasing knowledge of materials and natural laws provided by physics and chemistry.

The complex needs of present-day life demand that large quantities of certain chemicals should be readily available at a reasonable cost. The claim that sulphuric acid is the most important substance produced by the chemical industry is not an exaggeration, and owing to its widespread use it has been maintained that the amount manufactured is a useful index of chemical industry generally. The demand for sodium carbonate (ordinary *soda*) in the manufacture of glass and soap — two important commodities in modern civilization — may be said to have laid the foundations of



Uses of Sulphuric Acid

the heavy chemical industry throughout the world. The limited amount of soda available in Nature was supplemented by burning plants which had grown in salty soil; towards the end of the eighteenth century, however, the industrial "Leblanc process" was evolved. Leblanc, who was physician to the Duke of Orleans, erected a factory at St. Denis about 1787 which produced 5–6 cwt. of soda per day.

The outbreak of the French Revolution in 1789 checked the industry, and Leblanc was forced to make known the process, which is in two parts; in the first, common salt is treated with sulphuric acid, yielding "salt cake" and hydrochloric acid; and in the second, the salt cake is roasted with coke and limestone, thereby producing the sodium carbonate. In England, the occurrence of rock salt in Lancashire, Cheshire and near Newcastle, with easy access to coal and limestone, determined the locations of the new industry. In the first part of the nineteenth century, important factories were set up at Widnes, St. Helens, Runcorn and Newcastle.

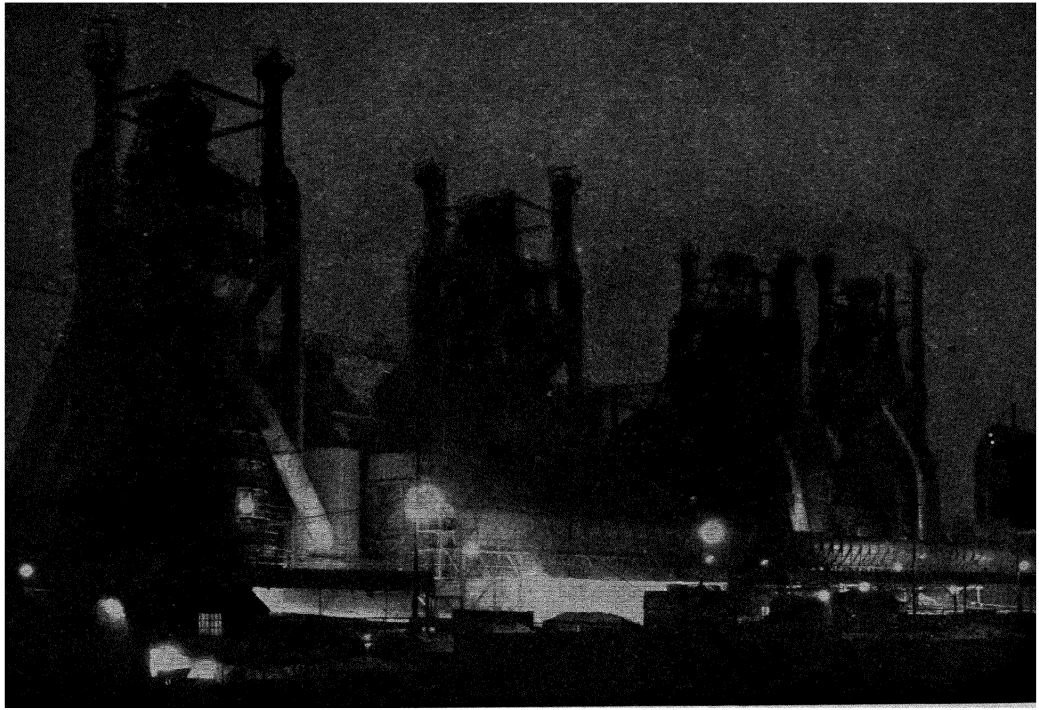
For the Leblanc process to be successfully employed *sulphuric acid* was essential, and this need was originally responsible for the large-scale production of the acid. The

accompanying illustration indicates the variety of ways in which sulphuric acid is used. The process referred to as "pickling" is the cleaning of iron sheets preparatory to coating with tin.

From early times the extraction of metals from their ores, and their adaptation for general use, formed one of the important industries of mankind. For example, the production of *iron* from its ores by means of charcoal gave rise to the blast furnace of today (p. 230). The iron ores employed are oxides, and the purpose of the charcoal (carbon) is to remove the oxygen in the form of oxides of carbon, leaving the iron mixed with the non-metallic rock or mineral which cannot be economically separated from the ore in mining. This material, called gangue (German *gang*, lode, or vein of metal ore), generally consists of clays and sands; limestone is fed into the furnace to enable the gangue to form a slag which melts easily and can be run off.

The product of the *blast furnace* is pig iron, or cast iron, which contains 2·5–5 per cent of carbon. Steel is obtained from cast iron by oxidation of the carbon; this is followed by addition of carbon and manganese in definite proportions, and of other elements such as nickel, chromium, tungsten, to give it special qualities. In 1856 Bessemer described the process which now bears his name, and which consists in blowing air through the molten pig iron. Cast irons rich in phosphorus can be used in the Bessemer process, and in this case a useful fertilizer (calcium phosphate) is produced, known as "basic slag".

Scarcely less important is the *alkali industry*; the preparation of caustic soda and caustic potash are essential in the manufacture of paper, glass and pottery — the latter being a part of the ceramic (Greek *keramos*, pottery) industry, which includes earthenware, porcelain, china and stoneware. The essential ingredient for the industry is clay, and the craft can be traced to the earliest stages of civilization. Another very old industry is *textiles* (Latin *texere*, to weave), the fibres for which may be vegetable, animal or artificial. Cellulose plays an important part in both vegetable and



By courtesy of Messrs. Stewarts & Lloyds Ltd.

A battery of four blast furnaces at night

artificial fibres — it is a carbohydrate material of which plant tissues are mainly constituted.

The treatment of *coal* and the long range of *coal-tar products* is another example of how chemical processes can produce highly valuable substances from very unlikely material. In the twentieth century, in particular, the development of organic chemistry has so stimulated the growth and production of *plastics* (Greek *plastikos*, mould) that the opinion has been expressed that we are on the threshold of another period of human achievement — the " plastic age ".

Mention will be made later (p. 267) of the drugs that have proved so efficacious in the twentieth century; though the preparation of drugs, especially those of vegetable origin, was long regarded as an essential part of the work of the " chemist " — who in the eyes of the law is a person qualified to make and sell drugs. The *dye industry*, one of the oldest in the world, received fresh impetus from the discovery in 1856 of the first aniline dye (Sanskrit *nili*, indigo) by William Perkin.

One of the largest branches of applied chemistry has been that of explosives — especially developed through the two World Wars. It may not be generally realized how dependent modern explosives are on two substances — nitro-glycerine and gun-cotton — discovered in 1846. The properties of the former were known to its discoverer, *Sobrero*, professor of chemistry in Turin, but it was not until *Alfred Nobel* (1833–96) and his father experimented with it that the production of nitro-glycerine on a large scale could be contemplated. In 1863 the Nobels set up a new laboratory near Stockholm, but an explosion which killed four people, including Nobel's younger brother, and caused the father to suffer from a paralytic stroke, led the Swedish Government to prohibit manufacture near the city. Undaunted, Nobel hired a barge, fitted it out as a laboratory, and anchored it on a lake two miles from Stockholm.

Nobel made the use of nitro-glycerine much safer by absorbing it in a light earthy substance, thereby producing the well-known " dynamite ". He also employed the

familiar fulminate of mercury for detonation. The story of the discovery of industrial " blasting gelatine " seems in keeping with Nobel's amazing energy and resource. Having covered a cut finger with a protective film of collodion, he was kept awake at night by the pain of the wound. Using these waking hours for thought on how to produce a more active form of nitro-glycerine than dynamite, and being painfully conscious of the collodion on his finger, he determined to try this substance. The next day the dream was realized; collodion (Greek *kolla*, glue), a nitrated cotton, dissolves in nitro-glycerine to form a semi-solid jelly-like mass, known as " blasting gelatine ", a powerful industrial explosive. Nobel also successfully used nitro-glycerine in the preparation of a suitably controlled propellant for military use.

Many dynamite factories were built in Europe and also in America, and Nobel was personally associated with that at Ardeer, in Ayrshire, which has become one of the largest in the world. The uses to which the nitro-glycerine explosives have been put, in civil and mining engineering and quarrying, leave no doubt of their industrial value for good. Emphasis on this, rather than on their destructive use in warfare, is reflected in Nobel's endowment of the fund to provide, among others, the Nobel Peace Prize.

The other explosive discovered in 1846 was gun-cotton, the result of an investigation of the action of nitric acid on cotton in the presence of sulphuric acid. This was carried through by *C. F. Schönbein*, professor of chemistry at Basle, who took out a British patent and became a partner in a firm at Faversham with the sole rights of manufacture. Unfortunately, a serious explosion in 1847 killed twenty-one of the staff and destroyed the factory. Similar trouble in France and Austria stopped production. Ultimately, research at the Government factory at Waltham Abbey ensured the chemical stability of gun-cotton. The diverse nature of the properties of the cellulose nitrates, containing different proportions of nitrogen, which have been produced by further research, enables them to be used as high explo-

sives; thus, with nitro-glycerine, they are used for the production of commercial blasting compounds and for propellants such as cordite. Other important products include plastics, paints, varnishes and adhesives; and the development of the artificial silk industry is also closely associated with pioneer work on nitro-cellulose.

The chemical industries as a whole afford a striking example of the dangers to the health of those who work in them. True, the coal mine had already presented its own peculiar problems, and as we have seen, Sir Humphry Davy was not slow in finding a remedy for one at any rate of its dangers; but with the widespread manufacture of acids, explosives and other dangerous materials the risks were manifoldly increased, and the protection of the individual could not be left to the devices or whims of any one firm. Just as the hours of labour and employment of children were restricted in the first Factory Act, 1819, so successive Acts improved conditions, and laid down safeguards which were enforced in every factory. A necessary prelude was an increased knowledge of the human body in health and disease, safer methods of surgery and of dealing with accidents and a sound technique for the prevention of illness. Fortunately, the century which produced such outstanding results in physics and chemistry did not fall behind in medical developments to meet these requirements.

CHAPTER XVIII : DEVELOPMENTS IN MEDICINE

THE foundations of electrical science were so well laid during the nineteenth century that, in the twentieth, not only engineering, but also all branches of human activity, benefited. But before electrical methods could be used to the best advantage for society, a knowledge of the cause and prevention of disease was essential. Fortunately, while discoveries were being made in electricity, equally important ones were taking shape in the realm of medicine, destined to revolutionize our attitude to disease.

Jenner

There are some country sayings about disease which have more in them than mere superstition ; in fact they have been founded on the experience of many generations. In the middle of the eighteenth century, it was a common belief in Gloucestershire that anyone who had already suffered from cowpox could not catch smallpox. Fortunately, in the district at Sodbury, near Bristol, there was a young medical student, *Edward Jenner* (1749–1823), who evidently kept this popular belief at the back of his mind, for in 1775 he began a careful study of the two diseases. While practising as a physician in Berkeley, near the Severn, in Gloucestershire, Jenner made extensive experiments and collected his results, with full particulars of the various "cases", in a book first published in 1798.

Inoculation (Latin *inoculare*, to ingraft; *in*, meaning in, and *oculare*, to furnish eyes or buds) had already been introduced into Britain from the East as a means of protection against disease. It consists of injecting into the blood a prepared substance or *vaccine* (Latin *vacca*, a cow) which

enables the blood to resist the attack of the disease. From careful observation Jenner believed that persons who had suffered from cowpox — a milder but similar disease to smallpox — did not catch the latter; in fact, they were "immune" from smallpox. The practical value of this could only be established by inoculating a healthy individual with a vaccine prepared from a patient suffering from cowpox, and at a later date inoculating the same person with a vaccine prepared from a smallpox patient. It was a bold experiment, but it was performed in 1796 on a healthy boy eight years old, and the full account is given as Case XVII in Jenner's book; the immunity of the child from smallpox justified the experiment. The inoculation against smallpox came to be known as *vaccination* and the term is still used. Jenner vaccinated the poor of Berkeley free, and with manifestly satisfactory results, so that eventually others trusted themselves to the new treatment.

Such a contribution to progress is not always recognized during a man's lifetime, but in Jenner's case he was hailed as a national benefactor, and in 1802 received a grant of £10,000 voted to him by the House of Commons. This grant, however, after the deduction of £1000 in fees, did little more than cover expenses. The grant was later increased by another £20,000.

Pasteur

The pioneer work which Jenner had done was extended by a French chemist whose researches led to our modern knowledge of disease and its prevention. *Louis Pasteur* (1822–95), the son of a tanner, was born at Dôle, a small town near the Jura Mountains lying between Dijon and the Swiss frontier. At sixteen years of age he went to the L'École Normale at Paris, which corresponds to an English training college for teachers. From here, despite poverty, the intellectual ability and imagination which he had inherited from his parents, together with hard work, enabled him to obtain a professorship at Strasbourg in 1849. Ulti-



LOUIS PASTEUR

mately he returned to Paris, where most of his bacteriological research was carried out between 1857 and 1888.

As a chemist, Pasteur was concerned with "fermentation", a process in which sugar is converted into alcohol. This can be caused by a vegetable organism known as yeast, and Pasteur's early work included microscopic study of this organism. He also found that the souring of beer and milk are due to other minute plant organisms, which we now call "bacteria"; they multiply at a very great rate, and many are strongly resistant to attempts to destroy them. Pasteur's chemical researches led him to apply the knowledge he was gaining about bacteria to disease.

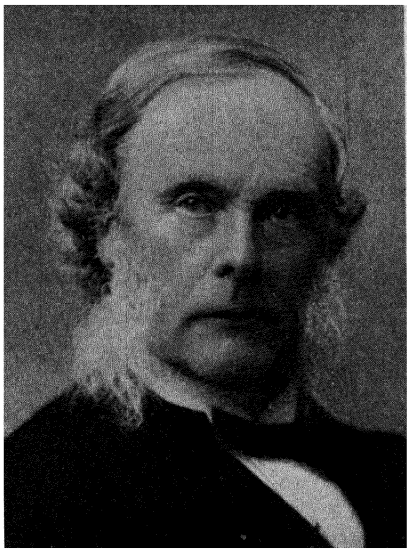
About 1860 a disease broke out amongst silkworms in the south of France, and Pasteur received an urgent request to investigate it. "But", he replied, "I have never handled a silkworm." "So much the better", answered Dumas the chemist, and so Pasteur worked for three years

in this field of pathology (the study of disease). His results showed that the disease was due to a particular bacterium. Next he studied the disease of anthrax with its deadly effect among sheep, and eventually rabies among dogs and hydrophobia among men bitten by a mad dog. Using the preventive method so successfully employed by Jenner against smallpox, Pasteur inoculated with a suitable vaccine, and thereby enabled the blood to attack the bacteria. The usual type of vaccine is a substance containing either dead or only mildly virulent germs of the same disease. In this way the human being or animal inoculated develops a mild form of the disease and the blood becomes accustomed to dealing with it, so that when attacked by serious infection it is able to resist.

Though at first the work of Pasteur was not very well received by medical men, his results showed the value of the discoveries he had made with regard to disease and bacteria, and, as in the case of Jenner, his work was recognized during his lifetime. Today there are several large institutions employing his methods and known as L'Institut Pasteur in different parts of the world, and on his death in 1895, Pasteur was buried in the one at Paris. His name, however, has become a household word in the " pasteurization " of milk: milk is heated and maintained at a certain temperature for a definite time, thereby destroying disease-producing bacteria without substantially altering the nutritive qualities of the milk.

Lord Lister and the Progress of Surgery

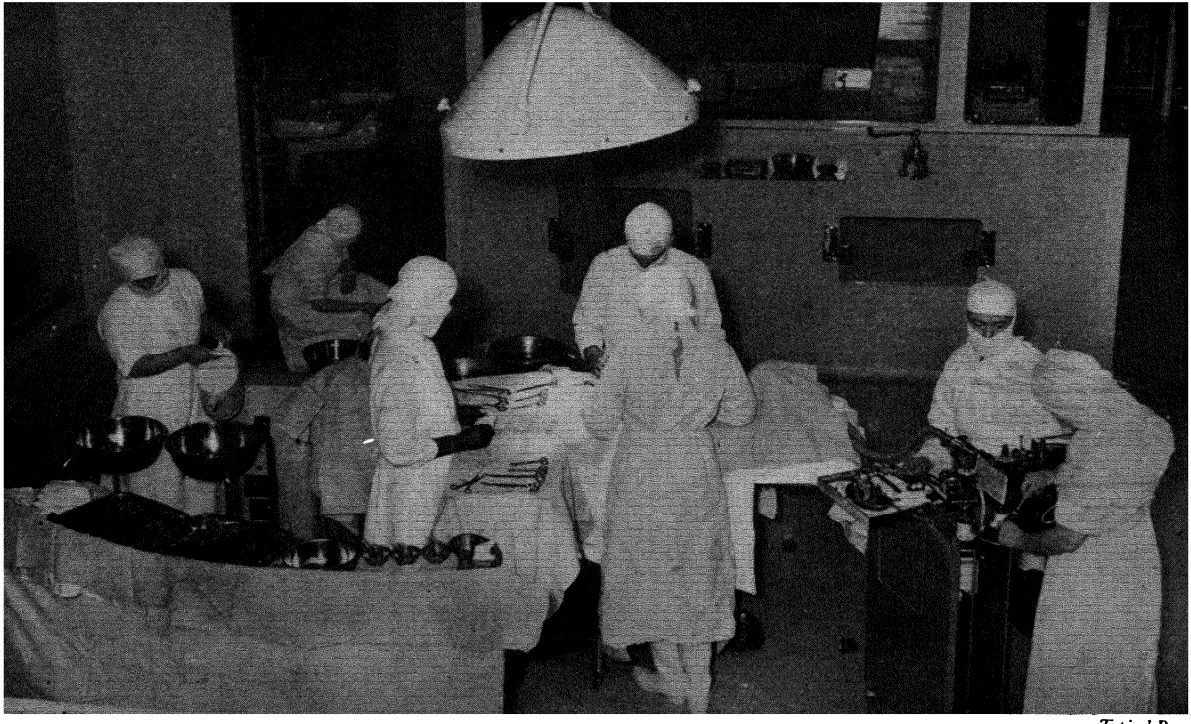
The discoveries of Pasteur were to have an unexpected sequel in the treatment and prevention of harmful bacteria in wounds. It was due to an English doctor, *Lord Lister* (1827–1912), that a great revolution in the methods of surgery took place, resulting in the saving of countless lives. One of Pasteur's few admirers, when most medical men were ridiculing his work on disease, was Joseph Lister. Born at



LORD LISTER

Upton in Essex, on the outskirts of London, his subsequent interests were many. His father, an eminent optician who had perfected the achromatic lens and improved the compound microscope, sent his son to the recently opened University College, London, where he graduated in arts and also in medicine.

As a house surgeon in University College Hospital, he had observed the great amount of poisoning which affected wounds, and which frequently caused death, even after simple operations. At the age of thirty-three he was appointed professor of surgery at the University of Glasgow, and here again he was deeply concerned at the great loss of life among patients in the hospitals suffering from sepsis or blood-poisoning — a state known as gangrene. Although gaining skill as a surgeon, he was defeated in his attempts to save life by this gangrene, which so frequently set in after an operation, and was also present in cases of accident when the skin was broken. Lister noticed, however, that in some



Topical Press

A surgeon at work in a modern **operating** theatre

accidents, though there might be an internal wound, such as that caused by a broken rib, the patient did not contract gangrene.

In the course of his work at Glasgow Infirmary during 1860–70, Lister recognized the importance of Pasteur's discovery that the air itself contained many harmful bacteria, and thus he associated gangrene, which only showed itself in wounds which were in contact with the air, with the bacteria in the air. Lister accordingly set out to find a substance which would kill the harmful bacteria which had entered the wound from the air ; the substance had to be capable of killing the bacteria, but not seriously injuring the tissues of the body. Carbolic acid had recently been introduced into commerce and used as a deodorant, and Lister found that wounds treated with a solution of this acid did not become septic. For this reason the new treatment was known as *antiseptic* (Greek *anti*, against; *septikos*, putrefying), and since the time of Lister increasing numbers of improved antiseptics have been made.

If bacteria could enter the wound from the air, it would clearly be desirable to have the air made free from harmful bacteria before an operation was performed, and if the instruments were made free of bacteria also, the risk of infection would be greatly lessened. This attempt to produce surroundings where there were no harmful bacteria is a development of the antiseptic treatment, and is referred to as *aseptic* (Greek *a-*, not ; *septikos*, putrefying). The photograph on page 239 shows a modern hospital operating theatre ; the surgeon and all his assistants are in sterilized clothing and their mouths and noses are covered by sterilized gauze pads ; the instruments used are carefully sterilized, and the air made as free as possible from harmful bacteria.

There is one further development to which reference must be made, namely, the use of *anaesthetics* (Greek *anaisthetos*, insensible). The elaborate precautions just described would not be of much value if the patient were conscious, for then serious operations would be out of the question. By the middle of the nineteenth century Sir

James Simpson (1811–70), following up work by Morton and other American dentists, had devised safe methods of giving anaesthetics, and in 1864 he performed the first operation in which chloroform was used.

Public Health

The outstanding developments in medicine of the nineteenth century centre round the prevention of disease, and the discovery of bacteria in relation to its origin. This in turn led to better methods of treatment and to the surgical skill which was made possible by the use of anaesthetics. The health of the individual and of the community was improved beyond all expectation by the adoption of numerous laws enforcing public health measures, and the twentieth century opened with medical practice ready to co-operate with other branches of knowledge in the new role that science was destined to take in society.

CHAPTER XIX : MAN AND HIS ENVIRONMENT

The Dignity of Man

AT the dawn of the nineteenth century visionaries were not lacking who believed in the dignity of man, and his ultimate destiny in matters of the spirit. *Goethe* (1749–1832), who lived in Weimar, held his fellow-Prussians in contempt for their barbarity, but he himself believed in self-culture as an end, being inspired in his writings by dramatists such as Shakespeare. His vitality showed itself in his interest in art, science and literature, and by his own example he proved his conviction that the human soul was supremely worth cultivating. Wordsworth's " Character of the Happy Warrior ", written soon after the battle of Trafalgar, emphasizes the ideals of

> . . . the generous Spirit . . .
> Whose high endeavours are an inward light
> That makes the path before him always bright.

The age was one of imaginative achievement. Music reached its zenith in *Beethoven* (1770–1827), and as a reminder that the full enjoyment of art cannot be realized without a corresponding improvement in social conditions, a Manchester cotton-spinner resolved to try an experiment in his own factory. Accordingly, *Robert Owen* (1771–1858) improved conditions of living, provided unemployment pay during a period of trade depression, established schools, and was partly instrumental in the passing of the first Factory Act in 1819. It appears strange to us that such an Act was necessary to prevent children less than nine years of age from working more than 12 hours a day in factories. At a later date *Charles Dickens* (1812–70) told the story of the hardship, poverty and lack of nutrition suffered by men, women and children unable to champion their own cause,

and he himself could write from the bitter experiences of his own boyhood. The conscience of mankind was being stirred to appreciate the value and dignity of the human spirit.

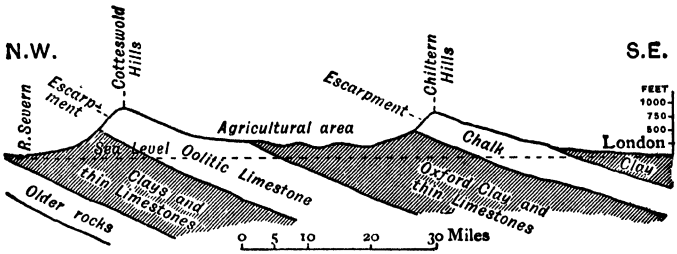
In such a background, while the mysteries of electricity were being explored and the foundations of preventive medicine were being laid, it seems reasonable that the wider study of man in relation to his surroundings should be attempted. The nineteenth century will always be associated with Darwin's discovery of the Principle of Evolution, but before his work on the origin of man could be completed, a careful study of man's environment was necessary.

During the second half of the eighteenth century a serious start had been made. *James Hutton* (1726–97) enunciated the fundamental principle that in earth history " the present is the key to the past ". In his book *A Theory of the Earth* (1795) he maintained that such natural agents as running water, the atmosphere and the sea, by " an infinity of small increments ", were adequate to produce many of the features of the earth's crust.

At a later date (1830–33) *Sir Charles Lyell* (1797–1875) published *The Principles of Geology*, a classic work which prepared the way for the theory of Organic Evolution, the popularity of Lyell's work being only exceeded by that of Darwin *On the Origin of Species*.

William Smith and the Classification of Fossils

Before the end of the eighteenth century, it was realized that many of the rocks which form the earth's crust had been deposited as " sediments " from former land surfaces, and had been contorted by subsequent upheavals. The orderly classification and interpretation of fossils, however, were the special contributions of *William Smith* (1769–1839). In his native village of Churchill, Oxfordshire, not far from Chipping Norton, he was in the midst of limestone country, rich in fossils. Owing to his keenness for collecting he did not take full advantage of even the limited instruction of the



Geological section of England between the Severn Valley and London

village school ; and later, as an assistant to a surveyor, he had to remedy his lack of knowledge of the rudiments of geometry. Smith ultimately built up a practice of his own, which involved considerable travelling in connection with the canal system which was being developed in England. Though he did not write much, he is famous as the first to make a geological map of England and Wales.

As soon as it was realized that " sedimentary " rocks were deposits, it became possible to state the first law on which Smith worked : " Of any two strata, that which was originally below is the older " ; and this " law of superposition " is of great value in making a geological map which is intended to show the nature of the rocks beneath the soil of the earth's crust. The diagram shows the succession of strata between the Severn and London. A " stratum " (Latin *stratum* from *sternere*, to strew ; plural, *strata*) is a single bed of rock, and it should be remembered that the term " rock " in geology includes soft clays as well as hard stones.

It is, however, difficult to identify rocks in different parts of the country which are similar (for example, limestones) but which have been deposited at different times. This leads us to the second law which Smith used, and the credit for its discovery is entirely due to him. As most of the sedimentary rocks were deposited under water, the remains of living creatures and plants were buried in the deposit. Traces of these remains were preserved as " fossils " (Latin *fossilis* from *fodere*, to dig). Now by extensively collecting,





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Leaf of a Coal Measure plant

Fossil Crinoid (sea-lily) from the Wenlock Limestone

comparing and classifying such fossils, Smith discovered that each bed or group of beds is characterized by its own particular set of organic remains. By using this second law he was able to get over the difficulty of identifying similar rocks in different places; if the characteristic fossils could be established, then it was reasonable to assume that the rocks were deposited at the same time.

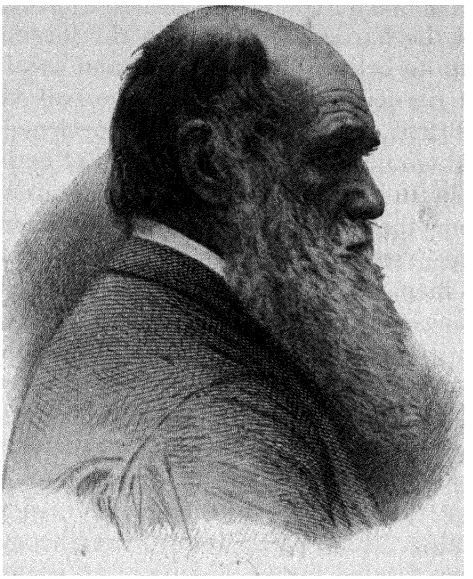
Though Smith's work began in the area between the Severn and the Chilterns, he extended his exploration so as to produce a geological map of England and Wales. By 1808 French geologists working around Paris confirmed the truth of Smith's second law, and so it became possible to link up the strata found above and below the chalk in England (which comes to the surface at Dover and elsewhere on the south coast of Britain) with the corresponding strata above and below the chalk in France (which comes to the surface south of the English Channel).

The principles on which William Smith worked have now been successfully tested and applied all over the world, and it is a tribute to this pioneer that his patience and ability have made possible the achievement of modern geology, with its far-reaching influence on economic problems. Water supply, foundations, building stones, soils, petroleum, minerals, chemicals, as well as precious stones, all come within the scope of the industrial geologist, without whose guidance much of the modern structure of civilization could never have arisen. Beyond this, however, there is one aspect of Smith's work, namely that relating to the sequence of fossils, which yields important evidence in support of the theory of evolution.

Charles Darwin

Of all the names which stand out from the long list of distinguished men of the nineteenth century, few are better known than *Charles Darwin* (1809–82). Not many pioneers can have exerted such widespread influence as he did, through his theory of evolution, in the spheres of religion, philosophy, politics and biology. Darwin came from good stock ; on his father's side there were varied interests — medical, scientific, philosophical and literary — and on his mother's the practical and artistic influence of his grandfather, the well-known potter Josiah Wedgwood, who despite physical handicap made such outstanding improvements in his craft. Born at Shrewsbury, Darwin's keenness as a naturalist soon exerted itself, and in addition he and his elder brother Erasmus spent much time on chemical experiments. Poetry and Shakespeare were also Darwin's interests.

It is not surprising therefore that his school career was regarded as somewhat unsuccessful ; his father, a medical man, decided to send both Charles and Erasmus to Edinburgh to be trained as medical men. But again, at Edinburgh Charles learned more about natural history than medicine, and Dr. Darwin proposed the Church as a career which



CHARLES DARWIN

would prevent his son entering what he considered an idle, out-door profession. Finally Charles agreed, and as a degree was necessary he was sent to Cambridge to study for the Church. At the end of three years he had obtained his degree, but his outdoor activities were still his main interest, and he had pursued his studies as a naturalist. At last fortune came to his aid. H.M.S. *Beagle* was being fitted out for survey work in the South Atlantic and Pacific oceans and a naturalist was required. Darwin wanted to apply, and his father's misgivings were finally dispelled when Charles' uncle (the son of Josiah Wedgwood) supported the project.

H.M.S. *Beagle* sailed in 1831, the year of Faraday's discovery of electromagnetic induction. The ship was small, only 250 tons and 100 feet in length, and space limited. Though not a good sailor, Darwin worked patiently and collected specimens throughout the five years' voyage. The smaller ones, whether biological or geological, were sent

home from various ports of call. At the Cape Verde Islands the study of the hard, white rock on the largest island (St. Jago) led him to believe that the shells and corals composing it had been hardened by lava, and then raised above sea-level. In Brazil he had first-hand experience of tropical forest, in Patagonia he found fossil bones of extinct animals, and farther south he saw glaciers which were moving towards the sea, along the coast line of Tierra del Fuego (Spanish, land of fire — so called from the fires lit by some of Magellan's men as a signal to the others that they had found the long-sought-for strait). In the Galapagos Islands, which lie on the equator off the coast of Ecuador, he made a special study of the birds. At Kuling (or Cocos) Island, to the south of Sumatra, he obtained information concerning atolls (a more or less complete ring of coral reefs, the enclosed water being called a lagoon), and afterwards formulated a theory of their origin which, in the main, is accepted today. Expressed simply, the theory is that an atoll has been formed by the sinking of an island which was surrounded by coral reefs.

In 1836 the *Beagle* returned to England, and the immense collection of specimens which had accumulated required sorting and arranging. Darwin reconciled himself to indifferent health by living quietly with his family in the village of Downe, Kent (see frontispiece). Here he continued his study of natural history of the present time and its relation to the life of previous ages. For this the work of William Smith was invaluable, as fossils provide one of the important lines of evidence in the theory of evolution. By the most careful study, spread over twenty years, Darwin came to believe that the different species (or kinds) of animals and plants were due to the gradual change in all living creatures of any particular group. Those groups which adapt themselves, survive, whereas those that do not, become extinct. Another naturalist, *Alfred Russel Wallace* (1823–1913), who had been working in the Malay Archipelago, had come to the same conclusion, and instead of quarrelling as to who should have the credit, the discovery

of evolution was published under both their names.

The care and honesty of purpose with which Darwin carried out his researches are revealed in the following words : " I followed a golden rule, namely that whenever a published fact, a new observation or thought came across me, which was opposed to my general results, to make a note of it without fail and at once : for I had found by experience that such facts and thoughts were far more apt to escape from the memory than favourable ones ". This is an illustration of that scientific attitude which was quietly making itself felt in the first half of the nineteenth century, and which ultimately was viewed with such suspicion by the holders of traditional views.

With the publication of Darwin's books, *On the Origin of Species* in 1859, and *The Descent of Man* in 1871, many people felt that the foundations of religion had been undermined, and there began an unfortunate controversy which reached its climax in a scene of much bitterness between Bishop Wilberforce and Thomas Henry Huxley, the able disciple of Darwin. The dogmatism on both sides which expressed itself so forcibly towards the close of the nineteenth century has largely ceased to trouble the outlook of the twentieth, and the spheres of both religion and science can now be seen in their true perspective.

The tombs of Darwin and Newton are not far from one another in Westminster Abbey ; these two great Englishmen represent the true spirit of scientific inquiry in which facts must give rise to theory, and theory be tested by the ever-increasing range of facts.

Mendel

In addition to the influence of environment on the development of species, there is an important factor called " heredity " with which in a general way everyone is familiar. But, as in most subjects, a great deal of pioneer work had to be patiently carried out before results, worthy of the name of science, could be deduced.

This was done by a contemporary of Darwin, *C. J. Mendel* (1822–84), an Austro-Silesian monk. Mendel found that by carefully cross-fertilizing one flower of a tall variety of pea by means of the pollen from a short variety, and noting the results spread over a great number of experiments, the offspring were always tall. If now plants were produced by self-fertilization of the flowers of these tall plants, Mendel found that some of the offspring were tall and others short, but none were intermediate in height. Over a great number of plants the ratio of tall to short was 3 to 1. Further and more complicated experiments were made by Mendel, but his results attracted little attention, perhaps because of the controversy aroused over Darwin's work and partly because they were published in a little-known periodical. It was not until the twentieth century had dawned that his papers were discovered by a well-known English naturalist, William Bateson, and the value of his work was realized.

Today we owe much to Mendel's painstaking researches. To mention one example only, their application to the production of food is seen in the improvement of grain ; thus some varieties of wheat have a good yield and can resist disease, but their stalks cannot stand up to bad weather : others have strong stalks and a poor yield. By careful cross-fertilization between different varieties, the good qualities can be retained and the poor ones eliminated ; the new varieties thus " made " enable the farmer to grow better-yielding crops and to choose varieties suitable to the climate and other conditions under which he farms.

Evolution as a Social Force

By the close of the nineteenth century, the broad principles of evolution had been established. From its implications the Churches at first recoiled, but most of them have now adjusted the statements of their faith to meet the new theories. What of the realm of politics ? Can the statesman ignore the findings of science, or society neglect its teaching ?

THE ATLANTIC PERIOD — MODERN

ACTION	KNOWLEDGE	VISION
A.D.		A.D.
1600		1600
		Francis Bacon
	BOYLE	
Cromwell		
Plague and Fire of London		The Royal Society
	NEWTON	
		Christopher Wren
		Pepys
		Pope
1700		1700
	JAMES HUTTON	
Frederick the Great	LINNÆUS	
		John Wesley
Seven Years War	ARKWRIGHT	
	LAVOISIER	
American Independence		
French Revolution	WATT	
1800	JENNER	Goethe 1800
Napoleon	WILLIAM SMITH	Beethoven
	STEPHENSON	Robert Owen
	FARADAY	Dickens
	CLERK MAXWELL	Tennyson
Crimean War		
	DARWIN	K. Marx
	MENDEL	Christian Science
	PASTEUR	Compulsory Education in England
1900	LISTER	1900

The publication of Darwin's books coincided with a period of intense individualism in England, and the idea of the survival of the fittest was acclaimed by many as support for the gospel of self-help and competitive rivalry. It was held that the State should encourage freedom of trade, and recognize the greatest happiness of the greatest number, but that interference by Government in the realm of the individual's freedom should be confined within narrow limits. One of the results was the bad side of the factory system.

During the second half of the nineteenth century, the national conscience was stirred by the unequal effects of this policy, whereby freedom for one section of the community had been gained at the expense of another. *Karl Marx* (1818–83) spent the last thirty-four years of his life in England, but his communistic views did not have much effect here ; according to Bernard Shaw, " Marx never got hold of the working-man for a moment ". It was the result of human compassion working on the circumstances of industrial life that initiated and confirmed progressive improvements in social conditions in Britain. By constitutional means rather than by revolution, it has been possible to adopt many of the reforms advocated by Marx in his *Communist Manifesto* of 1848. Along such lines of gradual progress and education, man may expect to raise his standard of living and improve his environment.

CHAPTER XX: DIMINISHING DISTANCES

A World Period

THE trend of European civilization westwards has already been noted. The early knowledge, which came from the river valleys of Egypt and Mesopotamia, spread from east to west over the shores of the Mediterranean. The spirit of exploration which led to the discovery of America also expanded the trade of the western coasts of Europe, and ultimately, of the western seaboard of the Atlantic. There were two developments, however, in the twentieth century which combined to introduce what can surely be called a *world period*, in which knowledge was becoming more and more international, and civilization was penetrating hitherto inaccessible regions of the earth. These two developments were scientific in origin. On one hand, there was the enormous progress made in the use of electricity for communication over long distances; and on the other, the astounding results achieved by the internal combustion engine in relation to air travel. Both have had the effect of virtually diminishing distances.

Communication by Electricity

The advance in electrical science during the nineteenth century enabled signalling to be done by means of an electric current. In 1836 Morse of Massachusetts invented the well-known Morse code of long and short sounds to represent letters. By making and breaking an electric circuit with a key (or " tapper "), long and short " bursts " of electricity corresponding to the long and short sounds

can be produced, and these " bursts " of current can be detected elsewhere in the circuit and can be made to control a " sounder " which will repeat the short or long sounds representing the letters of the message. Hence if the circuit goes from one place, *A*, to another one, *B*, then Morse code messages can be transmitted from *A* to *B* and vice versa.

In 1845 a submarine cable was laid between England and France, and by the time of the Crimean War (1854–56), improvements had been made in land telegraphy so that messages from the battlefields were sent to Paris and England at least part of the way by telegraphy. The problem of a trans-Atlantic cable presented many difficulties and was finally solved by *William Thomson* (1824–1907) in 1858, when greetings were exchanged between Queen Victoria and the President of the United States. In 1866 Thomson was knighted, and in 1892 he was created a peer as *Lord Kelvin.*

A great step forward was made by *Alexander Graham Bell* (1847–1922), who was born in Edinburgh but became an American citizen; he invented the telephone. In the original form which he used, the person speaking causes a diaphragm consisting of a thin iron disc to vibrate, thus producing changes in the magnetic field of one or two tiny coils. This sets up in the wires of the coils fluctuating electric currents which are conveyed to the receiver, where the process is reversed and the original speech reproduced. In the modern microphone, the vibrating disc presses on granules of carbon, altering the resistance of the whole, so that a current passing through it is made to fluctuate. The principle of the receiver has not been changed.

There is an obvious limitation in the extent to which the ordinary line telegraphy and telephony just described can be used. Suitable cables whether for land or submarine use must be laid and maintained, and must begin and end at permanent sending and receiving stations. If, however, the cables can be eliminated, thereby introducing the possibility of mobile sending and receiving sets, an immense step forward would have been taken in " diminishing distances ". That the cables *can* be eliminated is known to

everyone, and is indicated by our very use of the term "wireless". The short electrical waves produced by *Hertz* in 1887 were not only transmitted but actually received by him. At the same time, *Sir Oliver Lodge* (1851–1940), working independently, was equally successful, and his improvement in reception enabled him to be the first to send short-wave signals in Morse by wireless. The improvements of *Marconi* enabled this inventor to establish wireless communication between England and France in 1899, and between England and America in 1902.

These short waves have an exceedingly high "frequency", which implies that there are hundreds of thousands of vibrations every second. Their detection requires special apparatus; for whereas there is an audible frequency range of a few hundred to a few thousand "cycles" per second which can be transmitted to the diaphragm of a telephone receiver, there is no mechanically operated indicator which will respond to the high frequency of the relatively short wireless waves.

In 1904, however, *J. Ambrose Fleming* saw the possibility of using the knowledge that had been gained from previous researches on cathode rays and the transmission of electrons, and to him we owe the *thermionic valve* which enables the high-frequency wireless waves to be detected. This device consists of two electrodes in a glass bulb from which the air has been exhausted. The cathode is a filament which can be heated by a low-tension battery, and the anode consists of a copper cylinder. Now Edison had shown, in the eighties of the nineteenth century, that when an electric lamp filament is heated an electric current passes across the gap between the hot filament and another metallic conductor placed in the lamp bulb. Use is made of this in Fleming's valve (called "thermionic" because of the heated-filament phenomenon discovered by Edison). The copper cylinder is connected to the aerial, and is influenced by the alternating currents set up in the latter, owing to the high-frequency waves which it receives. The copper cylinder, or anode, thus becomes alternately positive and negative.

When it is positive the electrons from the cathode are attracted towards it, and a current passes between the cathode and anode; this is called the plate current, to distinguish it from current heating the filament. When the anode is negative, the electrons from the filament are repelled and no plate current passes. Hence the bulb acts as a "valve" and only allows the plate current to pass in one direction; if telephones are included in such a circuit, audible sounds are made.

There are many improvements on this early form of detector, and these have resulted in wireless telephony as we know it over very great distances. The twentieth century has seen a revolution in the speed at which communication can be established; for though large transmitting stations are necessary for the big distances, messages of what is happening in remote places can be passed to the permanent stations by means of comparatively small and mobile transmitting sets.

Travel by Air

There are various legends about flying; probably the best known is the story of Daedalus and his son Icarus. According to this legend, they were prisoners on the island of Crete, and in order to escape, Daedalus made wings of wax with feathers stuck in them, and so both father and son flew out of captivity across the sea to Italy. Icarus is reputed to have stolen the wings and practised flight on his own, but unfortunately he travelled too near the sun, whereby the wings melted and he fell into the sea. It is of course not sufficient proof of the story that the water to the west of the island of Samos is now known as the Icarian Sea.

For many years travel by air remained a myth, and during the Middle Ages it would be maintained that as the Almighty had not provided man with flying organs, anyone who claimed to have flown must have consulted the devil. In the thirteenth century, however, Roger Bacon ventured to prophesy of "instruments to fly withal, so that one sitting

in the middle of the instrument, and turning about an Engine, by which the wings being artificially composed, may beat the air after the manner of a flying bird". Two hundred years later Leonardo da Vinci, among his many interests considered the problem of flight from a scientific point of view, and made a careful study of the flight of birds. "A bird is an instrument working in accordance with mathematical law, which instrument it is within the capacity of man to reproduce." But little came of Leonardo's idea. By the end of the seventeenth century it became an accepted fact that the muscular power of man is insufficient to raise and maintain his body in the air.

Another approach to the problem of flight seemed possible. Just as early man had found that trees would float on water, and thereby provide a means of travel, so there was the hope that something less dense than air could be evolved to float in the atmosphere. In the seventeenth century the device of attaching to the proposed airship large globes made of thin copper, with air extracted from the globes, was seriously suggested and aroused interest in a *lighter-than-air machine*. The first balloons to "fly" were inflated with hot air, which is less dense than the air of ordinary atmospheric temperature, and the device of keeping the air hot by means of a fire carried under the balloon, was, to say the least, precarious. The discovery of the properties of "inflammable air" or hydrogen by *Henry Cavendish* (1731–1810) in the second half of the seventeenth century led to this gas being employed for the lighter-than-air balloon. Early in the twentieth century helium was preferred in view of its non-inflammable properties.

Shortly before, and during, the World War of 1914–18, there was considerable development of lighter-than-air machines. Internal combustion engines were fitted to them, and ever larger airships with very powerful engines were built and flown, such as the "Zeppelins". But they became so unwieldy, and were so much at the mercy of storms, that they did not play an important part in making air travel a decisive factor in lessening distances.

It is therefore to the *heavier-than-air machines* that attention must now be turned. In this connection the importance of work on gliders must not be under-estimated ; it is twofold. The glider tests the soundness of principles of construction and also gives the pilot the opportunity of controlling the machine when in flight. The final success of *Wilbur Wright* (1867–1912) and his younger brother *Orville Wright* (1871–1948) was due to the recognition of this twofold aspect of gliding. The brothers Wright were manufacturers of bicycles in Dayton, Ohio, but their ambition was to make a flying machine. They maintained that difficulties in the pathway to success in flying-machine construction were of three general classes : (1) those which relate to the construction of the sustaining wings ; (2) those which relate to the generation and application of the power required to drive the machine through the air ; (3) those relating to the balancing and steering of the machine after it is actually in flight. They accordingly built gliders, which enabled them to deal with the first and third difficulties. After a series of experiments on the Atlantic coast of North Carolina, they had by 1902 constructed a glider — a biplane — which was capable of flight, and amenable to control.

The problem now was that of power. As early as 1848 a model aeroplane constructed by Stringfellow had been driven by a steam engine a distance of forty yards. It was ultimately realized that steam power was not so promising as that of the internal combustion engine, which was reaching a considerable degree of efficiency towards the end of the century. *Daimler* (1834–1900), a German, made the first successful petrol engine ; he used it for propelling a bicycle, and at a later date he fitted one of his engines to a boat on the river Seine. The brothers Wright, after perfecting their glider, turned to the task of constructing a suitable engine and propeller, and finally produced a 30 H.P. unit which weighed only 7 lb. By December 1903 all was ready, and the following description by Wilbur Wright shows the epoch-making nature of the flight, which lasted 12 seconds, and was " the first in the history of the world in which a

machine carrying a man had raised itself into the air by its own power in free flight, had sailed forward on a level course without reduction of speed, and had finally landed without being wrecked ". The conquest of the air had been made, and though Wilbur and Orville Wright's achievement seems insignificant compared with modern standards, it only remained to improve the design of the aeroplane itself and to increase the effectiveness of the power unit.

The cross-channel flight of Blériot in 1909 was a forerunner of the coming revolution in air travel. The remarkable development of speed as shown by the performance of the machines flying in the Schneider Trophy Race of 1931 when a speed of 340 miles an hour was recorded, was largely due to the patience and inspiration of Mr. R. J. Mitchell, the designer of the well-known type of fighter aircraft known as the " Spitfire ". Speeds up to 504 miles an hour were recorded in 1939. Since the Second World War, speeds of more than 600 miles an hour have been reached by jet-propelled piloted aeroplanes, and velocities even greater than that of sound (about 750 miles an hour at sea-level), and referred to as supersonic, are prophesied.

CHAPTER XXI : INCREASING INTERESTS

THE opening years of the twentieth century have not only seen the inauguration of a " world period " of diminishing distances, but also they have witnessed increasing claims and interests of science. The tools which had been so well forged during the previous century were ready for use in every conceivable sphere of human activity. The men in whose hands they achieved surprising results are so numerous, and the age in which they lived is so recent, that it is scarcely possible to discern those whom future generations will regard as outstanding. Instead, therefore, of attempting to select names, it will be better to review the scope of scientific progress as a whole during the twentieth century, and a convenient starting point is the present-day view regarding the universe.

The Stellar Universe

From the earliest periods of recorded history observers have recognized order in the apparent movements of the heavenly bodies. But the explanation of that order proved of great difficulty, especially to the early astronomers. The most obvious solution was to consider the earth as the centre round which all other bodies revolved, and, as we have seen, this Ptolemaic view of the universe was held until the sixteenth century, when the Copernican view was propounded, namely, that the sun was the centre round which the planets revolved, and the stellar or star universe was outside. The increasing efficiency of telescopes revealed many patches of cloudy luminous material between the stars ; they are known as " nebulae ". Two only can be seen by the naked eye, one in the constellation of Orion and the other in Andromeda.

Laplace (1749–1827), an eminent French mathematician who was associated with the scientific activity patronized by Napoleon, propounded a theory with regard to the origin of these nebulae, and this is referred to as Laplace's Nebular Hypothesis. He believed that the planets were originally a vast nebulous mass, forming a sort of atmosphere around the sun, and extending beyond the outermost planet. Owing to rotation and gradual cooling, masses, at first like Saturn's rings, were formed, and ultimately planets were condensed and threw off their own satellites. The theory has been modified by recent research. To understand its significance, and the distances concerned, a new measure of distance is necessary — the " light-year ", which is the distance travelled by light in one year. Since light itself travels about 186,000 miles in one second, one light-year is roughly 55×10^{11} miles.

Sir James Jeans mentions three phases in stellar evolution. In the first, the universe consisted of a uniform gas of very low density, and of diameter at least hundreds of millions of light-years. In the second, condensations of matter developed in this gas at about a million light-years apart, forming separate nebulae with masses comparable to a thousand million suns. Lastly, condensations developed in turn in the arms of these nebulae, forming stars with masses comparable to that of our sun.

The New Physics

Men of science of the twentieth century have, however, not only been concerned with attempting to solve the question of stellar distances and the origin of the universe ; there has been, at the other end of the scale, a great amount of research into the nature of matter, involving almost infinitely small distances.

The great success of Newton's law of universal gravitation and his three laws of motion in predicting astronomical phenomena in which large masses of matter are involved, naturally encouraged physicists to believe that the same

laws could be applied to the very small masses and distances of atomic size. The new facts which have emerged, however, with regard to electrons and their relation to light and matter, have necessitated the use of such different methods from those of the Newtonian mechanics that the whole subject can conveniently be described as "The New Physics". In his book on *The Atom* Sir George Thomson, son of the late Sir J. J. Thomson (see below), has described the two or three years following the discovery of X-rays in 1895 as probably bringing forth "a larger number of discoveries of the first importance in physics than any equal period before or since". It will be a convenient starting point for our survey to trace the events that preceded this discovery.

The work of Faraday, by extending our knowledge of electricity, led to a considerable series of experiments on the passage of electricity through gases at decreasing pressures. The appearance of such a discharge is familiar in the various illuminated signs of the "neon" type, the orange-red glow in this case being due to the presence of the gas neon. When the pressure of the gas is still further reduced, a stream of particles called *cathode rays* passes from the negative wire to the positive, and these rays have certain important properties such as travelling in straight lines, and being deflected by a magnetic field. *Sir J. J. Thomson* (1856–1940), always known in the scientific world as "J. J.", showed that cathode rays consist of "electrons" or particles of negative electricity. It is the property of being deflected by magnetic force that has made the "cathode-ray tube" of such value commercially and in the Armed Services.

While working at the phenomena associated with the discharge of electricity through a rarefied gas, Röntgen noticed in 1895 that a screen of fluorescent material (that is, one which glows when exposed to the action of such radiation as ultra-violet rays) was illuminated although the tube containing the gas was apparently entirely screened from the fluorescent material. Evidently radiations with striking properties and able to penetrate glass-ware were

produced, and they were referred to as *X-rays*. They were also capable of passing through certain tissues, but not through bone, hence their use in medical science, especially as they could affect a screened photographic plate. They are also employed in various ways in engineering, such as the detection of flaws in metal castings. It is now known that X-rays are produced when the cathode rays strike an object, and a special " target " is introduced into the cathode tube to produce a suitable concentration of X-rays outside the tube on the object to be examined.

The discovery of X-rays led to great keenness among experimenters to discover whether similar rays could be produced in any other way. It was found that certain substances such as those containing the elements uranium or thorium became luminous or fluorescent when X-rays fell on them. In 1896 a French chemist, *Becquerel* (1852–1908), placed some uranium compounds on photographic plates (covered by black paper and left in the dark) and found that the plates were affected. Substances having this power were said to be *radioactive*. As thorium is used in the manufacture of incandescent gas-light mantles, a test can readily be made.

Soon after Becquerel's experiment with uranium compounds, it so happened that a Polish scientist, *Mme. Curie*, had to select a subject for her thesis for a doctorate of the University of Paris. Being already interested in Becquerel's work, she decided to follow it up, and during years of patient research she was helped by her husband. It was found that the mineral pitchblende (containing uranium) was even more radioactive than a prepared compound of uranium : this suggested that the uranium ore contained something much more radioactive than uranium. A substance was actually discovered (1898) one million times as radioactive as uranium ; it was the chloride of a new element, radium, though the metal radium itself was not isolated by Mme. Curie and A. Debierne until 1910.

For the analysis of pitchblende large quantities were needed, and the Austrian Government provided a ton from

the mines at Joachimsthal in Bohemia. (It was from these mines that silver coins were produced in the sixteenth century, and from the termination of the name they were known as " thalers " for short, from which ultimately we get our " dollar ".) Hitherto Mme. Curie had worked in an old store-room at the University of Paris, but now further accommodation was needed, and after much pleading she was allowed a wooden shed — cold and leaking in the winter, and stifling in the summer. The pioneers of radium worked under difficulties which frequently bring out the very best in human endeavour, and it is significant that their patient toil now holds out to thousands of sufferers a measure of alleviation, if not always a cure, of cancer. The radioactive substances, which in the early days caused severe injuries to the pioneer investigators, are now used in carefully controlled fashion to destroy cells which are diseased or superfluous, and for other purposes.

There is one aspect of radioactivity that must receive at least a passing reference. Through the work chiefly of *Lord Rutherford* (1871–1937), it has been demonstrated that when rays are given off from a radioactive element, there is an alteration in the structure of the atom itself within the element. This alteration causes uranium to break up or " disintegrate " into radium ; and a chain of " disintegration products " is formed until, when radioactivity ceases, the final product appears to be the metal lead. It is clear that such discoveries have an important bearing on theories concerning the *structure of the atom* and the ultimate nature of matter.

At first this would appear more of academic interest than of practical value, but the implications of even theoretical work can never be confidently assessed in advance. Time has shown that Rutherford's researches are leading to discoveries compared with which all previous achievements seem insignificant in their potential influence on the destiny of the human race. During the First World War he secured evidence of success in the artificial disintegration of the atom. During the Second, his successors, using the fact that

the uranium atom can be made to split up into two parts of nearly equal mass, releasing enormous amounts of energy, were able to produce the two atomic bombs which were dropped by the Allies on Japan in the summer of 1945 with such devastating results. It is a sad reflection on the state of human relations that the first use made by man of the controlled release of the huge forces known to exist in matter should have been for the destruction of his fellows and the devastation of their cities ; but men of science are confident that atomic energy, rightly used, will in due course be of the utmost service in promoting the welfare of mankind.

The natural disintegration of the atom has an unexpected application in estimating the *age of the earth.* If lead is the final product, and we know the rate at which the change is taking place, then by observing the lead residues in various rocks, some estimate can be made of the length of time required. Prof. A. Holmes suggests that the earth's age can be fixed at roughly 3350 million years.

In the development of the new physics, particularly on the mathematical side, the work of *Albert Einstein* (1879–) should be given special prominence. Born of German-Jewish parents, Einstein spent his school days in Munich, and ultimately studied mathematics in Switzerland at the Technical High School in Zurich, intending to take up secondary school teaching. He became a naturalized Swiss and served in the Swiss Patent Office during 1902–9, and in this period most of the fundamental ideas of his theories were formed. He afterwards held professorships at Zurich and Prague, and received a call to the Prussian Academy of Science in 1914. It was during the First World War that he developed his *General Theory of Relativity.* Prof. Einstein was also director of the Institute for Physical Research of the Kaiser Wilhelm Gesellschaft at Berlin.

The theory of relativity is not easy to explain in simple terms, but some of the implications of the theory have been upheld by actual observation, and the testing of the theory thus affords an excellent illustration of the application of scientific method. Every new theory should at least be

capable of explaining what has already been explained by previous theory, and if possible it should be capable of dealing with phenomena *not* previously explained. Further, the new theory is strengthened if it can predict phenomena which are ultimately observed. Einstein's theory is able to fulfil both these requirements. The revolutionary character of Einstein's theory lies in its modification of our conception of the universe based on Newton's ideas about motion and gravitation. Whereas in the Newtonian mechanics, time and space are regarded as independent, Einstein has demonstrated that they should be regarded as relative to the position and motion of the observer.

In the first place, the observed motion of the planet Mercury could not be completely explained on the basis of the Newtonian mechanics. Assuming the principle of relativity, the unaccounted part of the motion of this planet is explained within the limits of observational error. In the second place, a prediction was made on the basis of the new theory, that the path of a ray of light passing near the sun should be deflected. This cannot normally be observed because of the light from the sun, but in a total eclipse of the sun, when its light is obscured it is possible to photograph the stars which appear to be in the vicinity of the sun, and to compare the photograph with one taken at night, when the sun appears in another part of the sky. Several expeditions to observe total eclipses have given results in support of the theory. The new theory must not be regarded as lessening the importance of Newton's, but as supplementing that theory, by explaining phenomena with which Newtonian mechanics cannot deal satisfactorily.

Einstein, with other men of science, was expelled from Germany under the Nazi regime, and it is an interesting comment on any State, that it was prepared to do without the services of one of its most distinguished professors, one who is recognized throughout the civilized world as an outstanding genius. If a society can so lightly dispense with its scientific leaders, it is reasonable to ask what relation exists, or should exist, between Science and Society.

Science and Society

One of the first responsibilities of society is care for the *health* of its members. During the opening decades of the twentieth century, medical practice has made progress comparable with that achieved in other branches, and in the realm of public health science has extended her interests to embrace every aspect of social life.

Radium, X-rays and many electrical treatments are witness to the influence of the new physics on medicine. Skill in surgery has been increased beyond all expectation, especially during the First World War, and chemistry has added to the efficiency of antiseptics. The progress made by biochemistry has also been remarkable. One branch has produced important drugs, capable of destroying some of the most harmful bacteria. M & B 693 (so called from the initials of the firm producing it, and the number of the group of experiments in which it was discovered), one of the sulpha drugs, has been very effective against pneumonia; and the discovery by Sir Alexander Fleming of the effect of penicillin, has not only saved many from the gangrene which so often follows open wounds, but has also led to the production of a drug effective against certain bacterial disorders. Penicillin was discovered in 1928, but it proved impossible at the time to prepare material suitable for use therapeutically; this problem was solved by Sir Howard Florey and Dr. E. Chain leading a team of research workers at Oxford, and announced in 1942. In another sphere of research, careful study has been made of the relation of insects to disease. The patient work of Sir Ronald Ross (1857–1932), carried out under the handicap of conditions during the closing years of the nineteenth century in India, established that the mosquito is the carrier of malaria. Major-General W. C. Gorgas (1854–1920) successfully fought yellow fever by using the discovery that another species of mosquito transmits this disease from man to man. As a result, the mosquito-infested region of the Isthmus of Panama was cleared, and the construction

made possible of the Panama Canal, which was opened in 1914.

Mention must also be made here of "D.D.T.", a chemical product which has remarkable powers of destroying insects and has been used particularly against the lice which convey typhus fever; and of "Mepacrine" and "Paludrine", both of which were developed during the Second World War as substitutes for quinine in combating malaria.

Such outstanding developments are characteristic of the progress made in medicine in the twentieth century, and it is not surprising that the increasing health services have included school medical inspection, and the spread of general knowledge concerning personal and social hygiene, and the methods of preventing disease. In fact, vaccination and inoculation, in order to anticipate epidemics, have become a recognized part of our social life. Positive teaching has also been made available concerning wholesome food and a balanced diet, the importance of vitamins, the value of exercise and fresh air, including reasonable living and working conditions.

The treatment of mental disorders under qualified medical men known as psychiatrists (Greek *psukhē*, mind; *iatros*, physician) has developed from psychology, which is the study of the mind. Thus a valuable contribution is being made in the twentieth century toward the desire of the Latin satirist and poet Juvenal in the second century for a healthy mind in a healthy body ("*mens sana in corpore sano*"). The work of Mendel, which had been forgotten until 1900 (p. 249), has had an important influence on breeding, and in particular on "eugenics" (Greek *eu*, well; *gen-*, produce), the science of improving the human race. No one can fairly deny the enormous influence that science has had on the health of the community during the present century.

The effect of science in *industry* is equally apparent. Apart from the influence of fresh discoveries, efficiency, both in plant and personnel, is involved. Improved factory

buildings, air conditioning, employment of electricity, psychological statistics concerning fatigue and its relation to efficiency, medical and first-aid arrangements, these, together with processes continually being improved by scientific research, show the almost endless possibilities of harnessing the results of science to the requirements of industry. An engineer was defined in the Charter of the Institution of Civil Engineers (London, 1826) as one who is " able to direct the great sources of power in Nature for the use and convenience of mankind ". Today, the varied and unexpected results of scientific research are at his disposal as he seeks to solve the many problems of directing the forces of Nature so that they can be employed " for the use and convenience of mankind ".

But not only may science influence the health and the industry of a society ; it should also have a profound effect on the *thought* of its members. The scientific method which came to fruition in the nineteenth century is based on an attitude of mind, on a spirit of impartial inquiry, which cannot be isolated or reserved for use on selected problems. So far back as 1871, when Clerk Maxwell gave his inaugural lecture as the first Cavendish Professor of Experimental Physics at Cambridge, he realized that " the popularization of scientific doctrines is producing as great an alteration in the mental state of society as the material applications of science are effecting in its outward life ". Since that time, the leaven of the scientific spirit has been permeating society. The twentieth century has seen a general acceptance of the principle of evolution even by the descendants of those who were its bitterest opponents. It has also witnessed a growing tolerance concerning those matters of belief and experience which lie beyond the apparent world of Nature ; the truly scientific attitude involves a recognition of its own limitations.

The relations of science to society, in health, in industry and in thought, have been full of promise, but it is a humiliating admission that the first five decades of the present century have witnessed the catastrophe of two World Wars.

With all our opportunities of improvement, with science diminishing the world's distances and increasing her spheres of activity, the opening years of this world period of civilization have seen the devastating results of international conflict. Is this the inevitable result of the progress of science, or does the fault lie elsewhere? Are the discoverers to blame, or the civilization which has exploited their discoveries? Can we place the responsibility on Nature's yielding of her secrets, or on man's use of the knowledge he has gained? What is man's place in Nature?

CHAPTER XXII : MAN'S PLACE IN NATURE

Progress

" THE history of science is the real history of mankind." In this striking epigram a nineteenth-century writer links science with its background. Like most epigrams, its power lies in emphasizing by contrast an aspect of truth which may be easily overlooked. In this case it is easy to overlook the relations between science and mankind, and to treat the former as some abstract third party, which can sometimes be praised for its beneficial influences, but frequently and conveniently blamed for the horrors of war. Science and mankind cannot be divorced from time to time at man's convenience. Yet we have seen that, in spite of countless opportunities of improvement, the opening years of the present world period of civilization have been dominated by international conflict. Is this the inevitable result of the progress of science, or does the fault lie elsewhere?

The use of the word " progress " raises many problems. At the end of Chapter VII (p. 68) reference was made to Fisher's *History of Europe.* " The fact of progress is written plain and large on the page of history ; but progress is not a law of nature. The ground gained by one generation may be lost by the next. The thoughts of men may flow into channels which lead to disaster and barbarism." Looking back over the story of science, the truth of this statement is very evident. How much had to be learned again at the Renaissance, after the stagnation of the Middle Ages! But taking a long view, few will deny that modern science has progressed both in method and achievement. Attention has already been directed to the recognition of the essentials of scientific method ; yet these essentials may be seen on the

pages of history, appearing time and again over hundreds of years. At first, the search for, and later the formulation of a theory; then its acceptance and testing, in the light of further observation and experiment, and, if it is found wanting, further search; and so the cycle is repeated. We have traced this cycle — observation, theory, acceptance, testing — through some twenty-five centuries, and at last it is recognized as the essential of scientific method, applicable to every problem.

This idea of progress may be seen in scientific achievement as well as in method. Efficiency and improved technique are watchwords which accompany all modern endeavour in science. So much so that it was maintained that wireless communication and the increasing speed of air travel would, in themselves, ensure good international relations. What a disillusionment the first half of this century has produced!

The progress which is discernible in scientific method and achievement does not therefore automatically bring with it similar progress in human behaviour. And as most would agree that scientific progress could be, and has been, used for the betterment of mankind, we are thrown back to the second half of our question, Does the fault lie somewhere else? Admitting there is no inevitable law of progress, our survey of science and its background does, at any rate, give a clue to the answer. Science has proved beneficial when men have *used* the results of their discoveries in a beneficial way. For example, the progress in medical science associated with the names of Jenner, Pasteur and Lister was only beneficial when the results of the discoveries of these pioneers were *used* to alleviate human suffering.

Progress thus appears associated with the use of knowledge more than with its possession. The particular way in which we use anything is bound up with our ideas of value. To refer again to the work of Jenner, Pasteur and Lister, their discoveries are used to lessen suffering and prolong life, because we attach value to such ideals. Pasteur is well known in connection with his work on rabies, but all that

we owe to him for the treatment of the disease can be rendered of little worth if it is reintroduced into a country through selfish employment of modern inventions. Rabies was first recorded in Britain in A.D. 1000. By the middle of the eighteenth century it was prevalent among dogs in London, and during the nineteenth century thirty to forty persons died annually after dog-bite. In 1902 it had been eradicated, by stringent quarantine regulations. The misuse of the aeroplane in 1918 after the First World War to smuggle dogs, and so avoid quarantine, resulted in an outbreak of the disease in Cornwall, with all its attendant suffering and risk to man. The smugglers evidently thought the risk was worth while, balancing it against their own prospect of gain. But from the viewpoint of human life and animal suffering their action stands condemned.

Progress in its broadest sense is thus dependent, not only on improvement in scientific method and achievement, but also on the use to which these are put. Use, in its turn, is associated with our ideas of what is worth while; in other words, a sense of values.

A Sense of Values

At the International Congress of Mathematicians held at Cambridge in 1912, an address was given to the Educational Section by Prof. A. N. Whitehead (1861–1947) on "The Aims of Education", which begins, "Culture is activity of thought, and receptiveness to beauty and humane feeling". These words form a significant comment on what has just been written concerning the use of knowledge, and a sense of values. To appreciate Whitehead's statement more fully, reference may be made to the derivation of the English word "culture". It comes from the Latin *cultura*, the original meaning of which was associated with the care of a field, and the tending and tilling of land. Later the word was used for mental training, for respect, for worship. Running through these meanings is the idea of bestowing care on

something worth while, because of its ultimate value. When individuals or communities are prepared to do this, they do not fall far short of progress in its highest form.

Whitehead's definition of culture is thus closely related to progress. *Activity* of thought implies its use. Mere storing of information has no vital worth. There must be activity in its use, theories must be tested, ideas associated in various combinations. That it should be dynamic, and not static, is an essential of culture or of progress. But is this all? Are we content so long as we use our knowledge and actively employ the results of science?

The answers to these questions are in no doubt if we recognize the second aspect of culture already defined — receptiveness to beauty and humane feeling. It is not merely activity of thought that makes for progress, it is the atmosphere and way in which knowledge is employed. Masaryk, the first President of Czechoslovakia, in his book *The Making of a State* (1927), wrote, "English culture I hold to be the most progressive and, as I was able to see during the war, the most humane". Thus in the opinion of one who was in a position to judge, progress and humanity form the keystone in the arch of English culture. Such high tribute should produce a deep sense of responsibility.

A great advance is evident when the active use of knowledge is tempered with a sense of beauty and humane feeling. These are values which cannot be measured in terms of the ordinary units of science; but that is no reason why the results of science should not be used in harmony with them. They belong to the realm which may be described as "beyond" the apparent world of Nature, "praeternature". The laws of this unseen or spiritual world are not easily discerned, and it is not likely that their expression will be similar to the laws of the physical world.

The men of vision, the prophets, the poets and the artists are the pioneers in this realm of the spirit, and many of their findings have become the common heritage of mankind. That trinity of values, Truth, Beauty and Goodness, is a legacy of the great age of Greek thought. The

Founder of Christianity translated abstract ideas like goodwill and justice into a practical way of living. " Therefore all things whatsoever ye would that men should do unto you, do ye even so to them : for this is the law and the prophets." By example as well as by precept, He insisted that love to God and man should find expression in deeds, and not in mere words or sentiment. Despite the short-comings of men and nations, such ideals are increasingly recognized as the basis of the modern democratic State.

Frequently this realm of " praeter-nature " has been held to be the special province of religion, and even of one particular religious organization. A more modern view, which defines religion as " an attempt to live in harmony with the universe as a whole ", recognizes the oneness of Nature, and seeks to break down the artificial boundary between the religious and the secular. It emphasizes active participation in life, in harmony with the laws of the spiritual as well as the apparent world of Nature. It maintains that such harmony is possible and can bring with it the strength necessary for such a life. This view of religion is the culmination of the stages referred to in Chapter II— ritual, emotion, belief and rationalization.

The ideals which have just been outlined are not likely to be achieved at once, and frequently choice has to be made between conflicting alternatives. War against an aggressor is an example, and during the Second World War in particular, an illustration of such a choice was the destruction of the monastery of Monte Cassino. Few would deny the value of the latter from an aesthetic and historical viewpoint, but this was outweighed by the greater value of saving human lives, and upholding the cause of freedom. A sense of values is essential in life, and a simple method of appreciating their reality is to think of what living would mean without them. Exclude truth, beauty and goodness from everyday life and relationships, and the chaos is better imagined than described.

In a work entitled *Progress in Archaeology*, Stanley Casson directs attention to the risk of archaeologists becoming mere recorders, and writes, " While record is essential, the

appreciation of values is even more essential. . . . Archaeology is thus indissolubly bound up with artistic considerations." Life, even from the days of early man, is associated with a sense of values, and the use of science, which is so closely interwoven with the fabric of human affairs, is affected accordingly. It is here that an answer may be expected to the question of where the blame lies for this period of international conflict.

The Constructive Use of Science

To illustrate the part which a sense of values plays in ordinary life, consider the following picture, which may be adjusted to any familiar scene. A train is passing over a viaduct which crosses a deep gorge in the midst of well-wooded mountainous country. From the apparent world spread out before him, an observer may make many abstractions. His commercial interests may cause him to see the utility of the viaduct in linking producer with consumer. The engineer may think in terms of the safety factor, and wonder whether the structure will stand the storms of winter. Both are estimating values; the former pronounces judgement on usefulness, the latter on reliability. Again, the observer may be interested in the natural laws underlying the stresses and strains in the various parts of the viaduct, or he may be concerned with the flora and fauna of the district, and the fossils of the rocks, in order to support a theory of evolution or of earth history. This time another value is being extracted from the scene — the idea of truth, and its place in the story of man's environment. To many observers another value will emerge as the distant mountains are touched by the rays of the setting sun. The sense of beauty mixed perhaps with awe and reverence.

Into the picture just portrayed introduce the following incident; in which two individuals take part, having similar knowledge of explosives and equal skill in the art and practice of mountaineering. As the train approaches the

viaduct, a man is seen to advance from a perilous position and place a bomb on the rail-track. Almost at once the other dashes down, removes the bomb, but loses his life in the explosion which follows ; the track is undamaged and the train, with its human load, travels on in safety. Now the observer is faced with another appreciation of values. He has a definite feeling of right and wrong with regard to the two actions. He despises the man who uses his knowledge and ability to destroy life, and admires the constructive use made by the other man of the same knowledge and ability to save the lives of others, even at the cost of his own.

From the good action there are other values which the observer may abstract, such as love, self-sacrifice and honour; the man may not be conscious of them at the time, but they presuppose the ideals of the civilized community in which he lives, and which have guided the moulding of his character. Such individual actions are not confined to times of peace ; war frequently reveals how these values have become part of a common heritage. Love for a comrade may make a man prepared to give even life itself in the spirit of self-sacrifice, and honour demands that having heard the call for help, an attempt must be made to answer it.

The use of knowledge is thus closely associated with life itself, but its right use is not automatic. Just as the discoveries of any age are due to the men and women of that age, so the use of those discoveries is limited by the outlook of the community in which they were made. The pageant of scientific achievement that stretches across the centuries is full of possibilities for good. Science offers a better future both for the individual and society, but whether advantage is taken of the achievements of scientific workers depends on the individual men and women who compose the community, on their sense of values, and on what they consider is worth while. The strand of knowledge is interwoven with the strand of action and the strand of vision. But even if science is used constructively for the good of the community, what are the prospects of international goodwill taking the place of international conflict ?

The Rule of Law: World Co-operation

In one form or another the " duel " is a very old custom. In derivation the word comes ultimately from *duellum*, the early form of *bellum*, the Latin for " war ", *duellum* itself being derived from *duo*, which is the Latin for " two ". Just over one hundred years ago an association was formed in England to abolish duelling. In those days a man would feel that his very existence in the scheme of things involved being prepared to fight a duel in order to vindicate his honour. While appreciating values such as those mentioned in the last section, he believed in addition that duelling was a necessary institution and associated with his place in Nature.

Now, in Britain, that is changed; there has been a different assessing of values; honour is no longer vindicated in the duel. Differences are, if necessary, brought to the impartial tribunal of the law; an individual's life is held to be a responsibility of the community, and cannot be arbitrarily disposed of by the greater skill or better luck of his adversary. Commenting on the disappearance of the practice from English social life, G. M. Trevelyan writes, " But the regular duel with pistols did not fall into disuse until the bourgeois and Evangelical influences of the nineteenth century completed the work of humanity and common sense ". At the root of the change are " humanity and common sense ", or in the language we have been using, humane feeling, and a sensible use of knowledge. These have involved an appreciation of value which has modified man's idea of his place in Nature. Some at any rate of mankind do not now accept duelling as an essential part of the social structure.

Can a similar change be expected in the realm of international relations? It is almost a platitude to point out that the problem is far more complicated than in the case of individuals within one State. But that is not a sufficient reason for arguing that it is insoluble. There is a saying that the difficult takes a long time, and the impossible a

little longer. We shall examine presently some of the difficulties which may make the task seem impossible, but the story of science can point to many great obstacles equally formidable that have been overcome by the indomitable spirit of man.

> Say not, the struggle naught availeth,
> The labour and the wounds are vain,
> The enemy faints not, nor faileth,
> And as things have been they remain.
>
> . . . . .
>
> For while the tired waves, vainly breaking,
> Seem here no painful inch to gain,
> Far back, through creeks and inlets making,
> Comes silent, flooding in, the main.

These words of A. H. Clough (1819–61) do not ignore the difficulties ; to minimize them is no help in the solution of any problem. Where nations are concerned, the " rule of law " within a community is very far removed from the " rule of law " internationally. For example, in Britain, there was a growing body of public opinion against duelling which resulted in its disappearance, but there is no consensus of international opinion against war, or even agreement on major issues affecting military or economic policy. Nor has any common position been arrived at as to how far a Government's obligation to other powers should override what it considers reasonable from the point of view of the security and welfare of its own people.

Another reason for the reluctance of nations to accept the " rule of law " arises from the question of the control of power to enforce the law. Within *one* community, the Government that makes the law also controls the power to enforce its applications. Again, within one nation, when it becomes desirable to change the law, this is effected by the political Government of the time. But in international relations, where is the political power either to make, modify or enforce international law ?

We are thus brought to the heart of the problem, namely,

the creation of an international political order from which the " rule of law " may evolve. Considerations for such an order formed the basis of conferences between Allied statesmen before the end of the European conflict in May 1945, and at San Francisco afterwards. Progress towards such a goal depends ultimately on the consensus of public opinion in the countries of the world, and that in turn depends on what individuals consider of value and worth while.

But if Clough's first verse emphasizes the difficulties, the second one directs attention to progress already made. It is as unwise to underestimate assets as it is to ignore difficulties. One of the less obvious of our advantages is the common heritage of knowledge which has accumulated, independently of race and country. It is especially associated with the necessities and ordinary amenities of life and the economics of everyday existence. The skill of agriculture, the use of fire, the primitive boat, the sail, the lever and the wheel ; without this common heritage our modern civilization could not exist. Yet no names, or even places, can be allocated to these discoveries on which our economic structure rests, and with which our ideas of security are associated. Men are one in their dependence on these elemental skills.

Another asset is the common bond which unites scientific workers throughout the world, and this again is independent of race and locality. Here is the possibility of world co-operation on a scale which can be used to the greatest advantage in economic and social welfare. When, by common consent, these world resources are pooled for the common good, and used with some appreciation of their human value, their potential influence on international relations cannot be exaggerated.

A further cause for encouragement is the changed attitude in many countries during the last hundred years towards the preservation of human life, and the improvement of social conditions. The machinery set up by the League of Nations for dealing with such problems on an international scale has proved of great value. Even though in other

directions the League was not successful, and did not solve the problem of international differences, the very fact that such an attempt was made, at the end of the First World War, is in itself encouraging.

Equally significant, and it is to be hoped more efficacious, is the formation, at the end of the Second World War, of the United Nations Organization. At the first meeting in London in January 1946, the problems raised by the discovery of methods of mass destruction were referred to by Mr. Byrnes of the United States in the following terms : " In meeting these problems we must realize that in this atomic age and in this interdependent world our common interests in preserving the peace far outweigh any possible conflict in interest that might divide us. We must begin to put less emphasis on our own particular viewpoints and particular interests, and seek with all our hearts and all our minds to find means of reconciling our views and our interests for the common good of all humanity." A tribute to scientific workers and a warning to mankind are contained in the words of the Prime Minister of the United Kingdom spoken in November 1945, first to the Canadian Parliament, and later to the House of Commons : " Unless we apply to the solution of these problems a moral enthusiasm as great as that which scientists bring to their research work, then our civilization, built up over so many centuries, will surely perish ".

The " Rule of Law " and " World Co-operation " are not merely Utopian ideals, they are stern necessities if civilization is to survive. The following extract is a fitting commentary, and is taken from the statement issued on November 15, 1945, by Mr. Truman, President of the United States, Mr. Attlee, Prime Minister of the United Kingdom, and Mr. Mackenzie King, Prime Minister of Canada. These representatives of the three nations who held the secret of the atomic bomb, met in Washington for consultations on the future use of atomic energy, and the statement concludes : " Faced with the terrible realities of the application of science to destruction, every nation

will realize more urgently than before the overwhelming need to maintain the rule of law among nations and to banish the scourge of war from the earth. This can only be brought about by giving wholehearted support to the United Nations Organization, and by consolidating and extending its authority, thus creating conditions of mutual trust in which all peoples will be free to devote themselves to the arts of peace. It is our firm resolve to work without reservation to achieve these ends."

Freedom

With increasing belief in the sanctity of human life, there naturally developed a deeper respect for human freedom. From the mistakes of the years between the two World Wars, there came, in an arresting manner, a vigorous attempt to state the rights of man. The Atlantic Charter produced in the midst of battle, in August 1941, when the outlook for democracy could scarcely have been less hopeful, proclaimed those freedoms which most nations had come to recognize as fundamental: freedom from want, freedom from fear, freedom of religion and freedom of information.

Here again progress is seen to depend on the recognition of value, the value of human freedom. Man's place in Nature demands this emphasis on values, and the way of ensuring that world public opinion ultimately supports a political order founded on this freedom can only come through the active and patient example of those individuals and States which appreciate its value. As a recent writer expresses it: "There is a widespread feeling among men, if not among their governments, that the development of mankind depends on the fibre of the mind and spirit and not at all on the attributes of the gladiator, and there is a growing determination to supplant international terrorism with international law by applying to world society the experience of every civilized nation. Nor dare we leave out of the picture the eternal and irrepressible

demand of men and nations for the full flowering of their dignity."

It is beyond the scope of this book to discuss political theory, but the scientific spirit in its broadest sense is far more likely to flourish in a free State, with its recognition of human freedom, than in a totalitarian atmosphere, in which thought, speech and action are subservient to the authority of the State. It has rightly been maintained that a greater gain to the world than all the growth of scientific knowledge is the growth of the scientific spirit, " with its courage and serenity, its disciplined conscience, its intellectual morality, its habitual response to any disclosure of the truth ". Progress may be slower, when many facets of truth are put forward and discussed, but this very process, with its freedom of expression, produces an enlightened consensus of opinion which can never come from the heavy hand of arbitrary authority, whether political or military.

In the anniversary address to the Royal Society delivered on November 30, 1945, on " The Mission of Science ", Sir Henry Dale, the retiring President, directs attention to a serious danger. He maintains that the " intrusion of secrecy " into scientific research, whether for military or industrial reasons, threatens the very " integrity of science " itself. This warning has special significance in view of the fourth freedom mentioned in the Atlantic Charter. Freedom of information must not be restricted to the freedom of the Press, but must include that free exchange of results which is so essential to the progressive spirit of scientific inquiry. We are apt to think of dictatorship as dynamic, and if called into being to meet some special emergency, it should be. But if persisted in as a form of government which shackles minds as well as bodies, it is static and even worse, because it stifles that spontaneous expression of the human spirit whose rightful inheritance is activity of thought, coupled with receptiveness to beauty and humane feeling.

One of the agencies of the United Nations Organization has set itself especially to safeguard this inheritance. " Since wars begin in the minds of men, it is in the minds of

men that the defences of peace must be constructed." So starts the preamble to the Constitution of UNESCO — the United Nations Educational Scientific and Cultural Organization. Dr. Julian Huxley, at a London Conference on Science and the Welfare of Mankind, in February 1946, pointed out that the Organization's first task is to gain the support of the nations. This, as we have already seen, can only be achieved through an enlightened public opinion. Education, and the free exchange of scientific ideas, within the framework of a broad cultural background, are ideals of which our war-scarred earth stands in urgent need, so that the dignity of human freedom may be established throughout the world.

"*Swords into Ploughshares*"

In the same spirit an appropriate note was struck at the British Association's first full meeting after the Second World War. The meeting was held during August 27–September 3, 1947, at Dundee, the city which saw the uncompleted meeting of 1939, at the beginning of the Second World War — and the theme chosen, "Swords into Ploughshares", represented a genuine widespread desire to make an effective transition from War to Peace.

The British Association for the Advancement of Science, to use the full title, was founded in September 1831 "To give a stronger impulse and a more systematic direction to scientific inquiry, to promote the intercourse of those who cultivate science in different parts of the British Empire with one another and with foreign philosophers; to obtain more general attention for the objects of science, and the removal of any disadvantages of a public kind which impede its progress". In order to avoid interfering with scientific societies already in London, it was decided never to hold the annual meeting of the British Association in the metropolis, and this was observed until, by common consent, the Centenary Meeting was held there in 1931. It was to the Yorkshire Philosophical Society that the founders of the

British Association turned for their first meeting, which was held at York in 1831. Most of the eminent men of science of Britain have held office as president of the Association. Charles Darwin was prevented from doing so for reasons of health, but the Association is now fortunate in possessing a permanent link with the great naturalist; for the late Sir Buckston Browne presented Down House, at Downe, Kent, Darwin's residence for forty years, to the Association, to be held in custody as a national memorial (see frontispiece).

The British Association works in sections, according to the subject of interest, such as mathematics and physical science, chemistry, etc. An unexpected role fell to one of them, namely Section F (Economics), at the meeting held at Belfast in 1874, at the time of the Belfast Linen Strike. The Section had upon its programme a report and two papers upon various industrial topics, among which that of strikes was included. The discussion which followed centred upon the Belfast strike. Representatives of both masters and men had been invited to the meeting and were present. On the following day Tyndall, then president of the Association, was able to announce that, as a result of the discussion, the strike was ended and work was being resumed.

A special Division for the Social and International Relations of Science established in 1938 shows the importance which the Association has attached to work beyond the British Empire and Commonwealth. It is not therefore surprising that, with such a background of world-wide interest, the Association should seek, after a World War, to enlighten public opinion by directing attention from the applications of science in war to the possibilities of even greater achievement in peace: "Swords into Ploughshares".

The Adventure of Science

The individuals or States who justify war as a means of bringing out the best in men, could well study the story of science. The spirit of self-sacrifice, endurance, humane

feeling are all included in the background of the scientific worker. Take for example the story of polar exploration. In a broadcast, " South with Shackleton ", one of his comrades, Squadron Leader L. D. A. Hussey, put it in this way: " Sometimes people ask me what it was all for. I answer them not only with the scientific results of these expeditions, which were very real, but with some words that my old boss once used to me: ' It's the spirit of adventure, Huss. It was the spirit of adventure that sent Raleigh and Drake out in Elizabeth's day, and Captain Cook later, and Captain Scott; and as long as that spirit of adventure lasts the British people will last. . . . D'you know these lines of poetry, Huss? — they're favourites of mine:

> We are the fools who could not rest
> In the dull earth we left behind,
> But burned with passion for the South
> And drank strange frenzy from its wind.
> The world where wise men live at ease
> Fades from our unregretful eyes,
> And blind across uncharted seas
> We stagger on our enterprise.' "

Few can read the story of *Shackleton's Boat Journey*, told by Comdr. F. A. Worsley, without realizing the truth of the last two lines. The *Endurance* had been crushed and sunk, the eleven scientists and seventeen seamen camped in lightweight tents on ice floes which drifted 600 miles northward in five months. Then in April 1916 the floes broke up and the three boats, which had with difficulty been saved from the wreck and carefully preserved during those anxious months, were launched with their human freight. After overcoming incredible dangers, Elephant Island was reached. When the tents were ruined the men lived under the upturned boats. It was in one of these narrow gloomy spaces that an amazing operation was performed which saved the foot and probably the life of one of the members of the party.

Shackleton could have allowed others to face the further peril of the rescue journey from Elephant Island to South

Georgia in a 22 ft. open boat, but as he said, " Never for me the lowered banner, never the last endeavour " ; and Worsley adds significantly, " Always for him the forward post of danger ". There is not space now to tell of the heroism of the six men who made the journey, of the darkness settling on them, of the heavy seas, and of their steadily baling death overboard, hoping thereby to avoid the calamity of shipwreck on the craggy shore which loomed hazily ahead. Their undaunted human spirit cried, " She'll do it ! " even when they felt it impossible that any boat could win through in such a hurricane. Looking back on the fourteen days of peril, Worsley wrote thus of his chief : " At all times he inspired men with a feeling, often illogical, that, even if things got worse, he would devise some means of easing their hardships ".

The journey by land across the glaciers and mountains of South Georgia was full of fresh hazards, and was undertaken by three only of the party. Of this journey Worsley writes : " Three or four weeks afterwards Sir Ernest and I, comparing notes, found that we each had a strange feeling that there had been a fourth in our party, and Crean afterwards confessed to the same feeling ".

We are reminded of Hussey's reply when asked what it was all for. In addition to the scientific results, there was the spirit of comradeship and adventure. It goes beyond the apparent world of Nature into that spiritual realm in which fullness of manhood may be developed. Among the veterans of the South Arctic who heard the story of Shackleton's boat and land journeys, there was one white-haired Norwegian who, on being introduced to Sir Ernest and his companions, finished his appreciative tribute with the words : " These are men ! "

The quest for knowledge and the adventure of science in the service of mankind demand the very highest of which the unconquerable spirit of man is capable, even more than war. World co-operation is a healthier atmosphere than international conflict.

The Challenge of Today

In the survey of science and its background we have seen how the challenge of Greek thought and scientific achievement failed to stimulate, to any appreciable extent, the lethargy of the Middle Ages. At the scientific renaissance another challenge, involving a break with tradition, came to Europe, and this time it was accepted. We have traced the result, and watched the culmination of scientific achievement in the beginning of a world period of communications and interdependence. But our experience at the very threshold brings forth another challenge. This time it is not to the scientists as such, but to individual men and women everywhere. How is science to be used?

A simple illustration may be appropriate. You can purchase a clothes-line, and use your knowledge of ropes and knots to make a noose for self-destruction, or you may use it to make a scourge to flog innocent victims in a concentration camp, or you may use it to throw a life-line. But you cannot blame the source of your knowledge or the rope manufacturer for misuse of the clothes-line. Science provides an immense and increasing store of systematic knowledge. She is the willing handmaid of all who seek and believe in a better order. But neither the modern world nor the individual can escape from this new challenge, which involves not only the acceptance and extension of knowledge, but also an appreciation of value in its use. In the words of Sir Henry Dale, "The nations, in fact, have now to decide how they intend to use the powers and the resources which science stands ready to offer in growing abundance".

Learning has been likened to a torch, handed on from generation to generation, and some would describe the process as education. But education is greater; its end is not the acquisition of a modicum of knowledge, whether at school or college. It is also concerned with those unseen values and spiritual forces which lie beyond the apparent

world of Nature. It should be ready to help the individual in his attempt to live in harmony with the universe as a whole. When this is fully recognized, the challenge of modern science will be accepted in its true perspective. Knowledge will be actively used for the welfare of mankind, and beauty and humane feeling accorded their rightful place. The three strands of action, knowledge and vision, interwoven in the story of human achievement, are expressions of the true spirit of man. Our survey of science and its background cannot end on a note of finality.

There seems no limit to what may yet be achieved. Possibly in the march of progress we have reached the " end of the beginning ", to use a phrase coined by Mr. Winston Churchill in a speech at the Mansion House on November 10, 1942. Two days earlier Allied troops had landed in North Africa and a successful drive against the Axis Powers, Germany and Italy, at El Alamein appeared imminent. The relief of Stalingrad, closely invested by the Germans, seemed a possibility. Optimism increased as these events apparently heralded the end of the War, and the Prime Minister sought to place them in their true perspective in words which will not easily be forgotten. ". . . Now this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning. . . ."

The increasing pace of scientific discovery and its ever-widening influence have sometimes produced a similar optimism, and a feeling that the goal of human progress is in sight. But in their true perspective they are but the " end of the beginning ". Over the long centuries of geological time, river civilizations, Mediterranean culture, Atlantic venture and world possibilities, the indomitable spirit of man has emerged, a beginning has been made, and knowledge accumulated. Whether the " end of the beginning " has been reached, or whether the primitive stage of war-like rivalry is to continue, is a matter for this generation to decide.

This modern challenge concerns everyone. It is of greater significance than the challenge of Greek thought

or Renaissance scholarship; for now mankind has experienced, on an unprecedented scale, the destructive power of knowledge which is unrelated to human values. A new age, which has been called " atomic ", has dawned, and the challenge becomes all the more urgent. So certain is the devastation now made possible by using the results of modern research, that the world can no longer ignore the necessity of peaceful settlement of international disputes, if civilization is to survive.

Tennyson, with the insight of the man of vision, has put this challenge into verse, in a series of questions which the men of action and the men of learning must answer. Whether the nations are prepared to go forward from a period of international conflict, from " the end of the beginning ", into a period of world co-operation depends on the men and women of today, on their use of science, and on their receptiveness to beauty and humane feeling.

When the schemes and all the systems, Kingdoms and Republics fall,
Something kindlier, higher, holier — all for each and each for all?

All the full-brain, half-brain races, led by Justice, Love and Truth;
All the millions one at length with all the visions of my youth?

All diseases quench'd by Science, no man halt, or deaf or blind:
Stronger ever born of weaker, lustier body, larger mind?

Earth at last a warless world, a single race, a single tongue —
I have seen her far away — for is not earth as yet so young?

Every tiger madness muzzled, every serpent passion kill'd,
Every grim ravine a garden, every blazing desert till'd.

Robed in universal harvest, up to either pole she smiles,
Universal ocean softly washing all her warless Isles.

THE WORLD PERIOD
INTERNATIONAL CONFLICT

ACTION		KNOWLEDGE	VISION	
A.D.				A.D.
		DAIMLER		
		RÖNTGEN	Barrie	
1900	Boer War	Mme. CURIE	Shaw	1900
	Russo-Japanese War	RONALD ROSS		
		AMBROSE FLEMING	Baden Powell	
		WILBUR and	and the International	
		ORVILLE WRIGHT	Scout Movement	
	First World War	GOWLAND HOPKINS	Shackleton	
			Whitehead	
1920		J. J. THOMSON	League of Nations	1920
		RUTHERFORD		
		PLANCK	Masaryk	
	Japan & Manchuria	EINSTEIN		
	Mussolini & Abyssinia	JEANS	Disarmament	
	Spanish Civil War	EDDINGTON	Conference	
	Hitler & World Power			
1940		ALEXANDER FLEMING		1940
	Second World War	HOWARD FLOREY		
			United Nations	
			Organisation	

THE FUTURE ?

In this atomic age the survival of civilization depends on the way in which science is used, and, this again, depends on a sense of values.

The three strands of action, knowledge, and vision, can only be completely interwoven within the frame-work of

WORLD CO-OPERATION

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