SATURDAY, MAY 4, 1935

No. 3418 Vol. 135

Tribute of Science to the Royal Jubilee

AMONG the addresses received by H.M. the King after his accession to the Throne on May 6, 1910, was one from the Royal Society, in which reference was made to the interest which His Majesty, when Prince of Wales, had continually shown in the progress of discovery and invention. In consenting to succeed his father, King Edward, as Patron of the Society, King George expressed appreciation of these elements of national greatness, and assured the deputation of his "sympathy and support in your beneficent efforts for the promotion of natural knowledge". The collection of articles which appears in this special issue of NATURE, nearly all of which are by fellows of the Society, indicates some of the directions in which these efforts have been remarkably successful by adding new realms to the empire of science and conducting profitable explorations in them.

Science, like the universe, has no natural partitions either in space or time; so that any record of its achievements cannot be limited to a particular period or country. It happens, however, that the twenty-five years now being celebrated as the jubilee of the King's reign have seen a greater number of creative ideas in science than any corresponding period in the history of the world, and also that the contributions of British investigators to the rich harvest of scientific knowledge which has been gathered in are both distinctive and of supreme importance. The articles outline some of the fertile fields of research opened up during the past quarter of a century; and it is impossible to read them without realising that we are living in a golden age of scientific discovery. The talents with which scientific workers have been entrusted have been used to full purpose; and the results obtained are worthy of both royal and national pride.

In the main part the results represent scientific researches undertaken purely with the view of revealing natural phenomena and discovering new relationships or interpretations of them. This urge to penetrate into the unknown and reveal its mysteries cannot be repressed any more than can creative expression in art or literature. When, however, the spirit of an age is sympathetic towards any such intellectual activities, their advancement is increasingly ensured. On this account, acknowledgment must be made of the part played by the Department of Scientific and Industrial Research in the increase and use of natural knowledge. The Department was formed during the War as the result of a memorial from the Royal Society and other scientific and technical societies, exactly twenty years ago, urging the Government to afford assistance "for scientific research for industrial purposes". Two years later, Parliament placed a sum of one million pounds sterling at the disposal of the Committee of Council for the promotion of industrial research; and since then the Department instituted by the Committee has devoted a large part of the funds it derives from the State to fundamental scientific research in universities and other institutions, as well as in the promotion of research directly applied to industry. Two other national research organisations which have come into being during the past twenty-five years are the Medical Research Council and the Agricultural Research Council. The former arose from the Medical Research Committee, which was appointed for the purpose of dealing with the money available for research under the National Health Insurance Act of 1911; and provision for organised research in agriculture may be said to have grown up from the Development Act of 1909.

In addition to these and other endowments of research provided by the State since King George's accession to the Throne, there have been several munificent benefactions from private sources to establish research institutions or explore specific fields of investigation. On account of these extended facilities, the number of students and others engaged in scientific or industrial research has been multiplied many times during the past quarter of a century; and the output of original papers has increased to such an extent as to be unwieldy, and even oppressive, to scientific workers who desire to keep in touch with advances in their subjects. Our own correspondence columns represent this stream of tendency on a small scale, yet they are but a rivulet of the broad and swift river which is bearing rich cargoes of new knowledge to peoples along its banks and to ports in the seas beyond.

To attempt to survey adequately the scope and substance of scientific publications of even a single week would be to undertake a hopeless task. It is easy to understand, therefore, how incomplete any record must be which has to take a retrospective view of scientific progress in a period of twenty-five years. Obviously the only practicable plan is to select for description subjects which have opened new epochs of scientific history during the reign of the King, and not to endeavour to summarise developments in various branches of the physical or biological sciences. Beginning, for example, with the stellar universe, the knowledge gained during this period has led to entirely new conceptions as to its dimensions and structure, and their relation to the principle of relativity. Coming down to the earth, the views now generally accepted as to its age and constitution differ substantially from those formerly held, and are based upon firmer foundations. From the planet earth it is a natural transition to the planetary microcosm of the atom. Closely related are such subjects as isotopes, induced radioactivity, crystal structure, cosmic rays, the attainment of low temperatures, the constitution of the upper air, and weather forecasting. As to man himself, new light has been thrown on his ancestry and the factors favourable to his healthy development or injurious to it, as well as on the problems of heredity involved in his future. Chemistry is largely concerned with these and other biological problems, and has been able to give new aspects to them. In applied science the discovery of special steels has been largely responsible for progress in many directions, and without them there could not have been the remarkable developments in X-ray apparatus, radio communication through the use of thermionic valves, aeronautics or turbine machinery. These are the considerations which have decided the general order of the thirty articles now published.

The advances of knowledge have been accompanied by noteworthy changes of attitude of science towards philosophic and social problems. The implications of the theories of relativity and quanta, particularly in relation to notions of space and time, brought the physicist and mathematician into the realm of philosophy, while the philosopher has been giving attention to fruitful work in such specific problems as the nature of sense-data and their relation to physical entities, the character of space and time in their relation to one another, the basis of scientific induction, the interpretation of life and other intellectual concepts. Modern physical interpretations of the nature of the universe have thus led to the discussion and development of associated metaphysical problems, and the two fields of thought are now regarded as complementary to one another.

The view that the sole function of science is the discovery and study of fact, without regard to the philosophic or ethical implications of the knowledge gained, has undergone great modification in many minds. It is realised that science cannot be divorced from ethics or rightly absolve itself from the human responsibilities in the application of its discoveries to destructive purposes in war or economic disturbances in times of peace. Men of science can no longer stand aside from the social and political questions involved in the structure which has been built up from the materials provided by them, and which their discoveries may be used to destroy. It is their duty to assist in the establishment of a rational and harmonious social order out of the welter of human conflict into which the world has been thrown through the release of uncontrolled sources of industrial production and of lethal weapons.

It would scarcely be appropriate to deal with these aspects of scientific progress in the present collection of articles, though they are likely to become of increasing importance in national polity and international adjustments. We believe, however, that the wide range and high authority of the contributions now brought together in celebration of the silver jubilee of the King's reign are worthy of the occasion. It would be easy, of course, to point to other subjects which might have been included appropriately in such a retrospective survey; but, on the other hand, it would have been most regrettable to omit a single one of the present contributions, and these by themselves would make a volume of reasonable size if published in that form instead of the pages of NATURE. The articles are offered as a tribute of loyalty from scientific workers to the King and Queen; and it is hoped that they will be regarded as a stimulating conspectus of advances in natural knowledge during a memorable twenty-five years.

Twenty-five Years in History

By F. S. MARVIN

KING GEORGE'S reign will always be remembered in history for three, or rather four, unique events of world-wide as well as national importance. It has contained the whole period of the greatest war in history and the more difficult part of the reconstruction which followed it. It has seen the foundation of the League of Nations and its early growth. It has witnessed an unparalleled economic depression from which we are now slowly recovering, and which we hope and believe His Majesty will survive to see completely overcome. Lastly, in the sphere with which NATURE is more specially concerned, the King's reign covers the establishment of the most far-reaching transformation of our ideas of the material universe, for Einstein's ideas gained general acceptance just after the conclusion of the War.

It is one of the ironies of history that the greatest of wars should thus be connected with the name of one of the most pacific of kings. But there was not for a moment any doubt that the King fully sympathised with his people in all the four years of their trial, in spite of the family ties which connected him with the most formidable of their opponents. After the War, one noticed a marked increase in the public affection and esteem for a man whose good qualities at first suffered somewhat from a comparison with the *bonhomie* and genial character of his father ; and when, at the end of 1928, he was for a time laid low by a serious illness, it was clear that he had already won all hearts. Time has only strengthened that position. He is so obviously the good and devoted man, ready to bear everything and do everything for the sake of others, and, above all, for the restoration of the country and its prosperity in peace.

Next to the War, the League of Nations is, of course, the largest political issue of the King's reign. In this matter the King was fortunate in his position, and better guided by political instinct than the contemporary head of the American Republic. He was able, quite impartially, to commend the League as a common interest to all his subjects, whereas it unfortunately became a party issue in the United States. In England, King George could ask all his subjects to give it their support, and, with the aid of Great Britain and the British Dominions, it has already attained considerable success. France too has been a loyal supporter ; but, in the British Commonwealth, there was a league within the League without which the effectual functioning of the larger organisation is scarcely thinkable. At the moment, the adhesion of Russia and the close co-operation of the United States do much to set off the temporary abstention of Germany and Japan. The current year, which ushers in the King's jubilee, has seen several instances of the value of the League's work in carrying out the pacification of the world on lines entirely in accordance with the King's life-desire.

The work of social reconstruction, of healing the wounds of war and making provision for a fuller life in future, is still upon us. It was seriously aggravated, at about the time of the King's illness, by the bursting on the world of an economic depression which was as unparalleled in its severity as the War. It does not fall within the scope of this article to discuss the causes of this or the remedies which are now slowly overcoming it. Some of the difficulties no doubt are due to the fact that the resources of science in multiplying the productivity of the earth have for the time outstript our methods of distribution, and national barriers and new notions of national self-sufficiency have hindered the free circulation of the products. But one thing relating to science and arising directly from the War falls to be noticed here. The War stimulated scientific experiment on the mechanical, physical and chemical sides as it had never before been stimulated in history. The evil necessities of the time forced on work in the laboratory, in the forge and in the air which have had many not-evil results. Civil aviation has largely profited from what our engineers devised and our pilots carried out mainly over the Western Front. So also in the chemical laboratories, aiming for the time at the destruction of other men, an activity was developed which has since taken other directions. The Department of Scientific and Industrial Research, which now conducts inquiries into many matters of permanent national concern, dates from this time. It now has its own research stations and promotes the work of twenty-two industrial research associations. One may quite truly —while earnestly desiring a further abatement in the manufacture of arms—consider that most of the swords forged for slaughter have since been turned into ploughshares and pruning hooks.

So strange is the balance of good and evil in life that, while we were all, quite rightly, deploring the extinction of so many young and promising lights of science in the great catastrophe, science itself was taking some of its most prodigious strides forward.

It will always be remembered in history that the same year which saw the Treaty of Versailles and the establishment of the League of Nations, saw also the confirmation of Einstein's theory of relativity in the eclipse of the sun in 1919. The greatest step towards the permanent peace of the world coincides with the greatest step towards the establishment of the most comprehensive physical conception of the universe. In that eclipse the apparent displacements outwards of the positions of stars in relation to the sun, as shown on photographs of the eclipse, were found to be consistent with Einstein's calculations and confirmatory of his special theory. From that time onward, what had been regarded rather as a private speculation of an eminent man, took rank as the leading conception of a new era of thought. It is now found at the root of all the physical speculations about the material universe which make the more recent part of King George's reign one of the most notable epochs in the history of science.

The new outlook comes home to us more closely at the time of national rejoicing, because so many English and Anglo-Saxon names stand on the record of the advance. Two—Jeans and Eddington—are household words. Within ten years of the confirmation of Einstein's theory, man seemed to have gained a closer insight into the physical constitution of the universe than all the previous centuries had offered. It was shown to be congruous with the nature of the atom as revealed in the laboratory. New lines of development were suggested by which the heavenly bodies had assumed their present form and light. A view was thus attained which looked into the future as well as the past, and knit together what had been thought of as an infinity of space, into the expanding mind of man. This new synthesis was intimately connected with Einstein's theories, and its application, in the interiors of the stars and the remotest recesses of space, was made possible by the extension of photographic and photometric methods. An alliance was set up between work in the laboratory and work with the telescope which has led to the latest discovery of a universal fundamental number, which Sir Arthur Eddington explains in his new book.

It was thought at first that the new views were a revolution, and that Newton was superseded. But Einstein himself never countenanced this conclusion. To him, Newton was merely corrected and supplemented, and new and old thought found their place together in one essentially continuous evolution. But no doubt a shock was given to the finality of Victorian science in more than one respect. The universe of matter was no longer a finite thing, enclosed within an infinity of empty space. It became an expanding finite, full and similar throughout. Moreover, whereas absolute certainty and precision seemed to be given by the old Newtonian synthesis, the new view, coloured by the quantum of Planck, introduced an apparent indeterminacy into the old and apparently rigid laws.

In another respect the progress of science in the new century does not follow precisely the programme anticipated in the nineteenth. Thinking then that the Newtonian synthesis was final, it was commonly expected that the twentieth century would see added to this accomplished fact, another, equally complete and final set of laws, co-ordinating the phenomena of life. Now, in spite of the enormous extension of biology, this attractive prospect has certainly not been realised. Mathematical thinking has gone on pervading wider and wider fields, and gaining the conspicuous triumph which Sir James Jeans has made familiar to all. But biology, though invaded by mathematics and though engaging a constantly larger army of workers, has reached no synthesis comparable to that of Newton for astronomical physics. It has become more and more dispersed and specialised. The Mendelian laws have been added to Darwin's, but the nature of heredity and the cause of variations remain still in the realm of eager inquiry and speculation rather than of ascertained truth. The immediate sequel both of Darwin and of Mendel was rather the setting men to think and examine the details more closely, than the drawing of conclusions from well-established principles. Not deduction, but increasing experiment and induction, are still the leading features.

During the War, a school of biologists began to be spoken of as 'neovitalists', of whom the best-known name is that of Driesch. They were opposed to the idea that, by pressing on the investigation of the physical and chemical conditions of life, we might ultimately grasp the origin and nature of life itself. Such work is, of course, being incessantly done, and is one of the most prominent features of the biology of the day. But the school of neo-vitalists maintains that life is a thing *sui generis* and that, however far we may explain its conditions, we can never explain *it*, any more than we can explain the fact of consciousness by analysing the components of our sensations. Bergson, the most famous philosopher of the period, gave powerful support to this school of thought by developing his conception of an *élan vital* on the psychological side. On the biological, it revived to some extent the idea of Lamarck that the living being stretched out in the direction of its advantage in life, and that the result of such efforts were transmitted by inheritance from one generation to another. Such transmission is at the moment denied by the majority of biologists, but a vigorous school of thinkers, finding their inspiration rather in philosophy than chemistry, are working to reconcile progressive work in biochemistry with the study of life in the concrete. There are indeed signs that the rest of the century may come to justify the glowing prediction of the late Prof. Patrick Geddes, that it would see the triumph of life and be the age of biology. It is already true, in the more general sense, that men accept as a philosophical idea the community of all life and the development of higher forms of life from lower by some process in time which we have still to unravel.

It would be well if one could speak of the acceptance of a community of human life on the planet with as much confidence as the growing consensus of opinion as to its origin. In this matter, while the King's reign is distinguished by the establishment of the League of Nations, it cannot be said that the idea which it embodies or the practices which it exists to promote have made commensurate progress with what we have had to record of the progress of science. In some respects, there has been in recent years an actual setback. Germany and Japan have renounced the League, and the United States, though helpful and friendly, has not formally joined even the Court of International Justice at The Hague. Armaments have lately increased and no effective grouping or control of aviation has yet been effected. There could be no more flagrant instance of the contrast between the unity of thought, which has given man his command of Nature, and the want of unity in his application of it, than this wanton rivalry in military aviation. The most highly scientific means of transport and intercourse still threaten us as the most terrible method of mutual extermination, and the nations refuse an obvious resource to common action, common command, or even a common time-table for pacific purposes. Nothing could better signalise the later years of His Majesty's reign, or be more in keeping with the master-spirit of the man whose life we prize and are now commemorating, than the conclusion of such an agreement. It would be backed by all the scientific opinion of the world, and be the most striking proof of the progress of the reign in its essential quality—the pursuit of peace.

The Structure of the Universe

By Sir James Jeans, F.R.S.

In the last quarter of a century, our picture of the astronomical universe has changed almost beyond recognition, and yet we seem to be standing only on the seashore of the great ocean of knowledge.

The geocentric view of the structure of the universe became untenable for thinking men in the year 1610, but in 1910 many astronomers favoured a 'galacto-centric' view, believing that the galactic system was the central and dominating feature of the astronomical universe, with the earth very near to its geometrical centre.

Sir William Herschel had shown that such stars as he could see in his telescope constituted a coin-shaped structure, the more distant stars combining to form the faint band of light we call the Milky Way. In the astronomical language of 1910, a few classes of objects—spiral nebulæ and globular star-clusters—were found to 'shun' this plane, but the majority—irregular and planetary nebulæ, blue and Wolf-Rayet stars, eclipsing and Cepheid variables—'favoured' it, ranging themselves about this plane like flies on the two sides of a fly-paper. For this reason the plane of the Milky Way was thought to be fundamental in the structure of the universe.

So far back as 1755, Kant had shown that other views were possible, suggesting that the elliptical nebulæ were not "enormous single stars, but systems of many stars" similar to our own, but at so vast a distance that their light "on account of their immense multitude, reaches us in a uniform pale glimmer".

Herschel adopted this view, speaking of these supposed other systems of stars as "island universes". It fell into disfavour for a time, but Eddington, writing in 1914, remarked that "the hypothesis has recently been revived as regards the spiral nebulæ". He continued: "It must be admitted that direct evidence is entirely lacking as to whether these bodies are within or without the stellar system".

Then Hubble found it possible to measure the sizes and distances of these objects, and the problem was solved. Certain standard objects are believed to shine with the same intrinsic luminosity wherever they occur in space, so that their apparent faintness at once gives a measure of their distance. Among such standard beacon-lights are Cepheid variables of assigned period, long-period variables, blue stars of assigned spectral type, and novæ at maximum. Examples of most of these standard objects can be detected in the nearer nebulæ, and happily all tell substantially the same story as to the distances of these nebulæ. They tell us that the nearest nebula of all (M 33 in Triangulum) is about 800,000 light-years distant, while the second nearest (M 31, the Great Nebula in Andromeda) is at a distance perhaps about three per cent greater. This latter nebula subtends an angle of about five degrees in the sky, so that its diameter must be about 70,000 light-years. The diameter of our galactic system is generally supposed to be at least three times this.

Such measurements and studies have made it clear that these nebulæ are systems of stars like our own galaxy, that they lie entirely clear of this and are substantially smaller than it is. If we represent our own galaxy by London, then Birmingham and Bristol will represent the two nearest external galaxies fairly well in respect of both size and distance. A small nebula (M 32) which accompanies the Great Nebula in Andromeda may be represented by Wolverhampton or Coventry. Also two minor star-systems, the Magellanic Clouds, which lie so near our own galaxy (90,000 light-years from the sun) as almost to form part of it, may perhaps be compared to Croydon and Sutton. We must not place our sun in Central London, as Herschel imagined ; rather we are out at Hampstead or Highgate, and see the lights of Central London and the smoky pall over it in the distance, when we look towards the great star-clouds and dark nebulæ of Sagittarius.

Most of these nebulæ show the same flattened shape as our own galaxy, and it has long been conjectured that this flattening must indicate rotation. Recently rotation has been discovered spectroscopically in a number of the nebulæ. The central part of the Great Nebula in Andromeda, for example, rotates with a period of about 16 million years, while that of the well-known nebula N.G.C. 4594 in Virgo rotates about twice as fast. Quite recently Oort, Plaskett, Lindblad and others have found that the galactic system is also in rotation. The stars revolve much like the planets or the particles of Saturn's rings, the period of revolution increasing as we pass outwards. At the sun's distance it is at least 200 million years. This is $12\frac{1}{2}$ times the period of revolution just mentioned for the Andromeda nebula, but it refers to a point six times as far out. If the whole of this latter nebula were concentrated in or near its centre, the rotation period at the sun's distance out would be about 235 million years, so that the rotations are at least comparable.

From these rotation periods, it is of course possible to calculate the masses of the nebulæ and of the galactic system. The nebulæ are found to have the masses of thousands of millions of suns, while the galaxy has a mass of 100,000 million suns at least. We see that our galaxy is something of a giant in mass as well as in size ; if the nebulæ are island-universes, we still inhabit a continent.

As we proceed outwards into space, the Cepheid variables and other standard beacon-lights so far mentioned sink one after another into invisibility. Hubble has, however, found that nebulæ of assigned shapes and structure are themselves standard articles to a reasonably good approximation. Thus the faintness of the nebulæ themselves gives a measure of their distance, and it becomes possible to estimate the distances of even the faintest nebulæ, right up to the limits of vision of the telescope. The nebulæ prove to be distributed fairly uniformly at an average distance apart of perhaps 1,800,000 light-years.

If the matter contained in all these nebulæ were scattered evenly through space, the density would be of the order of 10^{-30} grams per c.c. This may give a clue to the mode of formation of the nebulæ, since a gas of this density would tend to condense into 'droplets' of just about the observed masses of the nebulæ. If nebulæ originated as such condensations in a fairly uniform gas, we have a ready explanation of the comparative uniformity of their sizes and structure.

When the light from any one of these distant nebulæ is analysed spectroscopically, the whole spectrum is found to be displaced homologously towards the red end. If we interpret these spectral displacements in the simplest way, as pure Doppler-effects, then these nebulæ are found to be receding from our galaxy at speeds almost exactly proportional to their distances—roughly, 105 miles a second for each million light-years of distance—and when allowance is made for the sun's motion through the galaxy, the same is found to be true of the nearer nebulæ also. In brief, the whole universe appears to be expanding uniformly, its linear dimensions increasing by one per cent every 20 million years.

It is likely that this apparent recession of the nebulæ is something more than a mere astronomical phenomenon, for the generalised theory of relativity seems to call for an expansion (or alternatively a contraction) of space itself. Thus the motions of the nebulæ may well be indications of something far more fundamental—a uniform expansion of the space in which they are imbedded.

The theory of relativity associates gravitation with a curvature of the space-time continuum ; this is curled up in the proximity of matter, and the curvature shows itself in the curved paths of planets and projectiles. At one time it scarcely seemed possible that the whole curvature of the space-time continuum could be of this kind, for analysis showed that, if it were, space could not stand still; it would either expand or contract. To avoid this apparent absurdity, Einstein imagined the continuum endowed with a further curvature of its own, independent of the presence of matter and so inherent in the space itself. This was specified by a quantity, the 'cosmical constant', which was supposed to have a uniform value everywhere and so kept the total volume of space fixed and unalterable.

There is no observational evidence that such a constant exists, for the curvature it implies is too small for measurement. The constant was only introduced because Einstein had thought space must be at rest, and there is no need to retain it now that space appears not to be at rest. On the other hand, we are under no compulsion to discard it. Actually Einstein and de Sitter have found that the constant can have a large range of values, including zero, without running counter to any of the observed facts of astronomy.

We may compare space-time to a river having space as its cross-section and time as the direction of flow of its stream. Two dimensions are, of course, missing; the cross-section of our river ought to have three dimensions instead of one, but as all three are all exactly similar, the suppression of two of them does no great harm.

If space could remain constant in size, this river would become a canal with parallel banks; Einstein's original space-time river was of this type. But Friedmann and Lemaître showed that such a space would be unstable; any slight disturbance or irregularity—such as would, for instance, be caused by the condensation of a primeval gas into nebulæ—would start it either expanding or contracting. For this reason Lemaître thought that the Einstein canal should be replaced by a sort of Amazon River, starting from minute beginnings and for ever widening as it flows—expanding space. De Sitter found that other values for the cosmical constant made two other types of solution mathematically possible. In one of these the canal-like river gives place to a sort of Panama Canal—space first contracts until it reaches a minimum and then expands again to an indefinite extent. In the other, space rhythmically expands and contracts, so that the space-time river becomes a series of regularly spaced lakes connected by narrows.

The Amazon-like space-time river of Lemaître was open to one grave objection. Its length, which is time—the whole time since the beginning of the universe—was limited, and its source was nothing like distant enough to allow for the observed stages of development of stellar systems —in brief, the stars were too old to have grown up within the length of the river.

The two more recent solutions of de Sitter and Einstein are not open to any such objection, and at present either of them appears capable of providing a true, although highly artificial, representation of the observed phenomena of the universe. At one time, de Sitter was advocating the Panama canal type of map, while Einstein favoured the rhythmical universe of lake and narrows—a space which alternately expanded and contracted. Einstein now appears to contemplate the possibility of a zero cosmical constant and a space of infinite extent. But it is, I think, fair to say that no one is satisfied with the present position. It may be that still other alternatives remain to be discovered, and another few years may witness some new formulation of the problem which will lead to a satisfactory solution.

The New Age in Physics

By DR. H. DINGLE, Imperial College of Science and Technology, London

EVERY advance in thought has two aspects —the loss of the old and the gain of the new—and it is probably inevitable that, after the first flush of excitement has faded away, the former should become the more conspicuous. It may inspire joy at the passing of a delusion, or regret at the failure of an ideal: in either case it is the negative aspect of the change which protrudes itself, because all are conscious that what they believed in has gone, but only a few can at first see the significance of the new thing which has come.

This is exemplified by the fact, which is in all our minds to-day, that King George V has occupied the throne of England for twenty-five years. What does it mean ? In 1910 we knew well enough what it would mean; but in 1935, who except a mathematical physicist will commit himself to an opinion ? Twenty-five years to one observer, we are told, may be fifty years to another, and neither can claim superiority for his time-scale. Why, then, not celebrate a golden instead of a silver jubilee ? The relativist knows, of course, that the destruction of absolute time is merely the necessary preliminary to the building of an absolute 'interval', and that twenty-five years is the *interval* during which King George has reigned. In this matter His Majesty's time is *proper* time, so that physics and patriotism support one another. But for one to whom this is the significant aspect of relativity, there are a thousand who know only that where they thought was certainty there is only confusion.

It will not be amiss, therefore, to look at the positive side of the changes in physical thought which the past twenty-five years have seen. What principles have been introduced into science during that time, or having already existed there, have been more clearly understood and more rigidly applied ? How does this epoch appear against the broad background of scientific history ? What is the character of the tide as distinct from the wanderings of individual waves ? Only future historians can give final answers to these questions, but we may attempt to answer them in a manner fitted to the needs of our time.

There seems little doubt that the essential contribution of relativity to science is the principle usually known as 'the rejection of unobservables'. It is not new in the sense that it has never before been applied : on the contrary, it is exemplified in almost every forward movement which physics has made. But it has been used unconsciously, instinctively, and therefore to some extent inconsistently. It has now been brought into the light of day. That is the significant thing, beside which the consequences to our understanding of mechanics and gravitation are of secondary importance.

It is very doubtful if this principle has yet been properly formulated, and quite certain that its full implications have not yet been grasped. It is probable, too, that it has on occasion been wrongly used. Though in appearance a merely negative principle, it is in fact a positive instrument of incalculable power. We venture to suggest the following two statements as a provisional expression of its meaning :

(1) *The criterion of objective physical existence is general observability by physical means**.

(2) *In the logical correlation of experience, the concepts employed shall be such that whatever is not generally observable by physical means is necessarily meaningless.*

Particular attention should be directed to the word 'necessarily'. It is not enough to reject unobservables : we must frame our laws of Nature so that they cannot arise to be rejected. It is this that makes the principle an inherently positive one. Its first fully conscious application by Einstein illustrates this excellently. It is not sufficient merely to say that because it is impossible to observe motion relative to the ether, such motion is meaningless. We must define the concepts of space and time so that its meaninglessness is a necessary consequence. This Einstein did, and therein lies his greatness.

So fundamental is this principle that some of its requirements are at present far beyond the possibility of practical application : they belong to the future. Consider the age-old question : Does an object exist when no one is observing it ? The first part of our principle immediately answers, No : for clearly it is impossible to observe an object at a moment when no one is observing it. Consequently, our final physical terms must be such that the question has no meaning.

Now the whole of what is known as 'field physics' necessarily involves existence without observation. Our observations are scattered, atomic, discontinuous, and we assume a continuum or continua (space, time, ether) in which they are distributed. Our field laws consequently describe realms of possibility rather than bits of actuality. The law of gravitation does not tell us the structure of the solar system. It gives us a prescription according to which an infinitude of solar systems might be built, but it cannot by its very nature tell us why we have our particular one. Our principle requires that this form of theory must be discarded.

Needless to say, the value of field theory as a means of advance is far from exhausted : it is its status as a possibly final form of scientific expression that is destroyed. Nor should this surprise us. A complete theory of the universe—that is, of all that is physically observable—can scarcely be pictured as a set of super-universal laws supplemented by an independent statement of how, from some quite arbitrary starting-point, a particular system developed in accordance therewith. We should not be satisfied with any theory of the universe which did not give the details of the system equal inevitability with the laws according to which those details took shape. We can, indeed, deduce this directly from our principle. The universe cannot be regarded as one of a number of possible universes, because the others, being unobservable (our own comprises all that is observable), cannot exist. Hence our final account of it cannot be in terms of field theory.

From this point of view it is highly significant that during this same period of twenty-five years the other great branch of modern physics—quantum theory—has been transformed from the heretical speculation of a few daring theorists into a system with claims to universal scope. Quantum theory, unlike field theory, postulates no unrealised possibilities ; it opposes discontinuity to continuity, and seeks to describe the actual rather than the possible. It provides the very soil in which the

* That is, intrinsic observability ; for example, an object is not to be considered unobservable merely because one is not in a position to observe it.

principle of rejection of unobservables would be expected best to flourish.

The principle does flourish there, but again the result is generally seen more as a negative than as a positive achievement: we are far less conscious of the growing fruit than of the lost blossom. The supreme product of the quantum theory so far is described as a 'principle of uncertainty', and it is often regarded as having ousted causality from Nature. It is worth while looking at this matter for a moment in its historical setting.

The idea of causality in its elementary form is almost as old as thought itself: intelligent action is impossible without an assurance that a given act will be followed by an expected event. Only at a later stage of reflection is volition eliminated, so that the initial and final states of the physical system concerned are seen standing in causal connexion; and it is still later that the conception is extended throughout space, the state of the universe at one instant being regarded as the effect of its immediately preceding and the cause of its immediately succeeding state. This was the level of thought when Newton's laws of mechanics apparently placed the reality of the conception beyond question by discovering the clue to the inevitable succession of states. Newton gave formulæ by which, if the position and momentum of each particle of matter in the universe at any one instant were known, its position and momentum at the next instant could be determined, and hence its position and momentum throughout all time, supposing it to be eternal.

Newton's mechanics has been modified in various ways, and the study of radiation, electricity and such phenomena has revealed a richer physical universe than that which he contemplated, but none of these developments has destroyed the possibility of prescribing the data necessary to predict the future course of events. The fundamental modification of Newton's contribution to the idea of causality has come from the study of the means by which data are obtained. Minute investigation shows that it is impossible to determine exactly the simultaneous position and momentum of any particle of matter because our means of observation are such that precision in one determination can be obtained only at the expense of precision in the other.

It is important to see just what this means. In one sense it virtually puts us back to our position before Newton. We cannot state what are the data which would enable us to predict the future of the universe, but we may, as then, regard the predictability of its future as a generalisation of our experience of causality in limited systems of events. How far such generalisation is legitimate is indeed an important question, but it is not affected by recent work: Galileo could have discussed it with us without being at much disadvantage. Furthermore, the experience of causality in limited systems is a fundamental fact. It is impossible that scientific developments can overthrow it without destroying their legitimacy, for it is their basis. The sum and substance of the matter is that we have found that the data by which we thought we could forecast the future are unattainable.

There is an important difference between this and the statement which is frequently made, that the quantum theory requires that an experiment can be repeated several times under precisely similar conditions with various results. If that were true, it would indicate an irrationality in Nature which would be the negation of science. What the theory does show is that, if we define similarity of conditions as similarity of positions and momenta of the physical systems concerned, we can never be sure that we *are* repeating the experiment under precisely similar conditions. The distinction is profoundly important, for the actual situation leaves open the possibility that other data may be specified which will precisely identify a system, whereas the incorrect statement leaves no room for such a possibility.

Now it is just at this point that our fundamental principle of rejection of unobservables comes in. Since simultaneous position and momentum are unobservable, we must not only reject them, but we must also re-express our laws in terms according to which they have no meaning. Position and momentum are functions of the continua, time and space, which are appropriate to field theory, but cannot be expected precisely to fit phenomena which are essentially discontinuous. The problem of physics, then, is to devise other terms.

That such terms are possible there seems little reason to doubt. A useful beginning has been made with the concept of probability. This is expressed mathematically as a ratio of integers, and so is more appropriate to discrete phenomena than any kind of continuous extension. It is sometimes said that we can no longer use models to represent physical conceptions. This, of course, is inaccurate, or physics would have no place left for the man with imagination; it would be a sphere of action only for the robot. What has happened is that mechanical models, which are spatial, have given way to epistemological ones, which are integral. To regard this as anything but a step towards better conceptions is to miss the significance of the new enlightenment. The error of the nineteenth century physicists was not that they used mechanical models (which were entirely appropriate to their stage of development), but that they did not recognise them as models. To imagine that probability has any greater claim to inherent permanency than mechanisms—and, in particular, to draw fundamental conclusions from the accident that probability suggests an intrinsic uncertainty—is to make the same error.

It seems likely that the quantum theory, so far from expelling precision from our description of Nature, really opens the door to it for the first time. For strictly speaking, a field theory can never allow absolute precision since continua are infinitely divisible. A particle having a co-ordinate represented by a non-terminating decimal, for example, could have its position specified as nearly exactly as we pleased, but not with absolute exactness, and an infinite future would hold the possibility of an indefinite amount of departure from a prediction based on such specification. Data which must necessarily be expressed in integers, however, are clearly susceptible of absolutely exact expression. The present position is therefore that we have escaped from a scheme of thought which made precise prediction impossible into one which, though we are as yet less far advanced in it, offers absolute precision as a possible goal.

Comparisons, if not odious, are liable to be misleading, and it would be unwise to stress them. Nevertheless, it may well be doubted whether in any previous period of twenty-five years, physics has experienced a more substantial forward movement.

Constitution of the Earth

By Dr. Harold Jeffreys, F.R.S., St. John's College, Cambridge

COMPARING the position of geophysics now with what existed in 1910, while we are struck by the great development that has taken place, we are equally struck, on looking more closely, by the fact that most of the theoretical advances are due, not to specifically new methods, but to the fuller application of methods that were already known. The work of Kelvin and Sir George Darwin on the rigidity of the earth, and on the evolution of the earth-moon system under the action of tidal friction, was already classical; Darwin's theory of the stresses needed to support continents and mountains was thirty years old; the existence of isostatic compensation, and the two alternative explanations of Pratt and Airy, had been known for fifty years, Stokes's theory of the determination of the figure of the earth from observations of gravity for sixty, and Poisson's theory of the longitudinal and transverse waves in an elastic solid for eighty. Dr. C. Davison, still with us, had put the thermal contraction theory of mountain formation on a quantitative basis in 1887, and Wiechert had shown how to reconcile the earth's ellipticity and precessional constant on the assumption of a thick rocky shell surrounding a dense metallic core. The existence of a change in properties in the crust in the continents at some small depth had already been inferred from geological considerations by Suess.

The chief new advance in the first ten years of the present century probably arose from the detection of radioactivity, the recognition of its effect in modifying the earth's thermal history, and the use of the rate of disintegration of uranium to find the absolute ages of minerals and to calibrate the geological time-scale. The age of the earth, estimated from thermal considerations by Kelvin at about 20 million years, was suddenly raised to about 1,500 million. Physicists did not all accept the new estimate without a struggle, though purely mechanical considerations might have given some ground for doubting Kelvin's value. Darwin, by adopting such a viscosity in the earth as would make the changes through tidal friction occur at every time at the maximum rate, the viscosity thus varying with time in a way very unlikely to correspond to the facts, could not bring the age of the moon below 54 million years. This might have been taken as an absolute minimum that was practically certain to be greatly exceeded.

The new source of heat was so potent that the present Lord Rayleigh pointed out that, if it was not confined to a depth of some tens of kilometres at the outside, it would produce more heat than is escaping from the earth; consequently it led Holmes to estimate the rate of decrease with depth. It was found to suggest that average granite could exist only to a depth of about 15 km. and agreed in principle with the conclusions of Suess.

Meanwhile, seismology made three great advances. Herglotz and Bateman provided a method of finding the velocity of an elastic wave at any depth in the earth from the observed times of travel of earthquake waves, which was first applied by S. Mohorovičić in 1916. R. D. Oldham found that longitudinal waves arrived at the opposite side of the earth about three minutes later than they would if the velocities found from observations at shorter distances were maintained to the centre, and inferred that at a depth of about half the radius there was a change of properties involving a diminution of velocity. The radius found for the core in this way was substantially less than that found by Wiechert; but it was not until 1926 that it was noticed that the compression of each layer in the earth by the weight of the matter above it would raise the density so much that, when it was allowed for, the radii found by Wiechert's method and Oldham's were practically identical, so that the Wiechert core and the Oldham core are the same thing. A. Mohorovičić, working on a small earthquake in Croatia in 1909, found that the records at short distances could not be represented by a medium the properties of which varied continuously. They showed a pair of strong longitudinal and transverse waves, which were overtaken at a distance between 100 km. and 200 km. by a weaker pair that travelled faster; the latter corresponded to the waves observed at greater distances. The interpretation is that the strong pair observed only up to distances of about 800 km. travel in an upper layer, while the others travel with greater velocities through a lower region of great depth. The correspondence with the geological and thermal considerations is plain.

All these lines of investigation were greatly developed by Gutenberg, particularly in relation to the waves through the core and reflected by it. The reduction of the velocity of a longitudinal wave on entering the core is about that of light on entering water from air; consequently the core casts a shadow, which can be recognised by the absence of the clear direct waves beyond a distance of about 105° and their replacement by a vague diffracted movement, and the rays passing through it have a caustic surface, which meets the outer surface before it has come to a focus. Thus there is a narrow zone, at a distance of about 143°, where the motion in the longitudinal wave is extremely strong. The estimated velocities led Gutenberg to calculate times of transmission of many other core waves, notably those reflected at its outside, the wave that is transverse in the shell but is partly refracted as a longitudinal one in the core, and one derived from the latter by undergoing one reflexion on the inside of the core before it comes out. These were all recognised on actual seismograms. It was much later, however, that attention was directed to this work in Great Britain, and Prof. H. H. Turner rediscovered several of Gutenberg's waves independently from the observational material supplied to the International Seismological Summary.

The most immediate consequence of the existence of the reflected waves is that the boundary of the core is a sharp discontinuity of material and not a gradual transition. This gives a direct verification of the inference, based on a slightly dubious analogy with meteorites, that the shell is stony and the core mainly iron, with probably a certain amount of nickel. Further, the mean densities found by combining the radius of the core with the mean density and the moment of inertia are about 4·5 and 12 respectively; but if we estimate what they would become if the high pressures were taken off, they are about 3·3 and 8, the former agreeing with the density of olivine and the latter with that of iron. The core appears to be liquid. Gutenberg calculated what the times of transmission of transverse waves through it would be if it was solid, but though several workers have found movements that they have thought to be these waves, their results are not consistent and seem to be capable of other interpretations. The most direct evidence on the state of the core is provided by the earth's tidal yielding, which is practically what it would be if the core was fluid, and substantially more than if the core was solid and had a rigidity in any reasonable ratio to its bulk-modulus.

Further work on the records of near earthquakes has shown that there is at least one intermediate layer, and there may be three. The thickness of the upper layer is 12 km., with an uncertainty of 3–4 km.; the intermediate ones together may be twice as thick. The study of the surface waves, mainly by Stoneley, has given similar results with a rather higher precision. The surface waves under the oceans, however, show a different structure; the thickness of the upper layer is substantially less, and the geological evidence indicates that it is not granite there, but probably andesite or even basalt.

The chief modern contributions to seismological technique are probably the wireless time service and Bridgman's invention of a method of experimenting at high pressures. Until recently, the time had to be determined independently by astronomical observation at every station; now a station with no astronomical equipment can fix its time with as great accuracy as was possible to the best in 1910. The result of this and of the increase in the number of stations is that the times of transmission of the various waves can be determined, in most cases, with an accuracy of a second or less; in fact, the accuracy is so high that it has become necessary to allow for the ellipticity of the earth before we can make full use of it, and it has only been attainable because the earthquakes used have been in much the same latitude, so that the effect of the ellipticity has always been nearly the same.

Testing the compressibility of actual rock specimens at high pressures has shown that the velocities of elastic waves in the upper layer are consistent with its being granite ; geologists seem to be coming to regard the upper layer as more like a granodiorite than a normal granite, but this is a minor change. The lower layer fits olivine or dunite in elasticity as well as in density ; it is definitely too dense and too stiff to be basalt, which, if it forms any extended layer at all, can only be the deepest and least clearly recognisable of the intermediate ones.

A strong curvature near 20° of the curves representing times of transmission against distance was first noticed by Byerly, and work by I. Lehmann, K. E. Bullen and myself has shown that there is a sharp change in the slope there. This appears to correspond to an increase of the velocity by about 10 per cent at a depth of about 350 km. The nature of this change is not yet understood. Apart from the upper layers, this discontinuity, and the boundary of the core, there are no other sudden changes in properties with depth. Search has been made for a sulphide layer, which has been expected to form the outermost part of the core, but it is necessary to do some violence to the observations to fit one in at all, and there seems to be no room for one more than a few kilometres thick at the most.

The study of gravity made a great advance in 1912 with the publication of Hayford's work in the United States, which showed that the larger mountain ranges of the United States are associated with such a defect of density below that the whole produces little disturbance of gravity. Unfortunately this work, and the later work of Bowie, have suffered greatly from exaggeration and misinterpretation. The general result was to assume that this compensation made a great reduction in the differences between observed and calculated gravity ; but it did not abolish them. It was inferred by many that the approximate compensation was exact, and elaborate theories have been constructed upon it, assuming that it showed not only the lower layer, but even the upper ones, to be completely devoid of strength, in direct opposition to the plain fact that the surface of the earth is not perfectly flat. Others, unwilling to accept the conclusion, have gone to the opposite extreme and denied that the observations imply any compensation at all. It still does not seem to be generally recognised that a theory that reduces the average residual in a mountainous region from twenty times to six times the probable error of a single observation, is on a different footing both from a theory that reduces it to the mean error of a single observation and from one that does not reduce it at all. On the other hand, the generality of the American results is not complete ; they seem to apply to all the great mountain regions where they have been tested, but they break down in India and in the East Indies, as De Graaff Hunter and Vening Meinesz have shown.

Meinesz's introduction of a method of determining gravity at sea by observing in a submarine is perhaps the greatest advance towards determining the figure of the earth accurately that has been made recently. Stokes showed how a complete knowledge of gravity over the earth's surface could give a determination of the external field ; but so long as observations were available only over the land, and very limited proportions of that, we were in the position of trying to locate one end of a rod of unknown and variable curvature by observing a lot of points near the other. Now lines of observed values of gravity are available right across the main oceans, though there is still a great need for more in the southern hemisphere.

The Measurement of Geological Time

By PROF. ARTHUR HOLMES, Professor of Geology, University of Durham

TWENTY-FIVE years ago, opinions as to the scale of geological time were still in a chaotic state. The earlier controversy between Kelvin and the geologists had come to a dramatic end in 1906 with the discovery by Strutt (the present Lord Rayleigh) of the widespread distribution of radioactive elements through the rocks of the earth's crust. The earth could no longer be regarded as a spendthrift living on a limited capital of ancestral heat. An independent source of income had been disclosed in the energy liberated during radioactive disintegration, and henceforth no thermal argument could set a limit to the age of the earth. Already, however, helium and lead had been recognised as the end-products of the uranium family, and Rutherford had suggested (1905 and 1906) that the accumulation of these elements in radioactive minerals might provide a measure of the age of such minerals.

In 1907 Boltwood made the first attempt to calculate the ages of minerals which had been analysed for uranium and lead. During the next three years, Strutt carried out his far-reaching researches on the accumulation of helium during geological time and on its rate of production in uranium and thorium minerals. Thus, by 1910 the foundations were being actively laid on which our present knowledge of the subject has been built. It was evident from the preliminary results that the earth might well be fifty times as old as Kelvin had thought. Geological evidence, based on a statistical comparison of rates of denudation with accumulated sediments on one hand, and with the salinity of the sea on the other, had suggested a period of about 100 million years for the age of the earth. The possibility that 1,000–2,000 million years might be available seemed to many geologists to be as embarrassing as the former limitation to 20–40 million years. Interest in the validity of the rival methods was thus re-awakened, and most of the discussion of the last quarter of a century has rightly been focused on this fundamental aspect of the subject.

For reliable measurements of geological time we require to know: (*a*) the rate at which some suitable process is going on at the present day; (*b*) the law of its variation during the interval to be measured; and (*c*) the cumulative change effected by the selected process during that interval.

Except in their application to relatively short intervals, none of the geological methods fulfils these requirements. Present rates of denudation are fairly well known over a wide range of environments, but there are many reasons for regarding their average as abnormally high compared with that of the geological past. River gradients are steeper than usual, because of recent mountain building; groundwater circulation is more active for the same reason; easily eroded blankets of glacial and fluvio-glacial sediments are widespread; and human activities—agricultural, engineering and chemical—have introduced a unique source of acceleration. Evidently no law of past variation can be formulated.

The total accumulation of sediments is difficult to estimate even approximately, since exposed sediments are worked over afresh by denudation, and deeply buried sediments may be metamorphosed beyond recognition by transfusion and granitisation. Measures of maximum thicknesses provide comparable figures for the individual systems, but no corresponding rate of deposition is available, since the maximum thicknesses are really measures of crustal depression. If the sodium method of estimating the age of the oceans is apparently simpler in form and superior in quality, it is only delusively so, and not only because present rates of chemical denudation are high. The geochemistry of sodium is still insufficiently explored in two directions. Sodium is probably returned to sediments by base exchange on the sea floor, and it is certainly added to them from plutonic sources by processes of albitisation and granitisation. The metamorphic cycle introduces incalculable sources of variation, but their effects are all in the same direction, so far as our problem is concerned. All we can conclude is that the actual age of the oceans must be many times higher than the estimate calculated from present conditions.

The radioactive methods are based on the generation of helium and of isotopes of lead from uranium, actino-uranium and thorium, and on the accumulation of these stable end-products in minerals, rocks and meteorites which have retained them. The original uncertainties, which Becker and Joly never allowed to be overlooked, have now been completely dispelled. Unless the contemporary state of scientific knowledge is as misleading in our day as it was in Kelvin's, we can now claim to be in possession of data that are securely founded in principle, and stable in the sense that continued research only increases their accuracy and extends their range*.

The present rates of production of helium and lead from uranium are well established ($\mathrm{U\,I} \rightarrow \mathrm{Pb}^{206} + 8\mathrm{He}$). To a first approximation, the age of a uranium mineral is given by the ratio of lead to uranium, (Pb/U), $\times 7600$ million years. But the investigations of von Grosse on the actinium series, and those of Aston and of Piggot and Allison, in recognising and disentangling the isotopes of lead leave no room for doubt that the actinium series springs from an isotope of uranium, AcU, and terminates in Pb^{207} ($\mathrm{AcU} \rightarrow \mathrm{Pb}^{207} + 6\mathrm{He}$). Thus, a slight error is introduced into the above formula, and this must be allowed for, especially in the case of old minerals. At present, the ratio of AcU to U I is about 4 to 96, and the former disintegrates about ten times as fast as the latter. Clearly the older the mineral the higher should be the ratio $\mathrm{Pb}^{207}/\mathrm{Pb}^{206}$, and hence this ratio itself constitutes an index of age.

The chief defect in Boltwood's original use of lead-ratios only became apparent with the recognition that the thorium series also terminates in an isotope of lead ($\mathrm{Th} \rightarrow \mathrm{Pb}^{208} + 6\mathrm{He}$). For a thorium mineral, the corresponding lead-ratio can be expressed as $\mathrm{Pb}/k\mathrm{Th}$, where k depends on the rate of lead production by thorium relative to that by uranium. Strutt's early work showed that k was not far from 1/3. Later estimates have varied between 0·38 (Lawson) and 0·25 (Kirsch). In Bulletin 80 of the National Research Council, Washington, D.C., referred to above, the value

* A complete résumé of the subject up to 1931 appears in "The Age of the Earth", Bulletin 80 of the U.S. National Research Council, Washington, D.C. Since then a remarkable amount of new work has been accomplished, largely as a result of the direct influence and co-ordinating activity of the National Research Council Committee on the Measurement of Geological Time. The annual reports of the Committee, prepared by its energetic chairman, Prof. A. C. Lane, not only record the rapid progress which is being made, but also enable individual workers in various parts of the world to keep in close touch with each others' results and ideas.

0·36 was adopted by Kovarik and the writer, and more recent investigations by Kovarik, Ruark and Fesefeldt on the period of thorium have confirmed this value. For minerals containing both uranium and thorium, as many of the suitable minerals do, the simple lead-ratio (uncorrected for the actinium complication and the wearing out of the parent elements) thus becomes Pb/(U + 0·36Th). The corresponding helium-ratio is He/(U + 0·27Th). If helium is stated in cubic centimetres per 100 grams of material, the age of the latter in millions of years (provided there has been no loss of helium) is given approximately by multiplying the ratio by 8·8.

The question whether the rate of generation of lead isotopes and helium has varied during geological time has now been satisfactorily answered. None of the physical or chemical conditions appropriate to the terrestrial environment of radioactive minerals has been found to disturb in any way the normal rates of spontaneous disintegration. But this is not all. Positive evidence of the inferred constancy of rate is provided by pleochroic haloes, the rings of which correspond in radii to the ranges of the respective α-particles responsible for their development. The range of each α-particle is connected in turn with the rate of disintegration of its emitter by a simple law. Hence, if the ranges measured from pleochroic haloes in old Pre-Cambrian minerals are identical with those from Tertiary haloes and experimentally produced haloes, the chain of evidence is complete. In 1923, Joly claimed that the uranium ring showed a progressive increase of radius with increasing age. However, more accurate measurements by Kerr-Lawson in 1927 failed to reveal the alleged increase, and indicated that Joly's identification of the rings had been at fault. A recent study of haloes by Henderson, Bateson and Turnbull, in which a highly sensitive recording photometer was devised to measure the halo features, shows that there has been no variation of range, and therefore no change of rate of disintegration, over a period of a thousand million years. Henderson has also identified a ring due to actinium C and indicated how its development can be used in comparison with that of the radium C′ ring to yield estimates of age. Preliminary results are clearly of the right order.

The third condition of validity implies knowledge of the total accumulation of lead isotopes or helium in the radioactive material under investigation. To consider first the lead method: the presence of initial lead, if any, must be recognised and allowed for, and evidence is required that the mineral has remained uncontaminated by external influences since the time of its crystallisation. Field occurrence, microscopic examination, chemical composition, atomic weight determinations of lead, and isotopic analysis of the lead all contribute data bearing on these important points. After rejecting those numerous minerals which fail to satisfy the requirements, there still remain many for which the evidence of reliability is good. Assurance is confirmed when it is found: (*a*) that minerals of the same geological age, but with varying values of U/Th, give concordant lead-ratios; and (*b*) that suites of minerals of varying geological age fall into an internally consistent time-scale. A good example of (*a*) is given by uraninite and monazite from a Pre-Cambrian pegmatite in Manitoba. Ellsworth obtained a lead-ratio of 0·260 from the first (a uranium mineral), while Miss Kroupa found 0·259 for the second (a thorium mineral), the corresponding ages being approximately 1,745 and 1,725 million years. To illustrate (*b*) the data set forth in the accompanying table will suffice.

AGE DETERMINATIONS BY THE LEAD AND HELIUM METHODS.

Geological Age	Material	Locality	Millions of years from	
			Lead-ratios	Helium-ratios
Miocene	Uraninite	Mexico	35	
	Brannerite	Idaho	38	
Tertiary	Tholeiite	Cleveland Dyke, Durham		28
Eocene	Basalt	Deccan, India		37
Late Cretaceous	Kimberlite	Transvaal		58
	Pitchblende	Colorado	60	
Late Jurassic	Ishikawaite	Japan	128	
Triassic	Dolerite	Connecticut		170
Early Permian	Pitchblende	Bavaria	205	
Close of Carboniferous	Dolerite	Whin Sill, Westmorland		196
Upper Devonian	Uraninite }	Portland,	283	
	Monazite }	Connecticut	278	
Late Ordovician	Uraninite	Fitchburg, Mass.	370	
	Cyrtolite	Bedford, N.Y.	380	
	Uraninite	Connecticut	380	
Upper Cambrian	Kolm	Sweden	455	
Late Pre-Cambrian	Basalt	Gwalior, India		500
	Basalt	Keweenawan, Lake Superior		580
	Pitchblende	Katanga	600	

The early applications of the helium method led to the conclusion that only minimum age determinations were possible on account of the leakage of helium from radioactive materials. Such loss is inevitable when the internal pressure of generated helium becomes high. In recent years, however, certain feebly radioactive substances, such as native metals and iron meteorites, have been found to retain helium completely, and fine-grained basaltic rocks also seem to be satisfactorily retentive. The technique for the determination of minute quantities of helium has been developed by Paneth to such a degree of precision that the amounts accumulated in iron meteorites and in basaltic rocks can now be accurately measured. In 1929 the writer pointed out that "since igneous rocks suitable for the helium method are far more abundant and far better distributed in time than are radioactive minerals suitable for the lead method, there is now available a practical means of effecting long-distance correlations and of building up a geological time scale which, checked by a few reliable lead-ratios here and there, should become far more detailed than could ever be realised by means of the lead method alone". In the accompanying table some of the results which have since been obtained by Paneth, Dubey and Urry are listed.

The oldest minerals so far reliably dated by the lead method are those of Manitoba, to which reference has already been made. A similar age of more than 1,700 million years has recently been found for zircons from a South Dakota granite, which itself is older than the South Dakota uraninite analysed by Davis (1,465 million years). At least one cycle of sedimentation preceded the intrusion of these oldest known granites of North America, and by analogy with other such cycles, this would seem to indicate that the age of the earth cannot be less than 1,900 million years. No approach to a closer estimate is practicable at present. It is not improbable that a maximum limit may be set by the age determinations of meteorites made by Paneth and his colleagues. The results range up to 2,800 million years, but while the origin of meteorites remains in doubt the significance of these figures remains speculative. It appears possible, however, that the earth, the solar system and the present organisation of the stellar universe may all be of the same order of age, namely, 2,000–3,000 million years.

To geologists, the exact age of the earth is of less importance than the application of age measurements to dating igneous rocks, correlating Pre-Cambrian formations in various parts of the world, and building up a reliable time-scale. With the aid of the latter it is becoming possible to estimate the rates at which various geological processes have operated in the past. It is already clear that, at least during the later part of geological time, there has been a remarkable acceleration of activity, and that during the Tertiary period, in particular, the earth was more vigorous in its behaviour than at any other time since the late Pre-Cambrian.

Atomic Physics

By THE RIGHT HON. LORD RUTHERFORD, O.M., F.R.S., Cavendish Professor of Physics, University of Cambridge

THE past twenty-five years has been a period of unexampled activity in physical science, and has witnessed a series of important discoveries which have widely extended our knowledge of the nature of the atoms and the interaction between matter and radiation. On looking back, we can see that the direction of advance was greatly influenced by three fundamental discoveries made at the end of last century—the discovery of X-rays, of radioactivity and of the electron. The proof of the wave-nature of the X-rays in 1913 led to the development of simple methods for studying the X-ray spectra of the elements, and thus gave us important information on the arrangement of the electrons deep in the atom and their frequency of vibration. The study of the radioactive bodies had disclosed that they were undergoing spontaneous transformation and gave us for the first time an idea of the enormous forces which must exist within the structure of the atom. Sir J. J. Thomson early recognised that the electron must be a fundamental constituent in the structure of all atoms, and had devised methods for estimating the number of electrons present in each atom.

The nuclear theory of the atoms, based on experimental evidence of the scattering of α-particles by matter, belongs to the beginning of the period under review. The proof by Moseley that the properties of an atom are defined, not by its atomic weight, but by its atomic or ordinal number, was an outstanding step in advance. It was shown that the atomic number was a measure of the number of units of resultant charge carried by the nucleus and also a measure of the number of electrons surrounding the nucleus. A relation of extraordinary simplicity was thus seen to connect all the elements—a relation which has governed all subsequent advances in our knowledge of the elements.

The proof that the chemical elements are complex and in general consist of a number of isotopes of different masses was an important advance. This conception, which we owe to Soddy, had its origin in the study of the chemical properties of the radioactive elements. In the nuclear theory, isotopes represent atoms of identical nuclear charge but different masses. They should have the same chemical properties, apart from mass, and almost identical spectra. Ashton showed in 1919 that the masses of the individual isotopes were nearly whole numbers in terms of O = 16. This whole number rule, while very convenient as a guide, is only approximate. The accurate determination of the masses of the isotopes is of first importance, for it serves in a sense as a measure of the energy stored up in the atom and thus enters into all calculations which have to do with the transmutation of atoms.

More than 250 species of atoms are now known, and even the lightest atom—hydrogen—has been shown in the last few years to consist of three isotopes of masses 1, 2 and 3. The isotope of mass 3 was first observed by Oliphant in transmutation experiments and has since been found to be present in ordinary hydrogen in about one part in a hundred million. The discovery of the isotope of mass 2, now called deuterium, by Urey, has had important consequences, since it can readily be separated in a nearly pure state, and made use of in many physical and chemical experiments.

This period has also seen the beginning and ultimate success of the application of quantum ideas to the explanation of the origin of the spectra of the elements, both X-ray and optical. This wonderful advance, which we owe largely to the work of Bohr, is one of the most spectacular triumphs of this age. Within less than a decade, the intricacies of the varied spectra of the elements were unravelled and explained along general lines. At the same time, there followed a complete understanding of the underlying meaning of the periodic table of the elements by taking into account the way in which electrons are grouped round a nucleus.

The application by Bohr of the quantum theory for the explanation of spectra was at first beset with many difficulties and ultimately led to the development of a new mechanics—the wave-mechanics—so closely associated with the names of de Broglie, Heisenberg, Schrödinger, Born and Dirac. This has proved successful in giving an explanation not only of the complexities of the spectra of the elements but also of many of the most recondite problems of atomic physics. It has been applied to account in a general way for certain radioactive relations like the Geiger-Nuttall rule, while Gamow has utilised the theory to account for the artificial transformation of elements by particles of very low speed which on classical mechanics had no possibility of entering a nucleus.

The essential correctness of the ideas underlying the wave-mechanics has been verified by the direct experiments of Davisson and Germer, G. P. Thomson and Stern, by observing the diffraction effects produced by electrons and atoms when they fall on a crystal.

It will be seen that the past twenty-five years has been mainly occupied in an intensive study of the properties and structure of the atoms of the elements. An enormous new territory of knowledge has been opened up and surveyed in detail. While the first idea of the quantum theory of radiation had been advanced by Planck in 1905 to account for the distribution of energy in the spectrum of a hot body, it was not until the period under review that the full significance and fruitfulness of the new conception was generally recognised. It was early applied by Einstein to explain the photo-electric effect and by Nernst and Debye to account for the variation of specific heat with temperature, but its full importance was not realised until Bohr's work on the origin of spectra. The interchange of energy between a quantum and an electron was made clear, while the interaction with an electron, which gives rise to scattering, was examined and explained by Compton on the quantum theory.

Another strange type of interaction between radiation and matter has recently been discovered. When a gamma-ray of high quantum energy interacts with the intense electric field near a nucleus, the energy of the gamma-ray may be transformed with the appearance of an electron pair—one positive and the other negative. Since the mass energy of the electron pair is about one million volts, this type of interaction only occurs when the quantum energy of the gamma ray exceeds this value. The passage of high-frequency radiation through matter of high atomic weight is one of the simplest ways of producing positive electrons for study in the laboratory.

Only brief reference can be made to two important problems which have occupied the attention of many investigators throughout the world during the last few years, namely, the cosmic rays and the transformation of matter. The existence of a very penetrating radiation in our atmosphere was first shown by Kolhörster, and the properties of this radiation have been examined by Millikan, Clay, A. H. Compton, Blackett and many others. When we consider the minuteness of the ionising effect of this radiation in an electroscope near the earth, much skill and technical ability have been required to make accurate observations often under difficult conditions. The investigations have been world-wide, and have involved measurements in deep water, on land and sea, on high mountains and at different heights in our atmosphere, extending far into the stratosphere.

It now seems likely that the main radiation consists of a stream of fast electrons, both positive and negative, possibly also protons with an admixture of high-frequency radiation. It is believed that some of the particles have energies so high as 10^9 volts and a few as high as 10^{10} volts —energies of a different order of magnitude from those to be expected from the transformation of atoms. Naturally there has been much speculation as to the origin and nature of this extraordinary radiation, which appears to come either from the confines of our atmosphere or from the depths of outer space. The conditions under which particles can reach such gigantic energies constitute one of the outstanding unsolved problems of physics.

While the natural transformation of the radioactive elements was made clear in 1903, the proof of the transmutation of many of the stable chemical elements by artificial methods belongs to the past quarter of a century. The study of these transformations has been very fruitful, leading to the discovery of three important entities in the structure of the atom—the proton, neutron and the positron, the counterpart of the negative electron of small mass.

In order to produce a veritable transformation of an element, it is necessary to change its nuclear charge or its mass or both together. The chief method employed for this purpose is to bombard the element under examination by fast particles like protons, neutrons or α-particles. Occasionally one out of a great number of these particles may happen to penetrate a nucleus and be captured by it. The resulting nucleus may be unstable and break up with explosive violence, hurling out a fast particle or particles, and sometimes emitting high-frequency radiation. The residual nucleus may be either a stable element or an unstable element which behaves like a radioactive body. The production of artificial radioactive bodies in this way by α-particle bombardment was recently observed by M. and Mme. Curie-Joliot.

The first successful experiment on transmutation was made in 1919 when nitrogen, bombarded by α-particles, was found to be transformed with the emission of fast protons. Rutherford and Chadwick found that about a dozen of the lighter elements suffered a similar type of transformation under the same conditions. In order to extend these observations, investigations were begun, often on a large scale, to produce intense streams of fast particles of different kinds to be used for bombarding purposes. Cockcroft and Walton first showed that marked transformations could be produced in the light elements lithium and boron when they were bombarded by streams of fast protons accelerated in a discharge tube. Lawrence, in California, used an ingenious method of obtaining fast particles by multiple acceleration in a magnetic field, and was able to obtain swift particles of energies as high as two million volts. He found that the ions of heavy hydrogen of mass 2 were even more effective than protons in producing new types of transformation in a number of elements. In some cases, neutrons as well as protons and α-particles appeared as a result of the transformations.

The discovery of the neutron by Chadwick has proved of great importance not only in simplifying our ideas of the structure of nuclei but also as an extraordinarily effective agent in bringing about the transformation of many elements, as was first shown by Feather and Harkins. Fermi and his co-workers, in Rome, made an important advance when they showed that neutrons could enter freely into the structure of even the heaviest nuclei, in many cases leading to the production of artificial radioactive bodies which broke up at a characteristic rate with the emission of fast negative electrons. More than fifty of these radioactive bodies are now known.

By these transformation methods, it has been found possible to build up heavier atoms from lighter, to break some atoms into fragments, and to produce radioactive isotopes in great numbers. New and unsuspected stable isotopes of the elements, like H^3, He^3 and Be^8, have been brought to light, and gamma-rays of much higher frequency than those from the natural radioactive bodies have been observed.

The rapid advance of our knowledge of nuclear transformations has been in no small part due to the development of new technical methods of attack; for example, the automatic method of counting α-particles and protons devised by Wynn Williams, the Geiger-Müller tube for recording positive and negative electrons, and that wonderful instrument, the cloud chamber, devised by C. T. R. Wilson. The development of fast diffusion pumps by Gaede has made possible the rapid production of high vacua and the application of high potentials to discharge tubes.

Our ideas of the structure of atomic nuclei are still in a very tentative state, but it is generally believed that the proton and neutron are the primary building units. The exact relation, if any, between the proton and neutron is still uncertain. Some believe they are mutually convertible in a nucleus by the gain or loss of an electron, and that even negatively charged protons may be formed. Much more information is required before we can hope to reach a satisfactory explanation of nuclear structure, and any detailed theory applicable to the nucleus is probably far distant.

Isotopes

By DR. F. W. ASTON, F.R.S., Trinity College, Cambridge

THE subject of isotopes is particularly suitable for inclusion in this special issue of NATURE, for it is just twenty-five years since Soddy published the first valid proof of their existence. The earlier speculations of Crookes and others had been found to rest on unsound observations. Discussing apparent chemical identities among the products of radioactivity, Soddy said : "Chemical homogeneity is no longer a guarantee that any supposed element is not a mixture of several of different atomic weights, or that any atomic weight is not merely a mean number". The basis of his evidence was the law connecting radioactivity and chemical change, in the discovery and enunciation of which he played so prominent a part. This law asserts that a radioactive element when it loses an α-particle goes back two places in the periodic table ; when it loses a β-particle it goes forward one place. It follows that by the loss of one α-particle followed by two β-particles, the atom, though weighing four units less, will have regained its nuclear charge and returned to its original place.

Such changes result in bodies to which Soddy applied the following words : "The same algebraic sum of the positive and negative charges in the nucleus when the arithmetical sum is different gives what I call 'isotopes' or 'isotopic elements' because they occupy the same place in the periodic table. They are chemically identical, and save only as regards the relatively few physical properties which depend upon atomic mass directly, physically identical also". Since the radioactive disintegration of uranium should result in lead of atomic weight 206, and that of thorium in lead of atomic weight 208, Soddy maintained that the lead found in uranium minerals should be lighter and that in thorium minerals heavier than ordinary lead, of atomic weight 207·2.

The idea that ordinary elements could consist of atoms of different mass received great opposition, for it appeared quite incompatible with such facts as the constancy of chemical atomic weight, the apparently perfect homogeneity of elementary gases, and the almost incredible invariability of such accurately measurable constants as the electrical conductivity of mercury independent of its source. Nor was it at first supported by the only available method of comparing the weights of individual atoms, Sir J. J. Thomson's parabola analysis of positive rays, which was then being perfected, for such elements as hydrogen, carbon, nitrogen and oxygen gave only single parabolas. Neon, on the other hand, gave two parabolas, the one expected at 20 and a second fainter one at 22. Experimental evidence indicating partial separation of the hypothetical constituents of this element by diffusion was obtained in 1913, and when the War stopped work, there were several lines of reasoning suggesting that it consisted of isotopes, but none of these was sufficiently strong to carry conviction.

During the War, Soddy's prediction concerning the atomic weights of leads from uranium and thorium minerals had been triumphantly vindicated by some of his most severe critics, the experts in chemical atomic weights, and it was realised that the most satisfactory proof of the isotopic nature of neon could be obtained by much more accurate analysis of its positive rays. An instrument using a focusing device capable of a resolution of 1 in 130 and an accuracy of 1 in 1,000 was set up in 1919 by the writer and called a 'mass-spectrograph', a term which has now been extended to all devices capable of analysing mass-rays. This instrument not only proved that neon was a mixture of atoms having weights, or mass numbers, 20 and 22, but also that chlorine consisted similarly of isotopes 35 and 37, and indeed that the majority of all elements were complex. Thus krypton, the first element shown to be multiple, had six isotopes, 78, 80, 82, 83, 84, 86. Of the greatest theoretical importance was the fact that the weights of the atoms of all the elements measured, with the exception of hydrogen, were whole numbers to the accuracy of measurement. This 'whole number rule' enabled the simple view to be taken that atoms were built of two units, protons and electrons, all the former and about half of the latter being bound together to form the nucleus.

The analysis of the elements advanced rapidly, Dempster in America discovering the isotopes of magnesium, calcium and zinc by means of an instrument of his own design having magnetic focusing. By 1925, when the first mass-spectrograph was dismantled to be replaced by a more powerful one, information on the isotopic constitution of more than half the elements had been obtained. The new instrument was designed primarily for measuring the minute variations of the masses of atoms from the whole number rule, and had a resolving power ample for the heaviest elements. By its means the search for isotopes has been carried on until a few months ago.

The difficulty of obtaining the necessary rays for analysis varies enormously from element to element. Two main devices are employed: the ordinary gas discharge which requires the element to be volatile or form suitable stable volatile compounds; and the anode ray discharge, in which the halide or other compound of the element is treated as the anode in a discharge at low pressure. The inert gases are particularly suitable to the first method, the alkali metals to the second, other groups of elements being intermediate. The largest group recently investigated was that of the rare earths. These yielded to anode ray methods, and during the work some thirty new isotopes were discovered.

From the point of view of the identification of the more abundant isotopes, our knowledge is nearly complete. Of the more common elements all but four—palladium, iridium, platinum and gold—have yielded definite information on their isotopic constitution. The resistance of these four is due to their chemical properties, which make the production of their rays peculiarly difficult. In all, some 247 stable isotopes are now known, of which seven were discovered by observations on optical spectra, and have since been confirmed by the mass-spectrograph. This large assembly shows many empirical laws, of which perhaps the most remarkable is that no odd numbered element, with the possible extremely rare exception H^3, has more than two isotopes. Even elements are not so limited. The most complex element so far observed is tin, with eleven isotopes ranging in mass number from 112 to 124. One of the most astonishing results is that, for practically every natural number up to 210, a stable elementary atom is known, many are filled twice over and a few three times with 'isobares', that is, atoms of the same weight but different chemical properties. Schemes of tabulation of all the known species have led to the prediction of isotopes and to theories of nuclear structure to account for their occurrence.

Instead of the original view that the nuclei of atoms consisted of protons and electrons, it is now considered more likely that they are built of protons and neutrons. In either case the binding forces holding the particles together must represent loss of energy, that is, loss of mass. Hence it is that the atom of hydrogen has abnormally high mass, and that the accurate determinations of divergences from the whole number rule are of such profound theoretical importance. As has been stated, my second mass-spectrograph was designed for this and found capable of an accuracy in favourable cases of 1 in 10,000. The atom of oxygen, 16, was chosen as standard and the percentage divergencies called 'packing fractions', were determined for a large number of elements. These when plotted against mass number were found to fall roughly on a hyperbolic curve. Our knowledge in this field has been notably increased by the brilliant work of Bainbridge, who, by means of a powerful mass-spectrograph of original design set up at Swarthmore, discovered new isotopes of tellurium, rectified results on zinc and germanium and made many of the most accurate comparisons of mass so far known.

The relative abundance of the isotopes of an element can be measured in several ways, the most general being by photometry of mass spectra. From this and the masses of the isotopes it is easy to calculate the mean atomic weight. This with proper corrections can be used to check the chemical atomic weight. During the past six years, nearly every atomic weight has been determined by this purely physical method, which has the great advantage of being, in general, independent of purity and requiring an almost infinitesimal quantity of material.

The masses of the atoms H^1, C^{12}, N^{14} and O^{16} as determined by the second mass-spectrograph and published in 1927 agreed to 1 part in 10,000 with the accepted chemical atomic weights of these elements, but shortly after, observations on band spectra made by Giauque and Johnson showed the presence of heavier isotopes 17 and 18 in oxygen. Their abundance determined by Mecke was such that the chemical unit of atomic weight O was about 2×10^{-4} greater than the physical one, O^{16}. Carbon and nitrogen were found later to possess heavier isotopes, and Birge pointed out that to satisfy the values hydrogen must have them also. Urey took up the problem and, happily unaware of the real uncertainty in the figures concerned, with the collaboration of Brickwedde and Murphy fractionated liquid hydrogen and proved by examination of the Balmer lines that H^2 was present. Washburn showed that its heavier atoms could be concentrated by electrolysis of water. This method was developed so rapidly and brilliantly by Lewis that, soon after its discovery, pure 'heavy water' had been obtained in appreciable quantity.

The isotope of hydrogen of mass 2 cannot be treated as a normal isotope. Its exceptional difference in mass enables it to be separated with comparative ease in a pure state. It has been given the name deuterium, symbol D, and heavy water (D_2O) is now obtainable in quantity at reasonable prices, one of the most surprising and interesting reagents in the whole history of science.

Induced Radioactivity

By DR. C. D. ELLIS, F.R.S., Lecturer in Physics, University of Cambridge

IT is just over a year since M. and Mme. Curie-Joliot announced that they had succeeded in producing radioactive atoms of low atomic number. In their first experiments they discovered that, when aluminium was bombarded by α-particles, a radioactive isotope of phosphorus was produced according to the reaction :

$$_{13}Al^{27} + {_2}He^4 \rightarrow {_{15}}P^{30} + {_0}n^1.$$

The behaviour of this radio-phosphorus was quite analogous to that of the naturally occurring radioactive elements, except that instead of β-rays, that is negative electrons, positrons were emitted, resulting in the formation of a known stable isotope of silicon :

$$_{15}P^{30} \rightarrow {_{14}}Si^{30} + \overset{+}{\varepsilon}.$$

The half period of the radioactive decay was about 3·2 minutes.

Similar results were found to occur using boron or magnesium instead of aluminium. With the ordinarily available α-particle sources, the amounts of these radioactive bodies that are produced is extremely small. Even if all the α-particles emitted from the source are arranged to hit the aluminium, the resulting radioactive phosphorus will have only about one millionth to one ten-millionth of the activity of the source. These small intensities are responsible for the main difficulties in the experiments, which would be impossible but for the delicate counting devices devised by Geiger.

Since the initial discovery of the Joliots, other methods, as suggested in fact by them, of forming radioactive elements have been discovered. Protons, deuterons and neutrons have all been found to lead to nuclear reactions which produce radioactive products. This is not the occasion to give a list of all the new radioactive isotopes that have been discovered. It will suffice to say that more than fifty have already been identified. One important aspect of this may be noted. Aston's work in furnishing a list of all the stable isotopes at least made possible speculations about the structure of nuclei—why certain combinations of protons and neutrons did occur and others did not. His later and more delicate work on the exact masses of the isotopes gave information about the energy of binding of these nuclei and provided a basis for quantitative theories. Now, directly following from the Joliots' discovery, this field is suddenly enriched by a large number of new nuclei about which, by appropriate experiments, we may reasonably hope to obtain similar information. Above all, this discovery must be considered as a remarkable extension of the possibilities of our knowledge.

It is interesting to consider the relation of these new radioactive isotopes to the already known stable isotopes. It is clear that certain combinations of protons and neutrons can form permanent nuclei. The criterion of this permanency lies in the fundamental laws of interaction of proton and neutron, but the question whether a given nucleus is absolutely permanent or radioactive is connected with what might be termed the possibility of existence of neighbouring nuclei. Whether a given nucleus A is stable or radioactive depends, so far as our present knowledge goes, simply on the question whether the reaction $A \rightarrow B + C$ is endothermic or exothermic, B and C being other possible nuclei. In practice, the only reasonable possibilities for C are proton, neutron, α-particle, electron or positron. In the natural radioactive elements, C is either an α-particle or an electron ; in the newly discovered radioactive elements, C is either an electron or a positron. As yet, no case is known of induced radioactivity with emission of a heavy particle.

In a general way, it is easy to see the factors which determine whether positrons or electrons are emitted. Assuming that nuclei are built up of combinations of protons and neutrons, an examination of the list of the known stable isotopes shows clearly that permanently stable nuclei are only formed when the ratio of the number of neutrons to protons lies within a narrow range. Isotopes with either a smaller or greater neutron/proton ratio do not occur naturally. Now the addition of an α-particle (two neutrons + two protons) and the emission of a neutron is, in effect, an addition of one neutron and two protons, and means, therefore, a lowering of the neutron/proton ratio. If this ratio for the new element lies outside the stability range, the element will be radioactive, and the change will clearly be in the direction of raising the neutron/proton ratio. This can be effected by the switch of a proton into a neutron with emission of a positron. On the other hand, if the initial absorption of an α-particle causes the emission of a proton, the situation is exactly reversed and a radioactive element so formed will emit negative electrons accompanied by a nuclear switch of a neutron into a proton. As an example of this latter process we may take magnesium bombarded by α-particles Magnesium has three stable isotopes and one of them undergoes the following reaction :

$$_{12}Mg^{25} + {}_{2}He^{4} \rightarrow {}_{13}Al^{28} + {}_{1}H^{1}.$$

The aluminium isotope so formed is radioactive with a period of two and three quarter minutes, with emission of negative electrons.

The use of protons and deuterons to cause nuclear reactions leading to radioactive products has already been referred to but is of especial interest, since the intensity of the bombarding beams is here under control, and by sufficient technical application can be largely increased. Already Lawrence has produced a radioactive body in amounts comparable with that of the naturally occurring radioactive substances. A particularly interesting example is that of sodium bombarded by deuterons, when the following reaction occurs :

$$_{11}Na^{23} + {}_{1}D^{2} \rightarrow {}_{11}Na^{24} + {}_{1}H^{1}.$$

This new isotope of sodium disintegrates under emission of β-particles with a period of fifteen and a half hours. The β-particles are not particularly energetic, having an upper limit of energy of only about one million volts, but an intense high-frequency γ-radiation of about five and a half million volts is also emitted. Using 1 microampere of 1·7 million volt deuterons for one hour gave already a two hundredth of a millicurie of radioactive material. This is an amount the effects of which can be detected by ordinary ionisation methods, and there is every reason to believe that it will be possible soon to increase the yield very greatly.

A great number of interesting investigations will be rendered feasible when it is possible to obtain in quantity a radioactive body such as this with a conveniently long period and emitting such high-frequency γ-radiation.

The most striking results, from the point of view of the number of new radioactive elements produced, have been obtained by Fermi, using neutrons as bombarding particles. The neutrons for these experiments are obtained by allowing α-particles to fall on beryllium, in practice by filling a small tube with beryllium and a certain quantity of radon. The number of neutrons is only about one hundred thousandth of the number of α-particles emitted by the source, but their efficiency in producing nuclear reactions is much greater. In fact, a large percentage of the neutrons which hit the nucleus produce an active atom. These experiments have also a far greater range than those using α-particles or protons, since the absence of charge on the neutron removes any distinction between light and heavy elements. The new radioactive isotopes formed in this way are spread fairly uniformly throughout the periodic table ; for example, active bodies are formed from fluorine and magnesium, and also from thorium and uranium. In general, for light elements the process of activation consists in the capture of the neutron and simultaneous emission of an α-particle or proton. The resulting nucleus has then a higher neutron/proton ratio than corresponds to stability, and the necessary balance is re-established by the radioactive change of a neutron into a proton inside the nucleus with emission of an electron. For elements of higher atomic number, the chance of the initial ejection of a positively charged α-particle or proton is diminished by the stronger attractive field of the nucleus, and the initial process is more likely then to be just a simple capture of the neutron, again leading to an active nucleus with too high a neutron/proton ratio.

There are several points about the processes involved in the direct capture of a neutron which are not at present easy to understand, but it is plausible that the probability of capture should increase as the energy of the neutron is decreased. Fermi has in fact shown that the efficiency of production of some radioactive elements may be increased ten to one hundred times by surrounding the source and target by paraffin or water during bombardment. The primary neutrons emitted from the source are slowed down by elastic collisions with the hydrogen nuclei, and in this state are more easily captured by the nuclei of the bombarded substance.

Finally, as an example of the flexibility of these methods of producing new nuclei, we may consider the formation of a certain radioactive isotope of aluminium, $_{13}Al^{28}$. This can be formed now in no less than five distinct ways, starting from different substances and using different bombarding particles.

Neutrons fired on to either aluminium, silicon, or phosphorus form this body according to the schemes :

$$_{13}Al^{27} + {}_{0}n^{1} \rightarrow {}_{13}Al^{28}.$$
$$_{14}Si^{28} + {}_{0}n^{1} \rightarrow {}_{13}Al^{28} + {}_{1}H^{1}.$$
$$_{15}P^{31} + {}_{0}n^{1} \rightarrow {}_{13}Al^{28} + {}_{2}He^{4}.$$

One can also use deuterons on aluminium or α-particles on magnesium, the latter reaction having already been mentioned in another connexion :

$$_{13}Al^{27} + {}_{1}D^{2} \rightarrow {}_{13}Al^{28} + {}_{1}H^{1}.$$
$$_{12}Mg^{25} + {}_{2}He^{4} \rightarrow {}_{13}Al^{28} + {}_{1}H^{1}.$$

In every case the same final product is obtained, which emits β-particles to form $_{14}Si^{28}$ and has a period of about two and three quarter minutes.

X-Ray Crystal Analysis

By SIR WILLIAM BRAGG, O.M., F.R.S., Fullerian Professor of Chemistry, Royal Institution, and Director of The Davy-Faraday Research Laboratory

THE development of the analysis of crystal structures by means of X-rays has fallen entirely within the period which the citizens of the British Commonwealth are now reviewing. Soon after the beginning of the present reign, a group of German scientific workers made the primary and fundamental discovery. But although the first step was taken abroad, the immediate and consequent advances were made in England; and throughout the whole twenty-five years British workers have taken a full share in the development of a subject which has now grown to extraordinary magnitude. The story of it falls happily, therefore, on the ears of those who now celebrate the King's Jubilee and consider the advances in knowledge which have been made during his reign.

The first experiments were made in Munich in 1912 and have been described in a fascinating manner by Friedrich, who helped to conduct them; his account is to be found in *Die Naturwissenschaftzn* for April 22, 1922. As has been pointed out by W. L. Bragg ("The Crystalline State", p. 271) the conditions in Munich at that time were peculiarly favourable to the event which gave rise to a new branch of science. Laue, a great mathematician, was profoundly interested in interference phenomena, and Sommerfeld, a great mathematical physicist, in the nature of X-rays and their excitation by the stopping of cathode rays, while Groth was the world's most famous authority on crystallography. The actual incident which precipitated the discovery was a doctor's dissertation by Ewald, who at that time had undertaken, under Sommerfeld's guidance, the study of the passage of light waves through a crystal, considered as a regular arrangement of scattering atoms. When discussing Ewald's problem, Laue was led to ask what would happen if the waves were so short that the wave-length was less than the interatomic distances in the crystal. He realised that spectra should be formed and that waves so short as to be diffracted in this way would be X-rays. An informal discussion on the possibility of observing this phenomenon took place after one of the colloquium meetings and Friedrich, who was then Sommerfeld's assistant, volunteered to carry out some experiments. Success came after several failures. Friedrich gives a vivid picture of his feelings when he saw the diffraction picture in the developing dish.

At that time the writer of this review was contending strongly that the X-rays must be regarded as corpuscular, if their general behaviour, and in particular their relations to cathode rays, were to be explained systematically. It did not occur to him at that time that undulatory and corpuscular theories could be held and worked simultaneously. Consequently, the new experiment seemed to be fatal to his views. It is now understood, of course, that the two theories must go in double harness, even if they do not always seem to pull together.

Naturally perturbed at the apparent contradiction, the writer suggested to his son, who had just completed his course at the University of Cambridge and was looking for a problem to attack, that he should study the new experiment and see if any reconciliation could be found. The conclusion that Laue was essentially correct was soon found to be inevitable. At the same time, it appeared to the young worker that Laue's explanation of the details of his zinc blende photographs was unnecessarily complicated. He found it simpler to approach the problem with the idea that electromagnetic pulses, equivalent to 'white light' in the X-ray region, were reflected from the crystal planes. This was suggested by the behaviour of the spots in the photograph when the crystal was tilted and by their shape. He was then able to draw certain conclusions as to the structure of zinc blende. This result was published in November 1912. The Laue photographs of sodium chloride and potassium chloride were found to be even simpler than that of zinc blende, so that all the details of their structures could be found. These two were the first crystals to be analysed.

Meanwhile, the writer at Leeds, and Moseley and Darwin at Manchester, examined the reflected beams of X-rays, using ionisation chamber and absorbing screens, and found that they had all the characteristic properties of the incident beam. From these researches came the X-ray ionisation spectrometer, which showed not only the 'white' radiation reflected over a wide range of angle but also the peaks of the characteristic line spectrum of the material of the target in the X-ray tube.

The discovery of the line spectrum had two results. In the first place, it made crystal analysis enormously more powerful. Several fairly simple structures were quickly solved by its means, such as zinc sulphide, iron pyrites, fluorspar and calcite. In the second place, the high-frequency spectra of the elements could be measured accurately. This led to the brilliant and well-known generalisation of Moseley who, by using an extended range of anticathodes, was able to formulate the laws relating frequency to atomic number. Moseley's death at Gallipoli in 1915 was a sad blow to the development of a new science.

The outbreak of War in 1914 put an end to most of the researches in crystal analysis then proceeding. In the two short years great progress had, however, been made. The determination of crystal structure had begun. The ionic, or heteropolar, character of many crystals had been discovered. It is to be observed that in some of these early determinations the X-rays were called on for nothing more than a simple and ready decision between structures already suggested by other considerations. But the decision was final and very helpful. The measurements of the intensities of the rays reflected from the various crystal planes had not yet come to play the important part that it does to-day. The measurements were used to determine the geometrical quantities of the crystal, the size of the unit cell and a few important data as to the relative positions of the elements in it. Intensities were measured in certain cases, but no great accuracy was required. Indeed, the technique was barely able to supply it. Moreover, there was the difficult question of the interpretation of the meaning of intensity measurements. Darwin had, indeed, covered almost the whole ground of the theory of X-ray reflection. He distinguished between the perfect crystal, which is indeed a rarity, and the so-called 'mosaic crystal', which consists of an assemblage of small and more perfect crystallites, mutually aligned with greater or less accuracy. But his results were not put to their full use.

In some of the neutral countries work was carried on, and important results were obtained. In Sweden, Siegbahn developed a fine school devoted to spectrum measurements in which extraordinary accuracy was obtained. In Switzerland, Debye devised the 'powder' method which could be applied to the analysis of materials so finely subdivided that the crystalline character could not be observed even with the aid of the microscope. The crystalline character of colloidal suspensions, for example of gold, was a discovery of great interest. In America, Hull made use, independently, of the same method. The consequence of this advance was the inclusion of a vast number of substances, hitherto not recognised as crystalline, within the range of the X-ray analysis.

As soon as the laboratories could settle down to work again, after the War was over, the new subject was energetically studied all over the world and progress was rapid. It was natural that in the first place efforts should be devoted to the task of shaping a new crystallography. The old had been founded almost entirely upon the external characteristics of crystals ; the new gave insight into the body of the crystal and was obviously much more fundamental. The discoveries that had already been made gave promise of various useful generalisations, and these called for careful examination. Three main types of structure were to be recognised. They may be illustrated from the work done before the War. There was the heteropolar type represented by rocksalt, in which ions were arranged so that each ion of one sign was surrounded by a certain number of ions of the contrary sign, all equally related to it. There was the homopolar type represented by diamond, in which the atoms were held together by the valency bonds of the chemist, now called co-valent bonds. In the diamond and other structures such bonds linked the crystal together into one whole. We know now that in most organic crystals only the atoms of each molecule are so linked together, the ties between molecule and molecule being the comparatively weak forces of Van der Waals. Lastly, there were the metals such as, for example, aluminium, in which the atoms were held together by what may be termed an electronic cement.

In all these types one common and most important feature at once emerged. The atoms or ions retained their characteristic dimensions in whatever structure they were embodied. The first tables of atomic or ionic radii were drawn up by W. L. Bragg, and in Finland by Wasastjerna. On these considerations Goldschmidt and his assistants reared a 'geochemistry' which showed how largely the various forms of crystal structure were governed by rules of geometry. To Niggli we owe the idea of a systematic deduction of the 'space-group' by means of X-ray data.

The most important constituents of the earth's crust are the silicates. Their immense variety of structure and chemical constitution had long presented an analytical problem which seemed to be insoluble by the older methods. W. L. Bragg and his colleagues at Manchester have been successful in resolving their complications. The oxygen atoms, it seems, play a leading part in the structure. They form the bricks, laid as regularly as possible ; while the other constituent atoms, used somewhat indiscriminately, bind the whole together. In the course of this work it has been necessary to measure the intensities of the reflections from the various crystal planes, determining their values relative to the primary rays. The electron distributions within the atoms also required evaluation, for which the theoretical work of Hartree and the experimental work of James and others proved invaluable. Also, at the University of Manchester a study of alloys has been very successful, Bradley's determinations of γ-brass and α-manganese leading the way. At the present moment this branch of the subject is developing rapidly; by its means new insight is being gained into many metallurgical problems. To the study of alloys, Westgren in Sweden contributed much pioneering work. Another outstanding contribution has been Hume-Rothery's theory that the electron-atom ratio is a major factor in determining the type of an alloy structure.

Crystals composed of the complicated molecules of organic substances require special treatment if complete solutions are aimed at. It can be shown that every reflection which a crystal yields implies a harmonic variation of electron density, the magnitude of which corresponds to the intensity of the reflection. By measuring the absolute intensities of one or two hundred reflections, and summing up the implied harmonic variations in the manner of a Fourier series, a picture of the distribution of electron density is obtained. The result is usually displayed in the form of a contour map, showing the densities projected upon some principal plane. The atoms are clearly outlined and their positions can usually be determined with great accuracy. Very interesting determinations have been made in this way by J. M. Robertson, Iball, Miss Knaggs in the Davy-Faraday Laboratory, by Wyckoff in America and others. Here again there emerges a remarkable constancy in the distances between atomic centres: given a pair of atoms and the character of the bond, single, double or treble, the distance that separates them seems to be always the same, in whatever structure they enter. In this case there is an added constancy in the orientations of the bonds in general: though in special circumstances variations may be forced upon them.

One of the most remarkable of the organic substances is the carbon chain which is the essential part of the paraffins, fatty acids, alcohols and the like. Its complete elucidation is due to Müller, Shearer and Piper in Great Britain, to M. de Broglie, Friedel and Trillat in France, and to others. The frequency with which the long chain appears in the construction of Nature is extraordinary and suggestive. It may be all of carbon, as in the cases just quoted: or it may include nitrogen as in the proteins, or as in cellulose it may consist of a series of linked rings each formed of carbon and oxygen.

Some of the most remarkable investigations in organic substances have been made by Bernal, his subject being the vitamins and other biological structures. In this way the X-ray analysis is now contributing to biology.

No one expected, when the new study began, that such a complicated substance as cellulose would have yielded to treatment: but Mark, and Polanyi in Germany, and many others have found it possible to gain much useful information from the X-ray photographs, ill-defined as they are in comparison with those of crystals that can be recognised as such. This work was, of course, inspired by the great importance of cellulose in many industries. Later, Astbury, at Leeds, was able to solve the curious problem of the extensibility of keratin and other proteins. He was able to show, for example, why wool is elastic and silk is not, basing his explanation on the determination of their fundamental structure. Recently he has explained in the same way the extensibility of nerve and muscle.

Naturally the determination of crystal structure has given a great opportunity to the mathematical physicist to formulate the laws which govern it, and to trace their actions. The new system of wave-mechanics introduced by de Broglie and Schrödinger has been brought to bear, and much interesting work has already been done. To this Born, Hund, Hückel in Germany, Hartree, Fowler, Lennard-Jones in England, Compton, Pauling and Slater in America, and many others in all parts of the world have made contribution.

Lastly, a word must be said in respect to the technical applications of X-ray analysis. These have been many and varied. A section of the staff of the National Physical Laboratory under Shearer has been engaged in the study of various problems submitted by industry. A vast amount of research has been carried out in various places on the deformation of metal crystals, and the alterations in structure and properties due to cold-working. In this Polanyi has been the pioneer. In England, G. I. Taylor has been a chief contributor, while Gough at the National Physical Laboratory has concerned himself chiefly with the special question of the nature of metal fatigue.

This short sketch does but touch on a few of the principal matters that have formed part of the development of a subject now grown to very large dimensions; and it has only been possible to refer by name to a few of the many who have contributed thereto.

Low Temperature Research: Methods and Results

By PROF. F. A. LINDEMANN, F.R.S., Professor of Experimental Philosophy, University of Oxford

FEW branches of scientific research have developed more rapidly in the course of the last quarter of a century than the investigation of the properties of matter at low temperatures. Twenty-five years ago such problems seemed of comparatively slight fundamental interest. One knew, of course, that the electrical conductivity of metals increased with falling temperature. Dewar had shown that the specific heats of solids diminished somewhat. But no striking new phenomena were expected, and no exciting theoretical developments appeared likely to arise from research in these regions. Low-temperature work had gone out of fashion. In Leyden alone, in the magnificently equipped laboratory of Kamerlingh Onnes, a series of elaborate and most accurate measurements of all sorts of properties of a series of substances attested that interest in this branch of knowledge was not extinct.

As so often happens, it was from quite an unexpected quarter that interest in the subject was revivified. In 1905 Nernst had enunciated his famous third law of thermodynamics, according to which, in any thermodynamic process, at the absolute zero the rate of change of affinity with temperature equals the rate of change of the heat content. To test this, the atomic heats near the absolute zero had to be ascertained, and to this end, with characteristic energy, Nernst turned over his Berlin laboratory to low temperature research. It very soon emerged, somewhat unexpectedly, that at low temperatures the atomic heats of all solids seemed to tend to zero. The kinetic implications of this discovery were far-reaching.

Already in the year 1900 Planck had enunciated his famous law of complete radiation. In order to derive this, it had been necessary to assume that linear oscillators obeying Maxwell's equations could only absorb or emit radiation in quanta the energy of which was proportional to their frequency. But since it followed from Kirchhoff's law that the same law of radiation must emerge whatever the radiating entities, nobody had felt constrained to attach great importance to Planck's revolutionary presupposition. True, linear oscillators on his premises would lead to a law agreeable to experiment, but then no one really believed that the radiation from a hot body was due to linear Hertzian oscillators. Thus Planck's epoch-making assumption was treated with the comfortable indifference with which one slurs over the details of processes introduced in so many imaginary thermodynamic cycles.

Even when Einstein pointed out in 1907 that the variation with the temperature of the specific heat of the diamond could be accounted for by applying Planck's premise to the atoms, it aroused little interest. For the diamond had long been known to form an exception to Dulong and Petit's law, and one was accustomed to attribute the anomaly to polymerisation or some similar question-begging explanation.

When it appeared that not only the atomic heat of the diamond, but also that of all solids, diminished at low temperatures, the matter took on a new complexion; and after it had been shown that the atomic heats of all simple substances when plotted against the temperature could be represented by the same formula, containing only one parameter characteristic of the substance, it became clear that, far from being a special assumption introduced in an imaginary case—unimportant, since any permissible imaginary process must lead to the right result—Planck's premise was a very vital physical fact.

If actual atoms in a space-lattice held in position by their mutual attractions and repulsions could only take up or lose energy in quanta proportional to their frequency, then there must be something radically wrong with the whole basis of classical dynamics. The atomic heat measurements at low temperatures seemed to prove the major premise; and though we have now learnt to express it in the form that there are only a finite number of distinguishable states within a given energy range for the atoms in a crystal, the minor premise has finally won general acceptance. Differences may still exist as to the best way of introducing the quantum hypothesis. Nobody would to-day deny that some definite break with the classical point of view was inevitable.

Until 1933 the methods used for producing low temperatures were the same in principle as were used by Dewar, Linde and Hampson, and indeed by Cailletet and Pictet. The obvious way to cool a substance is to place it in thermal contact with a substance colder than itself. Any substance will do, and it is clear that, in the first stages at any rate, a gas will be the easiest to cool; for to reduce the temperature we must slow up the motion of the molecules. There are two simple ways of doing this. The first is to let them collide with particles moving away from them. If a gas molecule is reflected from a fixed surface at the same temperature as the gas, its velocity on the average will be as great after the collision as before. But if the surface is not fixed but receding, the effective relative speed at the moment of collision will be reduced. Hence if gas molecules, instead of being enclosed in a vessel with fixed walls, are reflected from, say, a receding piston, their velocity will be lowered and the temperature of the gas will fall. This is what happens when the temperature is reduced by the conversion of heat into external work. The second method to cool a gas is to allow it to expand, that is, allow the molecules to recede from one another. If they naturally attract one another appreciably, this mutual attraction will tend to reduce their speed as they move apart, in other words, to reduce the temperature. This is the so-called Joule-Thomson effect which has been largely used in liquefying gases.

A liquid gas produced by either of these methods, or a combination of the two, can be further cooled by pumping off the gas above the liquid. This causes more molecules to escape than return, and thus by doing work against the mutual attraction, as in the Joule-Thomson effect, tends to cool the liquid. A limit is set to this method of cooling, of course, by the fact that the vapour pressure diminishes exponentially with falling temperature. When the number of molecules which evaporate in unit time is so small that their latent heat just balances the inflow of heat due to imperfect insulation, no further reduction of temperature can be achieved. By these means, using liquid helium and a battery of the most efficient pumps obtainable, a temperature of 0·7° was reached at Leyden by Keesom.

A totally different method, however, originally suggested by Debye and Giauque, has brought quite a new temperature region within our reach. The entropy of a substance is a measure of its state of disorder. A set of molecules at rest in an accurate space-lattice would be in a state of complete order, that is, their entropy would be zero. As soon as their positions or motions vary, the entropy increases. Now paramagnetic salts contain atoms which behave like small magnets. Obviously, if their axes are all aligned parallel to one another, their positional state of order will be greater than when they are oriented at random. If we apply an external magnetic field, the axes of the magnetic atoms will all set themselves parallel to the lines of force. The entropy due to their positional disorder will therefore decrease; hence if the substance is thermally insulated, the entropy due to their thermal motion must increase; in other words, heat will be developed. Now if this heat is carried away, for example, by placing the substance in contact with liquid helium, and the substance is again thermally insulated, it is clear that one can cool the substance by reversing the process. For when the external field is removed the axes of the atomic magnets will tend, under the influence of thermal agitation, to resume their natural disordered condition, the positional entropy will increase at the expense of the entropy of agitation and the temperature must fall.

This effect was utilised by Giauque in California and by de Haas and Wiersma in Leyden in 1933 and by Kürti and Simon in Oxford in 1934 to cool substances to extremely low temperatures. Experiments in the region between 0·03° and 1° can be carried out without difficulty, and at Leyden, where a very strong magnet is available, a temperature of 0·005° has actually been reached. A great deal of work will have to be done before this method is fully exploited, as for each temperature range a suitable paramagnetic salt is required, but there is little doubt that by employing it in cascade or otherwise, extremely low temperatures will be as readily accessible to research as were temperatures a thousand times higher twenty-five years ago.

The measurement of these low temperatures naturally presents quite a new set of problems. Down to 1°, of course an ordinary helium gas thermometer can be used; further, since all its constants are known, one can calculate the vapour pressure of helium and utilise this as a measure of the temperature down to 0·7° or even 0·5°. But at 0·1° the vapour pressure of helium is 10^{-30} mm. and at 0·03° it is 10^{-102} mm. of mercury. Quite different methods must therefore be employed to measure such temperatures.

Fortunately, one such method is ready to hand. The magnetic susceptibility of a paramagnetic salt is a measure of the ease with which the magnetic atoms can be oriented. The smaller the thermal agitation the more readily will they be directed by an external field. Thus, roughly speaking, the susceptibility will be inversely proportional to the temperature. Obviously this rule is no more than a first approximation. Accurate thermometry will only be possible when the susceptibility curve has been linked up to the gas thermometer curve by means of proper thermodynamic cycles, a research now in hand at Oxford. Once this has been done, these susceptibility measurements will form a very convenient form of thermometry enabling an accuracy of 10^{-5} degrees or even better to be achieved.

Most of the phenomena at low temperatures have fallen into line with the predictions or at any rate the explanations of the quantum dynamics. The atomic heats of simple substances agree as well as can be expected with the theoretical expressions, especially when one remembers the difficulty of working out and weighting all the modes of oscillation of a space-lattice of atoms or even complicated molecules. The atomic frequencies calculated from elastic constants agree with those derived from the atomic heat curves; even the fine structure in the spectral lines due to nuclear spin is mirrored in anomalies in the specific heats at the calculated temperatures. Quantum considerations, as Simon showed, enable one to understand the curious fact that helium remains liquid, in the sense that it has a very low viscosity, down to the lowest temperatures, though there is a point at which a certain order tends to be established. For with liquid helium the zero point energy is so great that at atmospheric pressure the substance can never become solid. If the pressure is raised, it can be reduced to the crystalline state even at temperatures ten times as high as its boiling point.

There is, however, one phenomenon, and that a very striking one, that has so far defied adequate explanation. In 1913 Kamerlingh Onnes announced that when mercury was cooled below 4° its electrical resistance vanished. Supra-conductivity, as this effect is called, was afterwards found to occur in lead, tin and a number of other metals, though not by any means in all, for example, not in copper as low as 0·05°. Even some semi-conductors exhibit the same property, such as niobium carbide—indeed in this substance supra-conduction sets in at the highest temperature so far observed, namely, 12°. All attempts to observe some trace of electrical resistance in the supra-conducting state have failed. A current induced in a ring of supra-conducting material continues to run with undiminished strength for days on end. The phenomenon does not seem susceptible of explanation by any of the ordinary theories of electron conduction.

Much work has been done in Leyden, Berlin, Toronto and Oxford on this strange effect, and the somewhat complicated phenomena are gradually being disentangled. But whether it will be possible to fit it into the general scheme or whether it may not require some new mode of approach it is too early yet to say.

Though more low temperature research has been carried out in the last twenty-five years than in all preceding periods put together, and though temperatures within one hundredth of a degree from the absolute zero have been attained, there is no question of our having reached finality. Our nearness to the absolute zero is apparent rather than real; if we had chosen to measure the temperature on a geometric rather than an arithmetic scale, it would have been less convenient in many ways; but it would have made it clear that, towards low temperatures, as towards high, there is always an infinite distance ahead of us; and in each such range we may expect new effects and new phenomena.

Fortunately, there are within the Empire laboratories where these effects can be studied. At Oxford, Cambridge and Toronto, work at liquid helium temperatures and below is being done. It may be hoped that the next generation will see the position of pre-eminence enjoyed by England in Dewar's time recaptured, and that advances as valuable and important as those which have signalised the past quarter of a century await us in the next.

Cosmic Rays

By DR. ARTHUR H. COMPTON, University of Chicago, and George Eastman Visiting Professor in the University of Oxford

THE twenty-five year period of King George's reign includes almost the entire history of the study of cosmic rays. The presence of these rays was revealed by a series of experiments carried on between 1909 and 1914. Wulf, on the Eiffel Tower, and Gockel, flying in a balloon to 4,500 metres, found that rays from radioactive sources in the ground could not account for the ionisation observed at high altitudes, and suspected some radioactive material in the upper atmosphere[1]. Hess, in a series of notable balloon flights, found an actual increase of ionisation with increasing altitude, and concluded "that a radiation of very high penetrating power enters our atmosphere from above". These experiments were at first criticised by other investigators, but were quickly confirmed by the more precise observations of Kolhörster, and have since been found correct in all their essentials.

After eleven quiescent years, Millikan made some bold speculations regarding the origin of these penetrating rays, which showed in a striking manner that their study might well give important new information regarding the evolution of the universe. Largely through his experiments and those of Hoffmann, the existence of the radiation was by this time generally recognised, and an intensive series of investigations was started by many physicists throughout the world. It was found that the rays which Hess had discovered are of a far more penetrating kind than any known before, being perceptible to a depth of hundreds of feet below the ground. They bring into the earth a total amount of heat somewhat smaller than that of starlight; but the energy of the individual cosmic ray is thousands of times greater than the most powerful artificial ray that man has produced. The more recent studies have sought to learn the nature of these rays, where they come from, how they are produced, and what effects they have on objects which they strike.

NATURE OF THE COSMIC RAYS

It was at first natural to suppose that these highly penetrating rays were of the same nature as the γ-rays from radium, the most penetrating rays then known. Though this view has not been entirely abandoned, the large majority of investigators now believe them to be electrically charged particles. This view of their nature was first urged by Bothe and Kolhörster, who found associated with the cosmic rays some electrical particles which were as penetrating as the cosmic rays themselves. They noted further that if such electrical particles approach the earth from all directions, some of those near the equator should be so deflected by the earth's magnetic field that the intensity of the rays should be less there than near the poles. Through the experiments of Clay and many others, the existence of such a 'latitude effect', which depends upon the earth's magnetic field just as the theory predicts, has at last been established. This has proved the existence of an important component of the cosmic rays which is electrically charged.

More recently, using methods developed by Piccard, Regener and others, it has been possible to extend the measurements of cosmic rays high into the stratosphere. Typical data taken at different latitudes are shown in Fig. 1. Here it will be noted that the latitude effect, which is only 15–20 per cent at sea-level, has become a factor of 40 near the top of the atmosphere. That is, nearly all the incoming rays are affected by the earth's magnetic field, and are hence electrically charged. Even of the small percentage which penetrates the magnetic barrier at the equator, supplementary experiments show that a large fraction and perhaps all is electrical in character[2,3].

A method of analysing the various electrical components has recently been developed[2,3], in which the earth is used as a huge natural mass-spectrograph, similar in principle to the laboratory instrument for identifying the isotopes of elements. The earth's magnetic field permits only those particles to reach the earth which have an energy, and hence a range in air, greater than a certain minimum. This minimum range is different for every type of particle. Analysis of such curves as those shown in Fig. 1 has enabled us to distinguish three groups of rays having distinct range minima. Best agreement between these observed minimum ranges and those calculated from the earth's magnetic field is found if the least penetrating group of rays is identified as α-particles, that of medium penetration as electrons (positive or negative), and the most penetrating ones as protons.

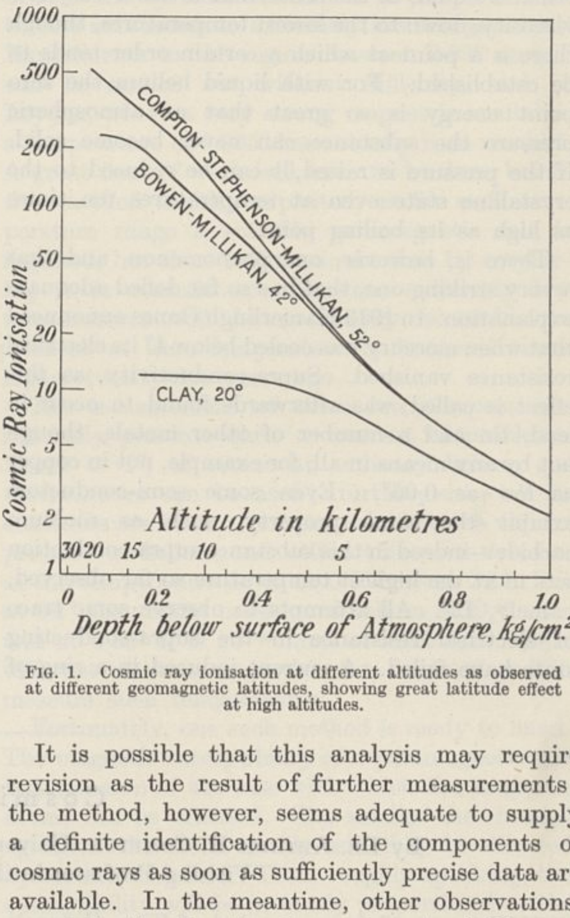


FIG. 1. Cosmic ray ionisation at different altitudes as observed at different geomagnetic latitudes, showing great latitude effect at high altitudes.

It is possible that this analysis may require revision as the result of further measurements; the method, however, seems adequate to supply a definite identification of the components of cosmic rays as soon as sufficiently precise data are available. In the meantime, other observations, especially the directional experiments of Johnson, Alvarez, Rossi, Clay and others, lend support to this tentative analysis[4]. Rapid progress is thus being made toward a complete determination of the composition of cosmic rays.

WHENCE COME THE COSMIC RAYS?

One of the most significant aspects of the latitude effect is its implication that the cosmic rays originate far beyond the earth's atmosphere. The earth's magnetic field is not strong enough to bend appreciably any radiation produced within the atmosphere before it is stopped by collisions with molecules. Furthermore, the cosmic ray intensity is found to depend upon the average magnetic effect of the whole earth, and to be almost unaffected by 'local' magnetic idiosyncrasies which may extend even over a whole continent. This must mean that they feel the effect of the earth's magnetism when yet thousands of miles from the earth's surface.

Except for deflection by the earth's magnetic field, however, the cosmic rays are found to approach the earth nearly uniformly from all directions. Outside the earth's atmosphere, we fail to find any isotropic distribution of matter within our galaxy where such rays might originate. The extra-galactic nebulæ or space itself would, on the other hand, satisfy the condition of spherical symmetry. Calculations by both Eddington and Lemaître have shown that the probable absorption of a cosmic ray traversing the matter in interstellar space with about the speed of light for 10^{10} years would be wholly negligible. If, however, these rays are subject to the same red shift as that which occurs in the light from the distant nebulæ, the rays originating at distances as great as 10^{10} light years would arrive at the earth with only a small fraction of their initial energy. If the rays are being continuously produced, therefore, their isotropic distribution suggests that most of them originate in the remote galaxies or in remote space, at an effective distance of between 10^9 and 10^{10} light years. An alternative would be to suppose with Lemaître that they were formed at the beginning of the expansion of the universe, and have ever since been coursing through space.

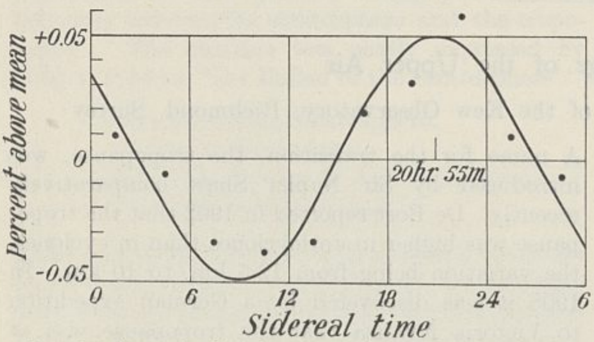


FIG. 2. Apparent effect due to rotation of galaxy. Curve, theory; data, complete year's observations by Hess and Steinmaurer.

Some positive support for this view of the remote origin of cosmic rays is given by the fact that there appears to be an effect on their intensity due to the rotation of the galaxy[5]. According to Stromberg and Hubble, this rotation carries us toward declination 47° N. and right ascension 20 hr. 55 min., at a speed of about 300 km. per second—one thousandth the speed of light. If the source of the cosmic rays is outside our galaxy and at rest relative to its centre of gravity, calculation shows that at our latitude this motion should cause a diurnal variation, following sidereal time, through a range of the order of 0·1 per cent. The best available records of cosmic ray intensity[6] show, as in Fig. 2, a variation with sidereal time of about the predicted magnitude, and with its maximum at precisely the predicted time. Though further experiments are necessary before other possible interpretations of this sidereal time variation are ruled out, the complete agreement with the predictions may justify the presumption that it is really due to the rotation of the galaxy. This would necessarily imply that an important part of the rays originates outside the galaxy, a long-wanted justification of their rather heuristic appellation of 'cosmic'.

HOW ARE THE RAYS PRODUCED ?

Of the many hypotheses regarding the origin of cosmic rays, none has received sufficient experimental support to gain general acceptance. Those which assume the primary cosmic rays to be photons appear to be in definite conflict with the observed latitude effect. Also those which would ascribe their origin to transformations of atomic nuclei with resulting loss of mass are unable to account for the huge energies of from 10^9 to almost 10^{12} electron volts which the more recent studies[7] seem to require for the individual rays. Local or interstellar electric fields have been suggested; but the maintenance of such fields in highly ionised stellar atmospheres seems an insurmountable difficulty. There remain, however, a number of theories which cannot thus be excluded. Prominent among these are Lemaître's hypothesis of 'super-radioactive particles' emitted at the initial explosion of his expanding universe, Swann's theory of the acceleration of electrical particles by electromagnetic induction from the changing magnetic fields of 'sunspots' on giant stars, and Milne's view[8] that the particles owe their energy to the gravitational attraction of the universe. At present we are unable to give these suggestions a definitive experimental test.

ACTION OF COSMIC RAYS ON MATTER

One of the most fruitful lines of cosmic ray research has been the study of their effects on passing through matter. Especially valuable have been the experiments with Wilson chambers in strong magnetic fields, and the use of Geiger-Müller counting tubes. These and other methods have shown that a complex mixture of secondary rays is excited by the primary cosmic particles. In this complex mixture, Anderson made the remarkable discovery of positive electrons, or positrons, which have since been found to play an important rôle in the absorption of high energy photons.

A prominent feature of the secondary radiation associated with cosmic rays is the occurrence of 'showers' of two to twenty or more high-speed particles emanating apparently from the same point. These particles are about equally divided between positive and negative electrons. Furthermore, these showers themselves frequently occur in groups, all excited by some 'shower producing radiation'. This 'shower producing radiation', according to studies by Rossi, Blackett, Anderson and others, seems to consist of photons, similar to X-rays, produced at the collisions of the primary cosmic ray particles with atomic nuclei. Studies by Johnson[4] of the directional asymmetry of the shower producing radiation suggest that it is excited chiefly by the electron component of the primary cosmic rays, and that this component consists of about equal parts of positive and negative electrons.

Contrary to the situation for rays from radioactive materials, it would seem that, for these very high energies, photons may be more absorbable than electrons of the same energy, and that protons are probably the most penetrating of all. The theories of Oppenheimer and Bethe and Heitler indicate that electrons are stopped chiefly by the excitation of photon radiation (X-rays). This results in an almost exponential type of absorption, similar to that of photons. These unanticipated results account in part for the confusion in our early attempts to identify the nature of the primary rays. The experimental study of these energy losses is beginning to give valuable results[9], while their adequate theoretical treatment seems to require a further extension of quantum-relativity electrodynamics. It seems probable that studies of these energy losses may supply our best means of testing those extensions of the present electrodynamics which are designed to account for the structure of electrons and nuclei.

Our analysis of the composition of cosmic rays is thus well under way, and from present indications should soon give conclusive results. The 'cosmic' origin of the rays, though perhaps not established, appears now more probable than ever. How they originate is still obscure; but increased knowledge of their characteristics has helped to limit the types of hypotheses that are admissible. Of immediate value is the use of these rays as a tool. They have made possible the discovery of the positron, and now afford a means of extending our studies of the properties of matter to energies a thousandfold greater than are available from any other known source.

[1] Detailed reviews of cosmic ray research, with comprehensive bibliographies, have recently been published by A. Corlin (*Annals of the University of Lund*, No. 4; 1934) and E. Steinke (*Ergeb. exakt. Naturwiss.*, **13**, 89; 1934). I shall here give references only to some of the very recent work not discussed by these authors.

[2] A. H. Compton and R. J. Stephenson, *Phys. Rev.*, **45**, 441; 1934.

[3] A. H. Compton, *Proc. Phys. Soc. London*, April 1935.

[4] Compare especially T. H. Johnson, *Phys. Rev.*, in press.

[5] A. H. Compton and I. A. Getting, *Phys. Rev.*, in press.

[6] V. F. Hess and R. Steinmaurer, *Sitzber. Preuss. Ak. Wiss.*, **15**; 1933.

[7] Compare, for example, A. H. Compton, NATURE, **134**, 1006; 1934. Similar estimates have previously been published by W. Kolhörster and E. Steinke.

[8] E. A. Milne, NATURE, **135**, 183; 1934.

[9] For example, C. D. Anderson, Proceedings International Conference on Physics, 1934.

Progress in Knowledge of the Upper Air

By DR. F. J. W. WHIPPLE, Superintendent of the Kew Observatory, Richmond, Surrey

IN considering progress in knowledge of the upper air during the past twenty-five years, the first point to notice is that it is roughly true that in 1910 there was little more to be learned about the condition of the atmosphere below 20 km. and a great deal to be learned about the atmosphere above that level.

THE STRATOSPHERE

The most striking discovery that has ever been made in meteorology, the discovery that the familiar decrease of temperature with increasing height comes to a sudden stop at some 10 km. above sea-level, was already well established by 1910. The discovery was announced in 1899 by Teisserenc de Bort, who afterwards coined the names stratosphere for the isothermal layer and troposphere for the lower part of the atmosphere. A name for the transition, the tropopause, was introduced by Sir Napier Shaw comparatively recently. De Bort reported in 1902 that the tropopause was higher in anticyclones than in cyclones, the variation being from 12·5 km. to 10 km. In 1908 it was discovered by a German expedition to Victoria Nyanza that the tropopause was at a height of nearly 17 km. and that the temperature was about 190° A., much lower than the average temperature, 216° A., recorded in Europe.

It was soon realised that the explanation of the existence of the stratosphere must be based on the study of radiation. The permanent gases of the atmosphere are almost perfectly transparent to radiation both in the visible spectrum and in the part of the infra-red in which objects at atmospheric temperatures radiate. On the other hand, water vapour absorbs and radiates in this part of the infra-red. The theory put forward by Gold in 1909 depended on the investigation of the balance of radiation absorbed and given out by water vapour. The theory remains incomplete, for it is not clearly understood why there should be a sharp transition in the temperature gradient at the tropopause, and the contrast between the conditions over the equator and in higher latitudes has not been explained.

During the last twenty-five years, knowledge of the temperature distribution in the stratosphere has accumulated. The meagre data from tropical regions have been supplemented by excellent series of observations in Batavia and in India, and in the far north the balloons sent up at Abisko in Lapland have yielded valuable information. It is now believed that over the tropics there is a considerable increase of temperature above the tropopause, the average temperature at 24 km. being about 220° A. On the other hand, near the Arctic Circle there is a wide annual range of temperature in the stratosphere. At 10 km. the range is from 212° A. in January to 227° A. in July. At 20 km. the averages in those months are estimated as 207° A. and 240° A.

The relations between pressure and temperature in the upper air were set out by W. H. Dines in 1911 in terms of correlation coefficients. Dines was impressed by the strong correlation between the pressure at a height of 9 kilometres and the other variables, the height of the tropopause, the temperature of the stratosphere and the average temperature of the troposphere. It looked as if the movements of the atmosphere must be dominated by developments taking place at the boundary between the stratosphere and the troposphere. The doctrine was neatly expressed by Gold in 1914 in "The Ballad of the Stratosphere' '

"I am the rolling Stratosphere,
I long to perturbate ;
So I tickle the top of the Troposphere,
To make him undulate."

Later investigations have concentrated attention on the lower strata of the atmosphere, and nowadays most of the meteorologists who are interested in the day-to-day changes of weather are content to regard the stratosphere as playing a passive rôle. There is, however, a school in Germany which regards 'stratospheric steering' as dominating the movements of cyclones and anticyclones.

The theory of the stratosphere has been developed by Simpson, who has demonstrated that the heat balance of the atmosphere is maintained in such a way that the energy of such solar radiation as is not intercepted and reflected by the clouds eventually escapes as long-wave radiation. According to Simpson, any increase in solar radiation would be followed by an increase in evaporation from the oceans and an increase in cloudiness. This would reduce the fraction of the solar radiation available for heating the ground, the oceans and the atmosphere, so that the rise of temperature would be comparatively small. It appears that the temperature of the stratosphere is governed by the properties of water vapour rather than by the strength of solar radiation. Simpson believes that the temperature would be changed but little if the earth received as much radiation as Venus or as little as Mars.

So early as 1875, Hann discussed the constitution of the atmosphere at great heights on the assumption that Dalton's law could be applied, each of the constituent gases behaving as if the others were not present. He showed, for example, that as oxygen is heavier than nitrogen the proportion of oxygen would fall off with increasing height. After the discovery of the stratosphere it was generally assumed that the same uniform temperature would prevail right through the atmosphere from the tropopause upwards, and that the density of each of the constituent gases could be calculated on that basis. Whilst the proportion of hydrogen in air near the ground was only three parts in 100,000, this gas was found according to the calculations to predominate at 80 km. and at greater heights. Wegener came to the conclusion that even hydrogen was not light enough to extend to the greatest heights at which aurora had been observed, and in 1911 he postulated a still lighter gas, geocoronium.

Faith in these calculations was rudely upset in 1922 when Lindemann and Dobson published their paper on "A Theory of Meteors and the Density and Temperatures of the Outer Atmosphere to which it Leads". Qualitatively there was little new in the theory of meteors. In his "Thermodynamik der Atmosphäre", published in 1911, Wegener says that on account of the great velocity of a meteor the air does not get out of its way but is compressed. The air is heated by compression, and heat from the air raises the superficial temperature of the meteor until it begins to evaporate. Wegener thought that the heated air would become visible, whilst Lindemann and Dobson insist that it is only when volatilisation begins that the meteor is seen. That is a small detail, however : the important step was to calculate how much air must have been encountered before the meteor would be raised to incandescence, how much before it was completely volatilised and therefore disappeared. The result of these calculations was that the air throughout the range of height through which meteors had been observed must be much denser, at 100 km. a hundred times denser, than the speculations based on the hypothesis of uniform temperature had indicated.

The natural deduction was that the latter hypothesis was wrong. The air at moderate heights must be sufficiently distended to support comparatively heavy air at the greater heights. The case was met by postulating that the air at heights of 60 km. and upwards was at a temperature of at least 300° A., about the average temperature prevailing on the ground. It was pointed out afterwards that better agreement could be obtained by placing the base of this upper region of high temperature a good deal lower, at 40 km.

The Transmission of Sounds to Great Distances

It was a curious coincidence that Lindemann and Dobson discovered the high temperature of the upper atmosphere in 1922. The observational material which they used in their calculations had been available for at least half a century. On the other hand, when they announced their discovery, investigations were in progress which were leading to the same conclusion. That the sounds of explosions could sometimes be heard at very great distances though inaudible at smaller distances had been noticed long ago ; there is a famous instance, recorded in the diaries of Pepys and Evelyn, of firing in the Straits of Dover being heard in London but not at Dover. The first detailed investigation of the phenomenon was made by van den Borne after a dynamite explosion at Förde in Westphalia in 1904. Previously it had been supposed that abnormal audibility could be explained by the effect of wind, but van den Borne came to the conclusion that this explanation was not adequate, and put forward the hypothesis that the sound waves travelled through the atmosphere at a great height. In his calculations he utilised Hann's estimates of the amounts of different gases in the atmosphere. According to these estimates hydrogen preponderated at heights exceeding 70 km. In an atmosphere of hydrogen the velocity of sound is about four times that in ordinary air. Van den Borne saw that waves passing from the lower atmosphere into an atmosphere which was mostly hydrogen would be refracted and would return to the ground. He reckoned that waves starting upwards in a direction inclined at 30° to the vertical would reach the ground about 116 km. from the source after culminating at a height of 75 km.

The theory seemed to fit the observations, though there was a good deal of scepticism as to the possibility of waves being transmitted through such attenuated gas.

Wegener's account of the theory is followed by the remark that systematic investigations of these sound phenomena could probably be carried out at no great cost and were much to be desired. The Great War provided plenty of opportunities for qualitative observations and directed general attention to the subject, but as a test of theory observations of the time of transmission of sound were needed. After the War, experiments were inaugurated by the International Meteorological Organisation.

These experiments and others have demonstrated that van den Borne's theory cannot be valid, for the times taken by the sound of an explosion to reach various distances are much less than the times computed by that theory.

When Lindemann and Dobson announced that the atmosphere at 60 km. was probably at a high temperature, it was seen at once that this provided the explanation of the phenomenon of 'abnormal' audibility of sounds at great distances. The same explanation was in fact propounded by Wiechert shortly afterwards without any reference to the work of Lindemann and Dobson.

The investigation of the waves from explosions has been carried on, mostly by the use of autographic records. Records of the transmission of air waves to great distances were secured within the Arctic Circle in Lapland and in Novaya Zemlya during the Polar Year. Observations which show that the outer zone of audibility is a universal phenomenon have been collected in other parts of the world.

Accordingly it is probable that high temperatures occur in the upper atmosphere in all parts of the world and at about the same height. More definite information can only be obtained by multiplying observations under controlled conditions.

Ozone

The existence of ozone in the earth's atmosphere was revealed by a remarkable feature of the solar spectrum, the absence of ultra-violet rays of short wave-length. The visible spectrum ends at about $0{\cdot}4\mu$, and photographs obtained with the quartz spectroscope show that there is a narrow band of ultra-violet, but this is cut off at $0{\cdot}29\mu$. In 1881 Hartley discovered that ultra-violet light was absorbed by ozone, and attributed to this gas the limitation of the solar spectrum, but Wegener, writing in 1911, passed over this evidence and based his statement that the quantity of ozone in the atmosphere increased with height on chemical analysis. He added, however, the remarks that the ozone was obviously produced by the action of ultra-violet solar radiation on oxygen, and the greatest part of this radiation was already absorbed at great heights. Accordingly, the distribution of ozone in a way which was inconsistent with Dalton's law was comprehensible.

The first estimate of the quantity of ozone needed to produce the absorption observed in the solar spectrum was made by Fabry and Buisson, whose work was first published in 1913. They announced that the ozone was localised in the atmosphere at heights above the regions accessible to man. Their method was to compare the intensities of light in different parts of the Hartley band and at different elevations of the sun. In this way they were able to eliminate the effects of absorption by haze and of Rayleigh scattering. The quantity of ozone is very small; it is equivalent to a layer of the gas at normal pressure and temperature only 3 mm. thick. If the ozone is in a layer 10 km. deep at such a height that the average pressure is 1/20 of an atmosphere, then in that layer the number of oxygen atoms united in molecules of O_3 is only $1/(2 \times 10^4)$ of the number constituting O_2.

The variations in the quantity of ozone in the upper atmosphere have been studied by Dobson with the aid of several collaborators. The results are striking. The annual variation in Europe has a range of about 30 per cent, the maximum occurring in the spring, the minimum in the late autumn. Both the mean amount (about 2 mm.) and the annual range are least near the equator. Within the Arctic Circle the mean is about 3 mm. and the range is nearly 50 per cent of the mean. There is symmetry in the northern and southern hemispheres.

No regular diurnal variation has been detected, but the amount of ozone varies with changes of pressure in the lower atmosphere. There is more ozone above places where pressure is low, the maximum amount of ozone occurring a little to the west of the centre of a cyclone. The minimum amount is observed a little to the west of the centre of an anticyclone. These results are consistent with the hypothesis that the ozone is transported by currents from polar or equatorial regions, and indicate that the currents at the levels at which ozone is found are generally in the same direction as the currents nearer the ground.

The earlier estimates of the height of the ozone depended on measurements of the absorption of the ultra-violet light in the direct solar beam at different times of day and especially on measurements made when the sun was very low; but the investigators were never very confident about the estimates which they gave of about 50 km. for the centre of gravity of the ozone.

Recently a new and powerful method of dealing with the problem has been developed by Götz, Meetham and Dobson. This method depends on measurements of the intensity of the ultra-violet light from the sky in the zenith. The essential difference is that, whereas in the older method the height of the ozone is compared with the radius of the earth, in the newer the height is compared with the heights at which the density of the air has assigned values. It is now found that the centre of gravity of the ozone is on the average at a height of about 21 km. The published observations refer to Arosa in Switzerland and to Tromsø within the Arctic Circle in Norway, and the difference in height is insignificant. In both locations the ratio of the densities of ozone and air is greatest at 35 km. or 40 km. It should be noted, however, that the Tromsø observations were made only in summer.

That the ozone is mostly below a height of 30 km. has now been confirmed in a very direct way by Regener. A spectroscope was carried up by a sounding balloon to about that height, and the spectrum of the light reflected upwards from a horizontal white surface was photographed automatically at regular intervals. It was demonstrated that as the maximum height was approached the spectrum extended at the violet end, clear evidence that the balloon had passed beyond the greater part of the gas which absorbs the ultra-violet light.

A "theory of upper-atmospheric ozone" has been developed by Chapman. The theory is too difficult and elaborate to summarise here. It may be mentioned, however, that oxygen is dissociated by the absorption of ultra-violet light of very short wave-length, that ozone is formed by the combination of molecular and atomic oxygen and that the ozone is eventually dissociated by the absorption of the ultra-violet of the Hartley band. Most of the oxygen atoms derived from the dissociation of ozone combine again to form new ozone molecules, so that the ozone is in a sense more persistent than the individual molecules of ozone. One notable success of Chapman's theory is that he declared that the ratio of the densities of ozone and oxygen should pass through a maximum at a moderate height, so anticipating the results of observation.

The theory that high temperature was produced in the upper atmosphere by the absorption of ultra-violet light was sketched by Lindemann and Dobson in 1922 in their paper on meteors. The theory was elaborated by Gowan. In his analysis he used the earlier estimates of the height of the ozone, and was led to the conclusion that, under certain assumptions as to the distribution of ozone and of water vapour, the air at such a height as 50 km. could be maintained at a temperature of 300° A., whilst much higher temperatures were to be expected at greater heights. The results were not in accordance with those derived from observations of the transmission of air-waves, which put the base of the high-temperature region about 10 km. lower down. Gowan's work requires revision in the light of the recent determinations of the height of the ozone layer, but at present it seems unlikely that the absorption of ultra-violet light by ozone and by oxygen can provide enough energy at the right levels to maintain the high temperature postulated to explain the refraction of sound waves. It may be that the hypothesis of high temperature will have to be abandoned in favour of the view that the lightness of the atmosphere is due to the dissociation of oxygen. It may also be that some source of energy has yet to be discovered.

AURORA

Whilst information as to the condition of the atmosphere at heights from 30 km. to 50 km. can be obtained in indirect ways, there is no method of investigating conditions between 50 km. and 80 km., though something can be gleaned from the occasional observations of meteor trails, which indicate that there are strong currents in this region. 80 km. is approximately the lower limit of the aurora borealis in southern Norway. Farther north there are few rays which come below 90 km. The majority terminate between 95 km. and 115 km., maximum frequencies occurring at 101 km. and 106 km. The upper ends of the rays are rarely above 400 km. during the greater part of the night, but after sunset, aurora can be seen above the earth's shadow extending to a height of 800 km. Krogness has suggested that the radiation pressure of sunlight drives the air forward so that the earth has a tail like a comet's, and that the high aurora is formed by corpuscles from the sun encountering this tail.

The spectrum of the aurora has been closely studied ; the majority of the lines in the spectrum are attributed to nitrogen, but the brightest, in the green, could not be identified with any line obtained in the laboratory until 1925, when McLennan and Shrum found it in an electric discharge through a mixture of helium and oxygen and demonstrated that the line was produced by a transformation of monatomic oxygen.

No lines associated with helium or hydrogen are observed in the auroral spectrum, so that it appears that the atmosphere in the highest levels consists of nitrogen and oxygen. It may be that any helium or hydrogen which diffuses to great heights is driven off in the comet-like tail of the earth.

It has been recognised for a long while that the corpuscles which produce the aurora carry electric charges and are diverted to the neighbourhood of the earth's magnetic poles by the action of the earth's magnetic field. The theory was elaborated by Birkeland about 1901 and has been developed further by Størmer. The height to which the auroral corpuscles penetrate is also the height of the lower of the two levels at which the atmosphere is a good conductor of electricity. These two layers have been discovered in the study of the transmission of wireless waves ; the lower is usually called the Kennelly-Heaviside layer and is at a height of about 100 km., the upper, discovered by Appleton, is at 220 km.

Chapman maintains that the ionisation at 100 km. outside the auroral zone is due to the bombardment of the atmosphere by neutral particles from the sun. These have about the same energy as the charged particles and penetrate to the same depth. The uncharged particles come straight from the sun, and therefore the supply is cut off at night. This theory is, however, open to question; for the observations made on the occasion of the eclipse of the sun visible in North America in 1932 appear to indicate that the ionising radiation travels with a velocity nearly equal to the velocity of light.

The upper ionised layer at 220 km. is probably the region in which the ultra-violet light of very short wave-length is trapped by oxygen in the atomic state.

The two ionised layers are of importance in theories of terrestrial magnetism. Chapman believes that the upper layer is the seat of the electric currents which affect magnetographs at our observatories and produce the variations of magnetic force in the course of the solar day, and that electric currents in the lower layer are responsible for the variations which are governed by the moon, the latter currents being associated with tidal movements of the atmosphere.

A layer which has not yet been identified is that from which the light of the night sky comes. It has been demonstrated that this light is not much-reflected sunlight and that it is not scattered starlight. The light must be generated in the earth's atmosphere by some slow process like the recombination of atomic oxygen. That atomic oxygen plays a part in the process is shown by the predominance of the green auroral line in the spectrum of the night sky. That the process is slow is proved by the fact demonstrated by Lord Rayleigh, that the intensity of the light varies but little during the night. Rayleigh finds in fact that the maximum intensity occurs about midnight. The layer from which the light comes must be rich in atomic oxygen. Chapman has given reasons for saying that this layer is probably between the Heaviside and Appleton layers.

Whilst the growth of knowledge of the upper atmosphere during the past twenty-five years has been rapid, there are probably more unsolved problems in sight than there were at the beginning of the period. It is safe to forecast that there will be a great consolidation of knowledge in the next twenty-five years, and that at the end of that period there will be still more problems awaiting solution.

Weather Forecasting

By DR. G. C. SIMPSON, C.B., C.B.E., F.R.S., Director of the Meteorological Office

THE most important advance in weather forecasting during the last twenty-five years owed its origin to the War; but unlike so many other war-time advances, it was not made in connexion with the prosecution of war.

Twenty-five years ago, the method of weather forecasting, developed and described by Abercromby twenty-five years earlier, had undergone very little change. Synoptic charts were prepared and isobars drawn to indicate the pressure distribution. Seven main types of isobars were recognised, and Abercromby had described in great detail what kind of weather is usually associated with each. To take one example: the most common and most important pressure distribution is the cyclonic depression, and Abercromby prepared a diagram showing the weather association with this type of pressure distribution. He drew two ovals, one inside the other, to indicate the typical shape of the isobars; a long arrow was drawn along the major axis to indicate the line of movement of the depression, and the space within the oval was filled with descriptions of the weather which occur in the different parts. In the front of the depression *Pale Moon and Watery Sun* are indicated; in the right fore quadrant, *Muggy and Gloomy* are entered; and near the centre *Dirty Sky* and *Driving Rain* are noted. The forecaster having found a depression on his chart and determined the direction in which it was moving, would issue his forecasts on the assumption that places over which the depression would pass would experience the weather scheduled by Abercromby.

Abercromby's descriptions of the weather associated with each type of isobar were well done, and a very useful percentage of correct forecasts could be made; but the method was, by its very nature, unsatisfactory; for only average conditions could be forecast, and one knew from bitter experience that very large variations from type were possible.

Meteorologists were well aware that better forecasts could not be made on such a system, and that it was necessary to learn more about the physics of the atmosphere, and to take the upper atmosphere into account. For a number of years a very active investigation of the upper atmosphere had been carried on and important results had been obtained: the stratosphere had been discovered and many interesting statistical relationships between the conditions at different heights had been computed; but none of them appeared to be of much use in practical forecasting, and in any event no method was then known by which information regarding upper air conditions could be obtained sufficiently rapidly to be of use in preparing a forecast for the next twenty-four hours.

Napier Shaw and Lempfert had tackled the problem in another way. They had investigated what happens in a depression by following the path of the air, and so determining where it came from and where it went. The result was a classical paper on the "Life History of Surface Air Currents", and Shaw in a subsequent paper came very near to making the discovery which ten years later was to have such a revolutionary effect; but all this work, in spite of its great theoretical value, had produced very little to help the forecaster, and when the War broke out, Abercromby's empirical method was still the basis of all weather forecasting.

In Norway, although far removed from the seat of War, it was practically impossible to carry on the State Meteorological Service during 1914–18 owing to the total cessation of meteorological information from the outside world. Under the guidance of Prof. V. Bjerknes, the meteorologists decided to try to compensate for the loss of the foreign observations by increasing the observation posts within their own country. Prof. Bjerknes himself was a mathematician and not a forecaster; but there were two young men, one his own son J. Bjerknes, and the other H. Solberg, who took charge of the practical work. The number of telegraphic reporting stations in the southern part of the country was increased from eight to about ninety. The observing stations were so close together that it was almost possible to follow individual masses of air from one to another.

When, by the aid of this close network of stations, the stream lines of the air were plotted, it was sometimes found that a broad and well-marked stream of air would seem to come to a sudden end. A long line could be drawn on the chart marking where the stream of air came to an end, and it was then found that beyond this line there was a strip of country, two or three hundred kilometres wide, over which rain was falling through a current of colder air flowing in a different direction. Further investigation, including a study of the temperature on each side of the line, showed what was really happening. In all such cases a stream of warm air had met a mass of cold air and been forced to ride over it, the cold air forming a wedge up which the warm air ascended. When air is forced to ascend in the atmosphere in this way it is cooled and precipitation takes place, thus accounting for the rain beyond the line marking where the ascent began. Frequently these broad bands of rain can be traced for thousands of kilometres across country.

On other occasions it was found that a broad stream of cold air would end as abruptly against a mass of warm air ; but in this case the rain band would be much narrower than in the former case and would be situated before instead of beyond the line of junction. The explanation was simple. In this case the moving air, being colder than the air against which it was impinging, could not ride over it, but must travel underneath. In effect, a wedge of cold air pushed its way under a mass of warm air and lifted it upwards over itself. The rain due to the ascending warm air fell through the wedge, and therefore appeared at the ground in front of the line of junction between the two air masses.

It was war-time, so it was natural to liken the process to that of advancing armies and to call the lines of junction between the masses of the air which extended for so many miles across the country 'fronts'. A front at which warm air advanced against cold air and was forced upwards was called a 'warm front' ; while one at which cold air pushed its way under warm air was called a 'cold front'. There was nothing very revolutionary in the idea of one current of air overriding another without mixing, the two currents remaining separated at a surface where there was a discontinuity of temperature and air motion. Helmholtz had investigated the conditions in which such surfaces of discontinuity could exist, Margules had worked out the formula for calculating the equilibrium-inclination of such surfaces and Shaw and Lempfert had already recognised them on their synoptic charts. It was, however, the next step made by the Norwegians which was so important ; for they showed that warm and cold fronts are an integral part of the formation and development of cyclonic depressions. A depression forms on a surface of discontinuity which, as the depression develops, becomes differentiated into a warm front and a cold front meeting at the centre ; while the precipitation is chiefly associated with these fronts.

Thus at last a physical structure had been put into a depression, and Abercromby's distribution of weather had been brought into an ordered relationship with processes taking place in the upper atmosphere. From then on, the forecaster had a new tool called 'frontal analysis' with which to work. He now searches his synoptic chart for fronts and surfaces of discontinuity, and when he finds them he knows what weather to expect. When a front has once been located, the surface of discontinuity associated with it can be followed by characteristic cloud formation and rain bands for a very long time. In this way the forecaster is able to foretell even minor changes of weather and to fix with considerable accuracy the time at which the changes will take place. This is of inestimable value in connexion with forecasting for aviation.

Fronts and surfaces of discontinuity are due to the existence of different masses of air which are brought into contact ; and it is now necessary to say a few words about 'air masses'. Air which remains for any length of time in one locality takes up the temperature and humidity characteristic of that locality ; thus the chief characteristic of the air in polar regions is low temperature, while that of air in tropical regions is high temperature. When air from polar or tropical regions moves into mid-latitudes it does not immediately take up new characteristics ; but it retains those of its place of origin for a relatively long time, and it is possible, especially when upper air observations are available, to determine the origin of the air over very large areas.

The two main types of air masses are polar and tropical, but polar air may come from a sea area or from a continental area, and although in both cases the air will be cold it will have different characteristics of humidity and lapse rate. In this way 'maritime polar air' and 'continental polar air' have come to be recognised. 'Mass analysis' is now an important branch of 'frontal analysis', and many different types of air masses are specified by different names. Each of these air masses has its own physical properties which are important from a weather point of view. Polar air is generally clear, with good visibility ; maritime polar air is very unstable owing to the warming of its lower layers when passing over the relatively warm sea, and in it showers and squalls easily develop ; tropical air is generally very stable, and showers do not occur in it, but it is the tendency of this air to override cold air which, aided by its high humidity, gives steady rain ; the visibility is generally poor in tropical air. The forecaster has therefore come to examine more closely the air masses, first because of their intrinsic characteristics, and secondly because it is at the junction between air masses of different origin that surfaces of discontinuity occur.

It has already been mentioned that, at the outbreak of War, upper air observations were not available, and if they had been forecasters would not have known what to do with them. The conditions are very different now; for aeroplanes have made it possible to get the information quickly, and our new knowledge of the part played by air masses and surfaces of discontinuity makes all information from the upper air of great importance. Practically all countries now use aeroplanes for upper air observations as part of their forecasting services.

There can be no doubt that during the last twenty-five years the forecaster has made great steps forward and forecasting is slowly being changed from an art, in which experience and intuition played the predominating part, into a science in which cause and effect are recognised and taken into account.

Conceptions of Man's Ancestry

By Sir Arthur Keith, F.R.S., lately Hunterian Professor of the Royal College of Surgeons

When King George came to the throne, anthropologists had begun to realise that man's family tree was to prove a much more complicated thing than was anticipated. The discoveries made in France between 1907 and 1909 compelled them to abandon the idea that mankind had been evolved by a single progressive series of stages which, beginning in an ape-like stage, ended in the races of modern humanity. They had to give up the single-stemmed family tree and substitute for it one with rather a shrub-like outline. Most of them regarded Neanderthal man as a stage in the evolution of modern man. The discoveries made in France, at the date just mentioned, proved that this could not be so, and that Neanderthal man, after occupying Europe for a large part of the pleistocene period, had been suddenly replaced by representatives of modern or neanthropic man. Whether the neanthropic races, which replaced the Neanderthal inhabitants of Europe, came from Africa or from Asia still awaits determination. Neanderthal man could not be fitted into any single-stemmed scheme; he represented the end twig of a dead branch. Since 1910, several more dead branches have been discovered and fitted into provisional reconstructions of man's family tree.

At the beginning of this period another idea relating to the antiquity of modern man was being much discussed. Was it possible that human beings, exactly similar to modern Europeans in details of structure, could have been in existence in mid-pleistocene times, when the 100 ft. terrace of the Thames was being laid down and the large Chelles hand-axes were being fashioned? There were many—including the writer—who answered this question in the affirmative. The case we relied on was that of Galley Hill, near Gravesend, but discoveries of a similar kind had also been reported from France, from Italy and from North America. Galley Hill man lay under mid-pleistocene strata which were apparently unbroken. The discoveries which have been made during the past twenty-five years have not supported the Galley Hillites; the opposite has been the case. Most anthropologists now hold that the human body is so unstable in its constitution—and always has been so unstable—that it cannot continue the same over a long period of time, but must change. Hence we are all inclined now, in the case of Galley Hill and all discoveries of a similar kind, to reject the geological evidence rather than believe that the human body can exist for a long period of time—say, 50,000 years—and remain unchanged.

Our knowledge of Neanderthal man has been greatly extended. In 1911 Marcelin Boule published his classical monograph on the anatomy of La Chapelle man—perhaps the best known of Neanderthal specimens. The earliest or oldest trace of the Neanderthal phylum is represented by the Heidelberg mandible, which was discovered in 1907. In spite of a prolonged search, this is still the sole trace we have of the ancestry of Neanderthal man in the earlier part of the pleistocene period. Two discoveries, however, have revealed stages which fill up in some degree the interval between the early Heidelberg and late La Chapelle stages in the evolution of the Neanderthal type. One of these was made in the travertine quarry at Ehringsdorf, near Weimar, in 1925; the other was made in a gravel pit, just outside Rome, in 1929. At Ehringsdorf and at Rome, the Neanderthal skulls were embedded in deposits formed during the long temperate interval which preceded the last glacial period. The Ehringsdorf man was big-brained and had certain characters more reminiscent of modern (neanthropic) man than the later Neanderthal specimens. There are reasons for linking the discovery at Ehringsdorf with that made at Krapina, Croatia, in 1906. A discovery made in 1924 revealed the fossil remains of Neanderthal man in the Crimea, thus carrying the distribution of this extinct type almost into Asia.

One very strange fact is that not a fossil bone of Neanderthal man has been found in England. Traces of his body were found in Jersey by Dr. R. R. Marett in 1911, and they have been found abundantly in France and in Belgium. Yet the work-floors of Neanderthal man abound in the south-eastern parts of England. Fossil remains of neanthropic man (*Homo sapiens*) have never been found in or under an intact stratum containing the stone implements of Neanderthal man—implements of the Mousterian culture. This culture has always been found in association with Neanderthal man.

The most remarkable and the most unexpected discovery of ancient man recorded in the period under review was made at Piltdown, Sussex, in the opening years of the King's reign. Eager search over a long period had brought to light human remains in many parts of England, but always they were of the present-day type. English anthropologists had come to believe that the first and only inhabitants of England were men of the modern type, when to the surprise of everyone the late Mr. Charles Dawson and Sir Arthur Smith Woodward produced Piltdown man—the most remarkable form of extinct humanity which has been discovered in any part of the world. The criticism which this discovery has met with, ever since its first announcement, has in no wise detracted from its authenticity or its importance. Piltdown revealed the fact that, at the beginning of the pleistocene period, England was the home of men who had in their structure a mixture of parts—most of them modern yet some strange, such as those of the forehead, and some ape-like, such as those of the lower jaw. Indeed, the Piltdown lower jaw has been assigned by quite competent zoologists to an extinct kind of chimpanzee. Sir Arthur Smith Woodward found small fragments of other individuals at Piltdown, but so far no other traces of this early type of man has been discovered in England or elsewhere in Europe. It is usually held that Piltdown man (*Eoanthropus*) represents a form of humanity which died out early in the pleistocene period. This, however, is a view which is not held so firmly now as it was formerly.

Another type of humanity in early England, authentic in all details relating to its discovery, came to light when foundations were dug for Lloyd's Buildings in the city of London in 1925. The London skull, which was found then, occurred under a stratum laid down in mid-pleistocene times. This places the ancient Londoner well within the period when the inhabitants of Europe were Neanderthalians. Although the London skull is incomplete, yet there is enough of it to justify the exclusion of its owner from the Neanderthal category. The London skull is essentially modern in character, but in the opinion of the writer it does show features which suggest a relationship to the Piltdown type. Only further discovery can determine the significance of the London skull and its place in the evolutionary family tree.

Although only a single specimen of the humanity which occupied England at the beginning of the pleistocene period has been discovered, yet there is abundant evidence that England was a home for evolving mankind as early as the pliocene period. Just before 1910, Mr. Reid Moir announced the existence of humanly worked implements in the sub-crag beds of East Anglia. He has added to his evidence in every one of the twenty-five years which have elapsed since 1910, and now distinguishes at least three distinct stone cultures under the Red Crag of Suffolk.

In 1925, students of fossil man had their attention directed to Palestine by a discovery made near Lake Galilee by Mr. Turville Petre. Deep in the floor of a cave, rich with stone implements of the Mousterian culture, he found part of a skull, which although Neanderthal in its main characters, yet had certain features which were of a different nature. Between 1929 and 1933, Miss Dorothy Garrod, working for the British School of Archæology in Jerusalem, explored the caves of Mount Carmel, and found them laden with human relics of the pleistocene period. In one cave Miss Garrod explored and examined a continuous series of superimposed strata 52 ft. in thickness—the most extensive and richest cave deposit known to us. The strata covered the period in which Europe was inhabited by Neanderthal man. Altogether, remains of about fifteen individuals were found in the Carmel caves, six of which represent approximately complete skeletons. The fossil remains of ten individuals lay in the smallest of the Carmel caves which was excavated by Mr. Theodore McCown. All the fossil remains from the Mousterian deposits of Mount Carmel are of the Neanderthal type, but like the Galilean specimen, show many strange features in some of which they approach the modern type of mankind. Thus we now know that for a very considerable part of the pleistocene period—roughly its middle third—Palestine was inhabited by a strange breed of Neanderthal man, some of them very tall and massively built. As in Europe, the Neanderthal race was suddenly replaced by men of the modern type at the end of the Mousterian phase of culture. The present belief is that these ancient Palestinians represent an extinct people.

Almost at the same time as Palestine, China claimed the attention of students of prehistoric man. By a series of isolated discoveries, it became known that the limestone hills at Chou-Kou-Tien, 37 miles from Peping, contained a vast cave packed with remains of the pleistocene period. Most of the contents of the cave had been brought within the cave very early in the pleistocene period. The oldest cave strata were found to contain crude stone implements, fossil remains of human beings and of hearths. The fossil remains were found to represent a primitive form of humanity which Prof. Davidson Black named *Sinanthropus*. *Sinanthropus* is certainly one of the oldest and lowest forms of humanity known to us. His exact position in the family tree which represents the evolution of humanity is still uncertain. Prof. Davidson Black, who was cut off by death at forty-nine years of age in March 1934, was the man, above all others, who was best qualified to solve the enigmatic position of Peking man. He died at Peping in the midst of his labours. It may be that this ancient fossil type, so unlike any of the modern Mongolian peoples, may nevertheless prove to be on the line of Mongolian descent, for there are now grounds for believing that the chief races of mankind have been evolved in the continents they now inhabit.

When the British Association met in Australia in the autumn of 1914, there was submitted to it a fossil human skull, known as the Talgai skull. It had been derived from a pleistocene deposit in Queensland, and was marked by the cranial characters of the Australian aborigine, save that the jaws were more robust than is usual in the modern native and the brain was rather larger. The Talgai skull, which was described by Dr. S. A. Smith in 1918, is the earliest representation of the Australian aborigine known to us.

The publication of Dr. S. A. Smith's monograph led Prof. Eugène Dubois of Leyden to divulge a secret he had kept ever since 1891–92, when he was in Java and discovered the fossil remains of *Pithecanthropus erectus*. He revealed the fact that he not only found these famous fossils, which came from very early pleistocene deposits—if not late pliocene—but also in deposits of late pleistocene date, two other fossil skulls. These two specimens, known as the Wadjak skulls, like that of Talgai, had large jaws and also a great brain space. Prof. Dubois recognised that the Wadjak skulls had Australian affinities. At first there was no suspicion of a direct relationship between the small-brained and lowly-placed *Pithecanthropus* and the large-brained Wadjak man. A discovery made by officers of the Geological Survey of Java makes it possible to believe that *Pithecanthropus* may be the ancestor of the Wadjak man, for the Solo skull, discovered in 1932, is intermediate to the other two skulls in many respects. It is intermediate in time and it is also intermediate in brain development. We cannot assert as yet that the Australian aborigines have been evolved from a pithecanthropoid ancestor, but with the Solo, Wadjak and Talgai discoveries providing a series of rising evolutionary steps, we have now to consider seriously the possibility of such an origin for the Australian aborigine. We have also to face the possibility of a separate or parallel evolution of various races of modern humanity. Modern races may have come by their neanthropic characters independently of one another.

In recent years, Africa has been providing evidence which raises a similar suspicion regarding the evolution of African races. In 1913 there were discovered at Boskop, in the Transvaal, fossil remains of a big-brained specimen of humanity. At first there was no evidence of its exact date, but now there are grounds for attributing it to a late phase of the pleistocene period. The Boskop type, with a strikingly large brain and relatively small jaws, proved to be the forerunner of the Strandloopers of South Africa. The Bushman type was also an inhabitant of South Africa in the later part of the pleistocene period as was proved in 1927 by the discovery of an ancestral form made by the Messrs. Peers in the Fish Hoek Cave, in the Cape Peninsula. The modern Bushman has not the size of brain or strength of jaw of his fossil ancestor. The Boskop and Bushman are cousin types, and we may hope to find their common ancestor.

Thus in later pleistocene times, Africa south of the Zambezi was the home of nearly related races, big in brain but short in stature. At a much earlier period—perhaps as far back as the pliocene period, this part of Africa was the home of a remarkable anthropoid ape—one which made a nearer approach to man than either the chimpanzee or gorilla. The existence of this remarkable ape—*Australopithecus* it was named by Prof. Raymond Dart—was made known by the discovery in 1924 of a fossilised skull of a young individual in a limestone quarry at Taungs in the Harts River Valley some eighty miles from Kimberley. The varying opinions formed by experts as to the significance of the Taungs discovery will be found in the columns of NATURE from 1925 onwards. Indeed every discovery of ancient man made in recent years has found a full record in these pages.

When we move to Africa north of the Zambezi, we enter another territory of human evolution. Deep in the mine at Broken Hill, Northern Rhodesia, a remarkable fossil type of man came to light in 1921. The fossil type thus discovered is one of the most primitive forms of humanity known to us. In his structural composition, Rhodesian man displays everything that we expect in an early stage of the evolution of modern man (*Homo sapiens*). Unfortunately, there was nothing found with the bones of Rhodesian man which tells us at what point in the pleistocene period he lived ; we infer from the circumstances in which he was found that he is at least mid-pleistocene in date. Some light has been thrown on this and other problems relating to the history of early man in Africa by Dr. Louis Leakey's researches. Dr. Leakey led three expeditions to East Africa between 1925 and 1932, in the course of which he demonstrated the existence of implement-containing deposits covering the greater part of the pleistocene period. Near the base of these deposits was discovered a fragment of a human lower jaw —which has characters not unlike those we expect to find in Rhodesian man. In strata of later but of uncertain date at Kanjera, Dr. Leakey found cranial fragments of the most primitive type of Negro known to us. At first sight, the difference between the Rhodesian and Kanjera types of humanity seems very great, and yet in the opinion of the writer it is possible to conceive the evolution of the Kanjera Negro from Rhodesian man. Whether this evolution has taken place or not is one of the many problems which students of fossil man may hope to solve in the near future.

When King George came to the throne our knowledge of ancient man was almost entirely confined to Europe. Java was the only exception. Discoveries of fossil man of extinct types have now been made in every continent of the world. Every large land area—Europe, Asia, Africa and Australasia—has yielded fossil remains of human types totally different from any now living—all save America. No evidence has been found of the existence in the New World of a type of humanity that differs materially from types which still exist in America.

Discovery and Significance of Vitamins

By SIR FREDERICK GOWLAND HOPKINS, P.R.S., Sir William Dunn Professor of Biochemistry, University of Cambridge

UNTIL the end of the first decade of the present century, official teaching concerning the nutritional needs of the human body was still based on the results of classical studies by Carl Voit and Max Rubner and on the views of the Munich School thence derived. The adequacy of a dietary was measured in terms of calories and protein alone. It was generally believed, alike by the academic physiologist and by those concerned with practical dietaries, that, questions of palatability and digestibility apart, so long as the food of an individual provided sufficient potential energy for the activities of his internal organs and for the external mechanical work he might be called upon to do, the only demand of a more specific kind made by his body was for a certain, rather ill-defined, minimum of protein, to subserve the growth and maintenance of its tissues. Beside the carbohydrates, fats and proteins which provide these essentials, natural foods were known, of course, to contain a variety of other substances. These, however, are present individually in very small amount, and except for certain minerals among them, necessary for the formation of bone and for the maintenance of particular physical conditions in the body, they assumed to be without nutritional importance.

Facts, nevertheless, were already known which might well have suggested that the body makes calls upon its food to supply needs more subtle and more specific than those thus recognised. The history of scurvy, for example, and the clear demonstration, made already in the eighteenth century, of the dramatic cure of that fell disease which follows upon suitable, though relatively very small, additions to an errant dietary, should, it would seem, have provided a strong suggestion for the existence in certain foods of a substance small in amount but with highly specific properties essential for the support of normal nutrition ; that is, for the existence of what we now define as a vitamin. But unfortunately, the views of the majority concerning the influence of anti-scorbutic foods remained for many years vague and obscure. It was attributed to such qualities as 'freshness' without further analysis of these qualities, or to known constituents without proof of their efficacy. True, so far back as 1841, an American physician, G. Budd, had ascribed the action of such foods "to an essential element which it is hardly too sanguine to state will be discovered by organic chemistry or the experiments of physiologists in a not far distant future". Had organic chemists or physiologists been then stimulated by this objective view to seek for a definite substance in such well-known anti-scorbutic materials as, say, lemon or orange juice—a substance which when isolated could display by itself the anti-scorbutic powers of these fruits—it is likely that a realisation of the significance of vitamins might have come long ago ; but current thought concerning nutrition was not yet prepared to profit from such suggestions.

Scurvy, of course, is now recognised as one of a group of so-called deficiency diseases—pathological conditions in each of which a group of symptoms is displayed, directly due to the lack of some necessary nutritional factor. It was in 1897 that evidence for the existence of another such disease was clearly revealed. Eijkman, a Dutch hygienist, had been led by extensive observations to the belief that the disease beriberi was associated with the consumption by human communities of polished rice as a basal food. He then found that it is possible to produce an illness in fowls similar to beriberi by feeding the birds on polished rice, and he was further able to prevent or cure it by administering an extract of rice polishings. The discovery that the disease could be thus produced and cured experimentally greatly assisted its study ; just as the later observation of Holst and Fröhlich that the guinea pig rapidly displays the symptoms of scurvy when placed upon scorbutic diets, while promptly cured by anti-scorbutics, made easy the experimental study of the latter disease and provided a ready biological test for the presence and relative amounts of the curative agent in various foods.

The explanation first offered by Eijkman for the production of beriberi during the consumption of polished rice was to the effect that the condition is a state of intoxication brought about by the consumption of excessive quantities of starch, and that in the so-called 'silver skin' which is removed by polishing, though not in the bulk of the grain, there is a substance which counteracts the toxic products of the disturbed metabolism. This hypothesis was far-fetched and inhibitory, but the conception of disease as the direct result of a specific deficiency in food was foreign to the thought of the time. Later, however, partly owing to the work of others and partly to extended experiments of his own, Eijkman came to the definite conclusion that there is present in rice polishings an individual substance differing from the then known food constituents, but essential to normal nutrition, though required in very small amount. Even before Eijkman himself had come to this final conclusion, the work of others had made it probable, and by 1910 the significant facts had become fully established. Among those whose work contributed to their establishment must be mentioned : Grijns, a countryman of Eijkman ; Vedder and Chamberlain, of the American Medical Service ; and the British investigators Fraser and Stanton, whose investigations were carried out in the Malay States. All of these helped to prove that the preventitive of beriberi is a definite chemical substance, and the last-mentioned in particular took pioneer steps which were ultimately to lead later workers to a successful isolation of that substance.

Those who worked on beriberi during these years thought and wrote as pathologists, with their attention primarily directed to the causation and cure of a particular disease. Though doubtless the suggestion for an extension of the kind of knowledge gained was ready to hand, as a matter of fact their writings at first contained no reference to the possibility that substances with the properties we now attribute to vitamins might function widely and prove to be necessary for the support of such fundamental physiological processes as growth itself.

This more general and more physiological conception of the functions of vitamins arose directly from the results of feeding animals on experimental diets. If the assumption were right that proteins, fats and carbohydrates, together with essential minerals, are the sole nutritional necessities, then these materials should support all the functions of the body when each of them is supplied in a pure form, no less adequately than when, in natural foods, they are consumed in association with small amounts of many other substances. The nutritional value of such purified materials supplied in artificial dietaries was at one time the subject of many experiments. The results of these were uncertain and contradictory, owing to the fact that purification was often not complete. It was not then realised that substances present in extremely small amount may profoundly affect the value of a diet. It is this circumstance that our present knowledge of vitamins has made so clear.

In 1906–7 the writer engaged in feeding rats upon highly purified materials of the above kind, and found them wholly unable to support health or normal growth, though certain additions, very minute in amount, greatly increased their nutritional adequacy. It happened that yeast extracts were among the addenda which were successful in this respect, but only, as is clear to-day, because the fat employed in these experiments was filtered butter fat. We know now that butter itself contains certain of the essential vitamins, while yeast supplied the others. These experiments confirmed a personal belief in the importance for nutrition of minor constituents in natural foods, and public expression was given to this belief ; but the experimental results were not then published.

In the autumn of 1911 the results of later experiments were communicated to the Biochemical Society, and these were published in the following year in a paper which made a general claim for the "importance of accessory factors in normal dietaries". Funk at about the same time impressively summarised the then available knowledge concerning deficiency diseases, and proposed the name 'vitamine' for the substance of which a lack might in each case be presumed to produce the pathological condition. On chemical grounds J. C. Drummond suggested that the final 'e' in Funk's proposed name should be omitted, and this has become customary. By 1912, then, there was fully adequate evidence for the wide importance of vitamins, and from that time progress in their study has been continuous.

Immediately before the War and until near its end, American investigators were the chief contributors to this progress. T. B. Osborne and L. B. Mendel at Yale and E. V. McCollum at Wisconsin (afterwards at Johns Hopkins University) were separately engaged upon nutritional experiments with artificial dietaries. For a little while after the present writer's publication in 1912, these workers were not fully convinced of the necessity for a vitamin supply. Osborne and Mendel believed for some time that they had succeeded in maintaining rats upon purified diets. Soon afterwards conviction came, and important contributions to the subject were made at both centres. In particular, American studies produced at this time proof that vitamins existed in natural foods in different associations, and led to a distinction between 'fat soluble' and 'water soluble' individuals; a distinction which, though in itself not of fundamental importance, greatly helped later developments in the subject, many of which have been due to workers in America.

During the later stages of the War, when many nutritional problems had to be faced, intensive studies began at the Lister Institute in London. These comprised pioneer work by A. Harden and S. S. Zilva, and the important experiments of Harriette Chick and her colleagues, which have continued to the present day. At this time, University College, London, became also a centre of activity owing to the work and influence of J. C. Drummond, while the classical experiments of E. Mellanby on the production of rickets were already in progress. A few years later, interest in the subject penetrated into every European country, and research became everywhere very active. Recently, publications dealing with vitamins have reached a total of a thousand in a single year.

To-day we have knowledge of some eight or nine vitamins, each proved to have its own specific influence in maintaining the normal course of events in the living body, and each exercising its functions when in exceedingly small concentrations. Happily the actual chemical constitution of some of them is now known.

It is, of course, impossible in a brief review to recount all the stages of discovery in the case of each of these substances. The existence of individual vitamins, each with its special influence in the body, has in the majority of cases been revealed by the experimental feeding of animals on the following general lines. Natural products or preparations—crude when experiments began—from natural sources, animal or vegetable, when simultaneously added in characteristically small amounts to a vitamin-free dietary, were found to render it capable of supporting normal nutrition. The tendency at first was to assume that each effective addendum contained one active ingredient. The next step in progress, however, involved the fractionation of each crude preparation, and this in many cases revealed the presence of more than one vitamin, with obviously distinct functions, each calling therefore for separate endeavours towards its isolation and purification. It may be mentioned in illustration that yeast, which because it represents a concentrated mass of living cells capable of active growth, and at the same time is available in large amounts, was early and justifiably looked to as a probable source of vitamins, has yielded some of them in a complex which even to-day has perhaps not been fully analysed.

The position of knowledge at the present moment will be made sufficiently clear if the most salient characteristics of each recognised vitamin are very briefly reviewed. Unfortunately, it is impossible at the same time to give credit to the many who have shared in the heavy labours involved in the remarkable recent advances in the subject.

Vitamin A. This vitamin is found in association with animal fats and exists in specially high concentration in the livers of fishes. It was discovered and studied in cod liver oil, and at first was not distinguished from vitamin D, but by 1922 it had become clear that there were two 'fat soluble' vitamins with functions entirely distinct.

Vitamin A exerts an important influence in the body. In its absence young animals fail to grow. Lack of a proper supply leads to degenerative changes in the epithelial cells which line the outer surfaces of the body, and among the characteristic symptoms which follow upon such a lack is a pathological condition of the eyes known as xerophthalmia. As an independent phenomenon night blindness may occur. Very noteworthy is the evidence which shows that an adequate supply of this vitamin protects against certain types of infection. One of the most interesting advances in our knowledge of vitamins is the recent proof that vitamin A is closely related chemically to the carotenes, a group of yellow pigments widely distributed in plant tissues, and the further proof that carotenes, when they are consumed in green vegetables, are converted in the liver into the vitamin itself. These discoveries have thus shown that vegetable foods are an effective source of the vitamin, and they have also greatly helped in leading to our present knowledge of its actual chemical nature. It has been obtained pure in the form of an oil, and chemical studies have revealed its essential molecular structure.

Vitamin B_1. This is the vitamin of which a deficiency in the food supply leads as a final issue to the disease beriberi. It exerts a general influence in the body, and would seem to be essential to the normal progress of carbohydrate metabolism, but a specialised aspect of its functions is the maintenance of a normal equilibrium in the nervous tissues. It is widely distributed in natural foods, but in concentrations which vary greatly. We have seen that the circumstance of its presence in the cortical parts of grains and absence from the endosperm led, through the work of Eijkman and his followers, to one of the earliest suggestions for the existence of vitamins. It is relatively abundant in yeast, and this has been the material chiefly used as a source of it for experimental work. Much effort in Great Britain, in particular by R. Peters, has been spent in the effort to obtain it in a pure state, an end which seems now to have been reached. Its actual molecular structure is not yet known, but its empirical formula is probably $C_{12}H_{16}N_4OS$. Alone among the known vitamins it contains sulphur in its molecule.

Vitamin B_2. When yeast extracts were first employed as addenda to deficient diets, their most notable effect, apart from the promotion of growth, seemed to be the prevention of nervous lesions. They were supposed to supply an 'antineuritic' vitamin alone. This is now B_1. Further studies of such extracts showed, however, that they certainly contain at least one other vitamin more stable towards heat than B_1, and clearly showing quite different properties. In its absence serious skin lesions develop resembling in animals those seen in the human disease pellagra. There is now indeed little doubt that a prominent factor in the causation of this disease is a lack of this vitamin in the food. It has been labelled B_2. Quite recently, however, a further complication has come to light in this connexion. Preparations of 'B_2' as hitherto employed would seem to contain two active factors, one promoting growth without being concerned with skin conditions, and a second to which the 'anti-pellagra' influence is due. The latter is now under intensive study, but its chemical nature is yet unknown. The former, like vitamin A, is related, as shown by the researches of R. Kuhn and P. Karrer, to a group of naturally occurring pigments, but in this case to the flavines. The vitamin is in fact identical with a flavine which is present in milk.

Vitamin C. While the prevention and curative influence of foods containing this, the antiscorbutic vitamin, has been so long known, it remained for quite recent research to establish its existence as a definite chemical substance, to produce it pure and to determine its exact chemical nature. It is present in most fresh foods but often only in very small amounts. It is present in greatest concentration in fruits and green vegetables, but in amounts varying greatly from species to species. Cereal foods contain none. It is characteristically less stable than the other known vitamins, being destroyed when foods are long kept, dried or heated; the influence of oxygen being a potent factor in its destruction. This instability accounts for many chapters in the long history of scurvy and its incidence. Much labour has been spent during recent years in determining quantitatively its distribution in foods and in endeavour to isolate it. Success in the latter aim was reached by A. Szent-Györgyi three years ago. Its constitution has been fully worked out by W. N. Haworth and his colleagues, revealing the interesting fact that the physiologically potent substance is related to the simple carbohydrates, being a derivative of the hexose sugar gulose. The vitamin is now to be known as ascorbic acid.

Vitamin D. This, the anti-rachitic vitamin, is generally associated with vitamin A in animal fats, and with the latter, is present in exceptionally large amount in fish liver oils. Studies in the etiology of rickets have proved that this disease can be prevented or cured, on one hand by an adequate supply of this vitamin in the food, and, on the other, by adequate exposure of the body to sunlight. A satisfactory explanation of this remarkable relation arrived with the proof that ultra-violet irradiation converts an inactive precursor into the vitamin itself, and that the former is present in the tissues. During the year 1929, owing in particular to the work of Rosenheim and Webster, and that of Hess and Windaus, it was made clear that the substance which on irradiation is activated is ergosterol, which in small amounts is present in most living tissues. As it is therefore present in many natural foods, the anti-rachitic value of these is increased by exposure to rays of suitable wave-length. A preparation of the vitamin made by the irradiation of ergosterol *in vitro* is known as 'calciferol'. Its potency is remarkable; one ten thousandth of a milligram a day added to a rickets-producing diet will in a rat entirely prevent the appearance of the disorder. In the case of a child the effective daily dose is a very small fraction of a grain. The rigorous proof that lack of a fat-soluble vitamin is responsible for the induction of rickets was furnished by the classical experiments of E. Mellanby begun twenty years ago. More recently, the importance of vitamin D in the processes of normal dentition has been shown by May Mellanby.

Vitamin E. In 1922 it was first shown by H. M. Evans and K. S. Bishop that a vitamin, distinct from others then known, is essential for successful reproduction. It has been termed the anti-sterility vitamin, but this term implies functions more specific than those which are actual. Deprivation of vitamin A, for example, will ultimately lead to failure in reproduction. Nevertheless, the influence of vitamin E (now so-called) is exerted on specific lines. In its absence, there is degeneration of the testes in the male and a failure of the placental functions in the female. The richest sources of this vitamin so far discovered are certain green vegetables and wheat embryos. It is, however, widely distributed in food-stuffs, and as it is active in very small amounts, the possibility of any lack of it can seldom arise. Its constitution is unknown.

These very brief descriptions of the known vitamins leave out, of course, a multiplicity of facts which have been discovered concerning each of them, and omit reference to the work of very many investigators. They may serve, however, to indicate the lines on which vitamin research has hitherto progressed.

Characteristic of each vitamin is the very small amount in which it exercises its physiological functions, and the circumstance that all are present in very low concentrations in the materials from which they have to be separated has greatly added to the difficulties of their study. It will be admitted, however, that we have now a sound body of knowledge concerning them, establishing their nutritional importance and throwing no little light on their nature. Research in the field is now receiving much help on its constitutional side from modern physical methods, and on its biological side from increasing interest on the part of a large number of clinicians. Vitamin therapy is now joining hands with endocrine therapy, and the League of Nations Permanent Commission on Biological Standards has recognised its growing importance by accepting standards for measures of vitamin activity and defining units in terms of such standards.

Some at least of the conditions which are now grouped as deficiency diseases are of world-wide importance, and though the clear-cut symptoms which the experimentalist can observe in animals under strictly controlled conditions are often obscured by intercurrent infections or other complications in clinical cases, yet, once a food deficiency has been recognised as an essential link in the chain of causation, the method of cure becomes in every case as certain as it is logical. On the other hand, once the hygienist has become convinced that this or that disease is really due to faults in the diet of communities, its prevention, with or without administrative action, should be easy to secure. Although a defect in the supply of a vitamin, if serious and continued, may result in actual disease, it is, in Great Britain, more important to realise that a sub-optional supply of any essential food constituent cannot fail to induce sub-normal health which, especially when induced in childhood, may leave permanent disability.

Apart from its own inherent importance, the revelation of the significance of vitamins can fairly be said to have directed closer attention to the nutritional importance of other minor constituents of natural foods. The specific needs of the body are proving to be numerous, and lack of materials called for in very small amounts are proving to be just as important to final issues in nutrition as are those required in much larger amounts. This applies to the mineral as well as to the organic constituents of food, and ill-assorted diets may be deficient in the former no less than in the latter.

For the progress of scientific knowledge concerning these needs, each separate factor has called, and continues to call, for separate and intensive study ; but the demands of right nutrition need to be viewed as a whole. We need to know what should be the ideal balance among the many essentials, and how best to secure that it shall be approached in the food supply of all classes of the community. Short of this, we have to-day sufficient knowledge to be sure that malnutrition in its subtler aspects often accounts for disabilities which have hitherto been ascribed to constitutional defects or to other circumstances. With present knowledge, moreover, it should be easy, economic questions apart, to prevent such malnutrition everywhere. There is almost sufficiency in the statement that certain foods often held to be luxuries have to be recognised as necessities for all. Recognition of this bears upon all the problems of a national food supply ; upon production, preservation, transport and distribution.

It is interesting to remember that the effective development of the recent knowledge concerning the more subtle aspects of nutrition has been almost co-terminous with the reign of King George.

Structure and Physiological Activity

By JOHN PRYDE, Lecturer in Physiological Chemistry, University College, Cardiff

A SURVEY of the road which the biochemist has trodden during the past twenty-five years reveals a plenitude of milestones whereby the rate and extent of his forward march may be judged. The year 1910 was within a short span of the birth of his science ; only four years earlier, the *Biochemical Journal* had first seen the light of day. The records of this now twenty-nine-year-old journal bear witness to the immense expansion and deepening, during the past quarter of a century, of our knowledge of the laboratories of the living cell, and there are many similar records to be found in other countries. New light has come from all sides on the chemical processes of the organism in health and disease, in life and in death. Innumerable new substances and previously unknown phenomena have been discovered and added to the ever-increasing physico-chemical complexities of living cells and tissues.

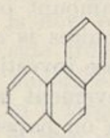
Yet despite this immense accumulation of detail, the answers to these persistent questions—"Just what happens in this particular living cell, and how does it happen ?"—seem to elude us. Consider for a moment the contraction of a group of muscle cells, surely one of the most universal processes of animal activity. In 1907 appeared Fletcher and Hopkins's 62-page paper on "Lactic Acid in Amphibian Muscle", the first really effective attack on the problem of the possible rôle of this acid in the contractile process. At that time, lactic acid was the only known 'intermediate' substance supposed to play a part in the phenomenon. Now turn to the list of substances, many then unknown, revealed to-day as participating in this apparently simple process—hexose diphosphoric and monophosphoric acids, α-glycerophosphoric acid, phosphoglyceric acid, adenylic acid, phosphoric and pyrophosphoric acids, phosphagen or creatine phosphoric acid, pyruvic acid, methyl glyoxal, glyceraldehyde, dihydroxyacetone, and . . . but who of us is bold enough to write *finis* to this catalogue ? In the numerous attempts to build up the chemical jig-saw here provided, many new and interesting and doubtless important facts have obviously been revealed, but we still seem to be almost as far as we were in 1907 from forming a really comprehensive picture of the sequence of events in a contracting muscle. Indeed one investigator has suggested that all the chemical transformations so far studied are really recovery processes, and do not directly participate in the contractile phase.

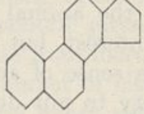
The present position of muscle chemistry will serve to illustrate one type of problem which the biochemist is studying in his attempt to provide an answer to the questions already mentioned. There are many similar problems. Most of them afford as much encouragement as the muscle problem to those who aspire to conquer fresh fields ! There are also, however, problems of a rather different type which likewise concern the biochemist. A scrutiny of the records of the investigations here referred to conveys a greater sense of immediate achievement than that which is derived from a consideration of the muscle and similar problems. Here we have revealed to us the nature, and in many cases the detailed structure, of compounds of immense physiological potency, compounds some of which determine the issue between life and death, whilst others possess well-nigh incredible potentialities for the well-being, in some cases the ill-being, of living organisms. All seem to exercise their functions in the minutest traces, a fact which has added greatly to the difficulties of their isolation and identification, but during the last decade the progress achieved in this direction is highly impressive.

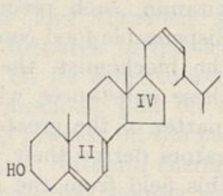
Most of the compounds now to be discussed may be assigned to one of two classes, hormones or vitamins—hormones if they are elaborated within the animal by specific tissues which derive their 'raw material' from the food supply, vitamins if they must be supplied pre-formed in the foodstuffs. This classification cannot be applied too rigidly, but it will serve. As we shall see, certain vitamins can be formed by the animal body, from precursors of very closely related chemical structure but devoid of the characteristic physiological properties of the vitamin. In the absence of the vitamin, such precursors assume the rôle of indispensable food constituents. To the chemist and the biochemist, the smallness of the amount of these substances which the animal requires is a matter of the greatest interest, but these investigators derive their main sense of achievement in this field from the ability to put down on paper the constitution or structure of the substances concerned. How the substances produce their specific effects is a secret so far guarded by Nature even more efficiently than that of the muscle. Nonetheless, science is for the present well content with having established the existence and structure of at least some of these enormously potent substances upon which animal life depends for its very existence.

The constitutions of the known hormones or vitamins do not afford, in the absence of empirical information from other sources, *a priori* grounds for deducing their physiological activities, or for differentiating between an active compound and some closely related inactive compound with a structure but slightly different from that of the active one. Such *a priori* deductions would necessitate much more fundamental correlations between structure and physiological activity than are yet available. But, in actual fact, empirical information is rapidly accumulating, and as it becomes co-ordinated it is found possible to make certain prognostications regarding structure and physiological activity, to suggest, for example, what type of structure is likely to possess a particular activity, and possibly how such activity may be modified when certain substituent groups are added to or taken away from the basic structure.

These general considerations are well illustrated by a series of compounds, including both hormones and vitamins, which have in common as a structural basis the condensed benzene ring system which the organic chemist calls phenanthrene. The reduced phenanthrene system plus a fourth five-membered carbon ring forms the cholane nucleus ; this nucleus is found in the bile acids and in cholesterol and the other sterols. One of these sterols, ergosterol, $C_{28}H_{44}O$, when subjected to the action of ultra-violet radiation, undergoes a sequence of transformations, and amongst the products formed under suitable conditions is calciferol, which is isomeric with the original ergosterol. Calciferol, which has been isolated in a pure crystalline condition, is vitamin D, the anti-rachitic vitamin essential for adequate ossification and for the control of calcium metabolism in the animal organism. The structure of ergosterol is not yet ascertained in all its details, but existing evidence is in accord with the formula shown in skeleton below.


Phenanthrene

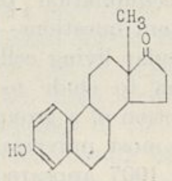

Cholane nucleus



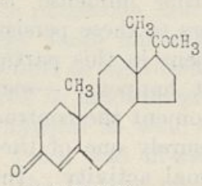
Suggested formula of ergosterol

It would appear that the transformation of ergosterol into calciferol involves the shift of the double bonds in ring II in the direction of the double bond in the side-chain of ring IV. But a final decision cannot yet be reached. The vitamin calciferol may be ingested as such by the animal. On the other hand, it may be formed within the animal from previously ingested ergosterol. This synthesis *in vivo* of the vitamin from its nearly related precursor has been proved experimentally to occur when ultra-violet radiation impinges on the skin. The active rays have sufficient penetrative power to effect the transformation. We have here the basis of the curative action in rickets of ultra-violet rays of solar or other origin.

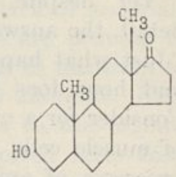
A structure of the cholane type is found in a series of recently discovered hormones possessing remarkably interesting properties. These are the sex hormones which determine the secondary sex characters of animals. Three have been definitely characterised, the female follicular hormone or œstrone, the female corpus luteum hormone or luteosterone, and the male testicular hormone or androsterone. All three show close structural relationships with each other and with the bile acids and cholesterol, amongst which their biological precursors are likely to be found. The accepted structures of the three hormones are given below.



Œstrone

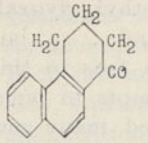


Luteosterone

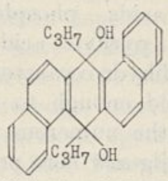


Androsterone

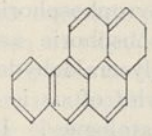
A development of exceptional interest in relation to structure and physiological activity is the preparation by synthetic means of artificial œstrogenic substances, that is, of substances not found naturally, but which possess an activity similar to that of œstrone. One of these is 1-keto-1 : 2 : 3 : 4-tetrahydrophenanthrene, another is a derivative of the hydrocarbon 1 : 2 : 5 : 6-dibenzanthracene, of which further mention will be made.



1-Keto-1:2:3:4-tetrahydrophenanthrene



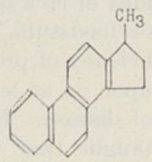
Derivative of 1:2:5:6-dibenzanthracene


1:2-Benzpyrene

The phenanthrene structure, common to all the substances so far considered, will be seen in the formulæ shown above. These two synthetic œstrogenic substances, it is of interest to note, do not show any androsterone activity.

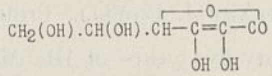
In the hydrocarbon 1 : 2 : 5 : 6-dibenzanthracene, we encounter one of the very interesting and, from human standards, very sinister synthetic carcinogenic hydrocarbons. This hydrocarbon produces, when applied to the skin of mice and rats, tumours which can be transplanted and are in all respects similar to malignant cancerous growths. Yet the addition of two *n*-propyl and two hydroxyl groups converts it to an œstrogenic substance! Dibenzanthracene is but one of a number of synthetic carcinogenic hydrocarbons. All of these contain the phenanthrene nucleus. Moreover, the long-recognised cancer-producing action of certain tars has now been traced to the presence of a hydrocarbon allied to dibenzanthracene and known as 1 : 2-benzpyrene. It has been synthesised independently of its isolation from coal tar, and the powerful carcinogenic action of the pure substance has been amply confirmed. It is, in fact, the most potent carcinogenic substance so far discovered. It too will be seen to contain the phenanthrene nucleus.

Suggestive and interesting as is the rôle of the phenanthrene nucleus already outlined, three further references are required to complete the tale. First, a series of toxic cardiac-stimulating glucosides is known. These are derived from various plants including those of the species *Digitalis* (foxglove) and *Strophanthus*. The aglucones (that is, the non-sugar parts) of digitoxin, strophanthin and several other closely related substances embody structures of four carbon rings which ally them closely to the sterols. For example, the dehydrogenation of the aglucone strophanthidin with selenium yields the well-known Diel's hydrocarbon, $C_{18}H_{16}$, of which the constitution has been established by synthesis. It has been prepared from several members of the cholane series, and its relationship to this series is beyond doubt. Many other structural details are known concerning the aglucones of the cardiac-stimulating glucosides and in some cases a complete structural formula can be suggested even now. Secondly, mention must be made of the toad poisons, amongst which is the Chinese drug Ch'an Su. These contain structures closely allied to those of the cardiac aglucones, and possess a characteristic action on the heart similar to that of *Digitalis* preparations. Lastly, brief reference may be made to the significant fact that the phenanthrene nucleus is present in some of the most powerful alkaloids, in morphine and codeine of the opium group, in the corydalis alkaloids and in colchicine (meadow saffron).



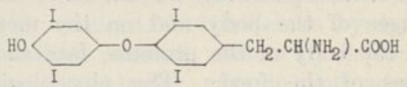
Diel's hydrocarbon, $C_{18}H_{16}$

Let us leave now these inimical carcinogenic hydrocarbons, toxic glucosides, toad poisons and alkaloids and return to the kindlier theme of vitamins and hormones. From the remainder of our story there stand out two achievements. In both cases the proofs of the nature of the substances concerned—a vitamin in one case, a hormone in the other—have been clinched by syntheses. Ascorbic acid, as the anti-scorbutic vitamin C is now termed, and thyroxine, the iodine-containing amino acid which confers upon the secretory protein of the thyroid gland its specific function as a regulator of the metabolic rate, have both been isolated in a pure state, and both have been synthesised. As a justification for treating these two diverse substances together in this way, we may cite the exceptional brilliance of the work on the synthetic side. The structures are shown below. It will be seen that ascorbic



Ascorbic acid

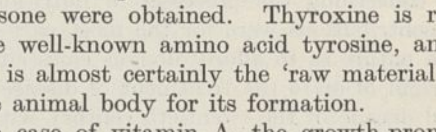
acid is a near relative of the carbohydrates—the starting material used in its laboratory synthesis



Thyroxine

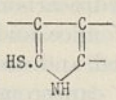
was a hexose, *d*-galactose, from which *l*-lyxose and *l*-lyxosone were obtained. Thyroxine is related to the well-known amino acid tyrosine, and the latter is almost certainly the 'raw material' used in the animal body for its formation.

The case of vitamin A, the growth-promoting vitamin, is especially interesting, since here we have another case of a vitamin which may be taken into the animal body as such, or in the form of a closely related precursor. The precursor is the remarkable, intensely coloured polyene hydrocarbon carotene, with no less than forty carbon atoms. At least four isomeric carotenes occur in natural plant sources, and all appear to give rise to vitamin A in the animal body. Approximately one half of the carotene molecule goes to form vitamin A, which almost certainly has the formula $C_{20}H_{30}O$. The structure of the vitamin cannot yet be regarded as settled, but there is much evidence in favour of that given below.

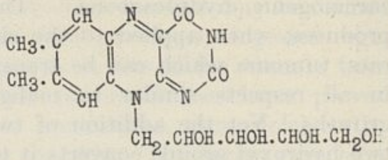


Probable formula of vitamin A

We may end our survey with a reference to advances which are being made in the elucidation of the structures of vitamins B_1 and B_2. Vitamin B_1 has the formula $C_{12}H_{18}O_2N_4S$. There appear to be two ring systems present ; one a glyoxaline or pyrimidine, the other a pyrrole containing a substituent sulphur. Interest in vitamin B_2 has been greatly stimulated by the recent discovery that the flavins, which are yellow water-soluble dyes present in both animal and vegetable sources, possess intense vitamin B_2 activity. The flavins are derivatives of alloxazine, and a substance stated to be identical with lactoflavin of milk whey has already been synthesised. It possesses the complex ring systems shown. So discovery



One of ring systems of vitamin B_1



Lactoflavin

marches onwards ! Who shall say what additional structural formulæ will be recorded in a similar survey after the lapse of another quarter of a century ?

Diet and Disease

By PROF. STUART J. COWELL, Professor of Dietetics, St. Thomas's Hospital Medical School, London

THE twenty-five years of His Majesty's reign which are now being celebrated correspond remarkably closely with the establishment of a new era in the science of nutrition. At the opening of the twentieth century, attention was being focused on the quantitative relations of the energy exchanges of the body and on the metabolism within the body of the proteins, fats and carbohydrates of the food. The physiologists and chemists working at these problems were making most valuable contributions to the body of knowledge concerning the processes of nutrition, but such contributions were for the most part not of such a nature as to afford obvious clues either to the origin of or to the treatment of disease. The second decade of the twentieth century witnessed the rapid development of the view that the adequate nutrition of an animal depended on the presence in its food of hitherto unsuspected elements. The absence of such essential elements from a diet was proved to result regularly in the appearance of predictable signs of disease, and the fundamentally new idea of deficiency diseases became gradually established in current medical teaching.

Before mentioning any of the effects which this new conception of nutrition has had on the problems of the prevention and treatment of disease, it will be useful to hark back to the 'pre-Georgian' era to review the current teaching of the medical profession regarding the relation of diet to disease. The fact that faulty diets are often the direct or indirect cause of disease was of course fully recognised, as it had been for many centuries. But there was little precise knowledge available to enable definite diseases to be ascribed to specific dietetic errors. Over-eating was regarded as predisposing to many gastro-intestinal diseases, gout and raised blood pressure, and under-eating was considered to render the body more liable to invasion by harmful bacteria. The idea of lack of balance between the various classes of foodstuffs, for example, relative excess or deficiency of protein, carbohydrate or fat was looked upon as at least an important contributory cause of disease. In the case of scurvy, it was already taught that the absence from the diet of some principle which was present in fresh foods but not in stale foods contributed largely to the production of the disorder. Otherwise the production of disease by faulty diet was largely related to the presence of toxins, pathogenic bacteria or living parasites in food which had become accidentally contaminated.

With regard to the practical dietetic management of diseases now known to be due to specific dietetic faults, the degree of divergence between the methods of twenty-five years ago and of the present day is distinctly less than would have been expected from a consideration of the knowledge available then and now. Specific remedies in medicine have again and again been discovered empirically, and this is true in the realm of dietetics. The treatment recommended twenty-five years ago by at least some enlightened authorities for many of the diseases now spoken of as deficiency diseases would prove satisfactory enough to-day, although such treatment was based on no actual knowledge of the dietetic factors involved. Scurvy was treated by giving fresh fruit and fresh vegetables, rickets and osteomalacia by giving cod liver oil and milk, beriberi by increasing the 'nitrogenous' constituents and diminishing the carbohydrate of the diet—some individuals were even claiming that it could be prevented by adding rice polishings to the diet of highly polished rice which was usually eaten in districts where this disease occurred—and finally pellagra was to be treated by cutting maize out of the diet.

This list of diseases comprises most of those commonly regarded to-day as vitamin deficiency diseases, and there are not lacking critics of modern nutritional research who profess to be unimpressed by its practical value in clinical medicine because many of its obvious applications had been forestalled by empirical methods of treatment. Such arguments fail to recognise the frequency with which valuable methods of treatment fall into disuse or are replaced at least temporarily by worthless imitations when little or nothing is known of the physiological action of the agents effective in alleviating the symptoms of disease. Thus the value of fresh lemon juice in curing scurvy was known in the eighteenth century, but was forgotten for long periods, and far inferior therapeutic agents were sanctioned by high authorities as late as the present century. Similarly the value of cod liver oil for the cure of rickets had been appreciated for many years before the discovery of vitamins, but this did not prevent the subsequent recommendation of inert vegetable fats as satisfactory substitutes.

It is not argued that empirical treatment has no stable foundation in therapeutics, for clinical medicine still makes use of many old-established therapeutic measures which have as yet no scientific basis. But it is no less certain that the scientific demonstration of a definite cause for a disease offers the best chance for the discovery of satisfactory preventive and curative treatment, and when the cause is proved to be a comparatively simple deficiency in the diet, there should be no excuse whatever for allowing such knowledge to sink into oblivion.

It is now proposed to show how the conception of food deficiencies as a cause of disease has developed during the past twenty-five years. The great stimulus to the remarkable activity shown in this field of medical investigation during this period was undoubtedly the discovery of the vitamins, but the success rapidly attained by those engaged in studying the effects of vitamin deficiencies encouraged the investigation of the effects of other deficiencies, for example, deficiency in the mineral components of the diet, with the result that in such fields also many observations of the greatest importance have been made which have already proved invaluable alike in clinical and in veterinary medicine.

The period of nutritional research which we are surveying had already been heralded by isolated suggestions regarding the importance of dietetic factors other than proteins, fats, carbohydrates and minerals salts for the maintenance of health. Already in 1897, Eijkman had published his experiments on the production of beriberi, which led ultimately to the discovery of the antineuritic vitamin. Hopkins had stated in 1906 his conviction that scurvy, rickets and probably other states of ill-health were caused by unknown dietetic errors the nature of which was bound up with a defective supply of obscure food components. In 1907 Holst and Frölich paved the way for the identification of the antiscorbutic vitamin by producing experimental scurvy in guinea pigs. But it was not until Hopkins had demonstrated in 1912 the fundamental importance of 'accessory factors' in the diet for securing normal nutrition that the idea of specific food deficiencies as a cause of disease began to gain any general acceptance.

It is common knowledge that, since Hopkins's original announcement, the number of accessory food factors or vitamins generally recognised as being concerned in animal nutrition has been steadily increasing, though not all of them have been shown to be concerned in the production of human deficiency diseases. By the end of the first decade of King George's reign, overwhelming evidence had been produced to show that beriberi was produced by deficiency of the water-soluble antineuritic vitamin, xerophthalmia by deficiency of a fat-soluble vitamin, rickets by deficiency of the same or a similar vitamin and scurvy by deficiency of the water-soluble antiscorbutic vitamin. It is not possible to trace in detail subsequent investigations, which have led on one hand to the chemical identification of many of the vitamins and on the other to some understanding of their physiological action. It must suffice to point out how such knowledge has been applied to the prevention and treatment of disease.

In countries such as Great Britain, frank vitamin-deficiency diseases, with the single exception of rickets, are uncommon, but there is increasing evidence that partial deficiencies of vitamins, particularly during the period of growth, are often responsible for sub-optimal physical development, inperfections in the structure of bodily organs and tissues, lowered resistance to certain infective diseases and many vague subjective and objective symptoms of ill-health. It is almost certain, for example, that mild degrees of skeletal deformity caused by faulty feeding in childhood help to raise maternal mortality in childbirth by increasing the mechanical difficulties of labour. The low resistance of the teeth of large sections of our population to decay, with its many sequelæ of chronic disease and ill-health, is due in large part to faulty development of the teeth during the early years of life brought about by dietetic faults, of which vitamin D deficiency is the most prominent. Similarly it has been shown that, in dogs at least, the tendency to the development of pyorrhœa alveolaris in adult life is largely determined by the supply of vitamin A which was available during the period of growth. These few illustrations must suffice to indicate that the original conception of vitamin-deficiency diseases has extended its boundaries to include a variety of diseases attributable to past dietary deficiencies, preventable by suitable feeding during the period of growth.

Similar results have been achieved during the period under review by the study of specific mineral deficiency diseases. Prominent among those mineral elements deficiency of which in the diet may lead to recognisable symptoms of disease are iron, copper, iodine, phosphorus, calcium and magnesium. Lack of sufficient iron in the food has been shown to result frequently in the development of anæmia. Such 'nutritional' anæmia is particularly common in infants, and is accounted for by the fact that milk is a poor source of iron. The recognition of this form of anæmia has proved to be of considerable practical importance, because it is often associated with an increased susceptibility to many of the common complaints of infancy and can be corrected with great ease. The enormous amount of work that has lately been carried out on the relation between iodine deficiency and the development of goitre has not yet completely solved the problem of the causes of thyroid enlargement, but it has certainly provided very successful methods of wholesale prophylaxis in districts where goitre is endemic. Lastly may be mentioned the revolution in the cattle-rearing industry of South Africa which has followed the discovery of phosphorus deficiency as the immediate or ultimate cause of serious losses in this branch of agriculture.

There can be no question that already the modern conception of nutrition has produced practical results of immense significance in both preventive and curative clinical and veterinary medicine. The results are not confined to the prophylaxis and treatment of diseases which arise as the result of actual deficiencies in the food supplied. They have already been extended to include the treatment of diseases in which defects in the absorption or utilisation of particular food elements rather than faulty diets are responsible for the development of co-existing signs of deficiency diseases. The term 'secondary deficiency disease' is now being used to distinguish this particular class of nutritional disorder. In this group might well be placed that once fatal malady pernicious anæmia, which the brilliant researches of the past decade have shown to be amenable to simple dietetic treatment, although there is no evidence that dietetic errors play any part in its causation. As more and more precise information is gained concerning the intimate processes of metabolism within the body, there should be increasing opportunities of preventing and successfully treating disease by adjusting the diet to influence those metabolic processes which may produce the symptoms of disease when they deviate from their normal course. This has long been one of the aims of clinical medicine ; its ultimate realisation has surely been brought one stage nearer fulfilment by the nutritional investigations of the past twenty-five years.

Viruses as the Cause of Disease

By DR. JOSEPH A. ARKWRIGHT, F.R.S., Lister Institute of Preventive Medicine, London

AT the end of the nineteenth century, a new category of infective agents was discovered which are now classed as viruses, in the modern sense of the word. The chief property which unites them, and by which they have been distinguished from previously known minute parasites, is the extremely small size of their component particles, since these are smaller than bacteria, and many of them are not visible even with the highest powers of the microscope. Until quite recently, it was customary to speak of all viruses as invisible, but in some cases the minute granules of which the virus appears to consist can be clearly seen, when stained, by direct microscopic observation ; but in most cases they cannot be distinguished by their shape, but only by their uniformity, numbers and their source in special parts of the diseased tissues. The recent investigations by Barnard with the ultra-microscope and photomicrography by ultra-violet light have added to our knowledge of their size and form.

A special feature by which the invasion of the cells of the host by many viruses can be recognised is the occurrence of 'cell inclusion bodies'. These forms, of which there may be one or more in a single cell, vary in size and may be larger than the nucleus. Opinion as to their nature has undergone various vicissitudes. After their discovery, when they were at first hailed as protozoal parasites, they were for long regarded as merely reaction products of the cell protoplasm to the presence of the virus, a position now favoured for the 'inclusion bodies' associated with virus diseases of plants. More recently it has been shown that in some virus diseases of animals these 'inclusion bodies' consist of masses of the minute filterable forms of 'elementary bodies' held together by a soluble matrix. These bodies have been most completely and fruitfully studied in fowl-pox, small-pox, vaccinia, ectromelia—a disease of mice —and psittacosis, the infective disease of parakeets which also attacks man.

The list of diseases of man and animals due to filterable viruses is continually being increased, and considerably more than fifty are now known; their study has been intensified and especially productive during the last fifteen years.

The original recognition of the existence and importance of these agents was due to the use of earthenware and porcelain filters which retained the smallest bacteria. When tissue extracts or secretions from an infected animal were passed through such filters, the filtrates were shown to be infective and capable of reproducing the disease in a fresh animal; this process could be repeated indefinitely, proving that the active agent multiplied in the animal body and was not merely a chemical substance or toxin. The virus of foot-and-mouth disease, the first shown to cause a disease of animals, was discovered in 1898 by Loeffler and Frosch. It passes through finer filters than any other known virus, so that no question of visible particles has arisen, since massed granules or inclusion bodies have not been observed. The most essential qualifying characteristic of a virus has ever since been its filterability.

Most viruses remain active after being dried over sulphuric acid, and some are more resistant to alcohol and certain other disinfectants than bacteria. Many viruses are present in the tissue juices in high concentration, and such suspensions in liquids can still prove infective when diluted 1 in 10^5 or 1 in 10^6. The resemblance in many respects of a virus to an excessively minute bacterium has led to the belief in their similar nature which is now held by most pathologists. It must be admitted, however, that part of the argument is based on analogy, since viruses cannot be subjected to the same tests as bacteria to prove that they are living agents causing disease.

Besides the small size of the ultimate particles of a virus and the resulting absence of a recognisable differentiating morphology, there are certain other peculiarities distinguishing these two classes of agents. Bacteria, with few exceptions, can be propagated on sterilised artificial culture media, and can be obtained in pure culture by the method introduced by Koch of selecting single colonies grown on a solid sterile medium. By this means their infective and other activities can be examined without the risk of contamination with substances derived from the host. A virus, on the other hand, in most cases requires the presence of living cells of the host to enable it to multiply, and it often appears to grow only or chiefly inside the cells of the animal tissues. Artificial culture of a virus can, however, very often be maintained in pieces of animal tissue kept alive and growing apart from the body. The virus of fowl-pox, vaccinia or vesicular stomatitis of the horse and of some other diseases can also be propagated in the living embryo in an incubated hen's egg.

The fact that tissues of a host are needed to enable viruses to multiply has led to the suggestion that the virus may not necessarily be alive but may only serve as a stimulus to the host cells, causing them to reproduce the virus, and that the particles seen in a suspension containing a virus and indeed the virus itself are really products of the host.

This suspicion has been especially strong in the case of the infective transmissible sarcoma of fowls described by Rous, which can be reproduced by injecting a filtered cell-free extract of the diseased tissues into a normal fowl. The resemblance of avian sarcoma to other virus diseases extends to the recognition by Ledingham and Gye, by the use of the high-speed centrifuge, of minute particles resembling those of other viruses. The nature of these particles was moreover confirmed by their reaction (agglutination) with the blood serum of animals which had been injected with the sarcoma, in the same way that similar reactions have been demonstrated with the elementary bodies from other virus diseases.

The resemblance in structure and behaviour of the sarcoma of fowls to the malignant growths of mammals gives rise to hesitation before admitting that it is caused by an extrinsic virus, since mammalian malignant tumours have never been found to yield an infective cell-free extract and have been usually regarded as due to intrinsic tissue changes, though both mammalian and avian sarcomata can be induced by external physical and chemical irritants, such as tar and certain other substances.

If therefore an extrinsic virus is one of the essential causes of fowl sarcoma, it must already be present in every susceptible fowl. The view that viruses which produce disease are not essentially invading parasites, but are produced by the host, is opposed by the regularity with which diverse viruses can be propagated in the same kind of animal, and by the fact that the same virus may infect several widely different species. For example, there are three distinct types of foot-and-mouth disease virus which produce apparently identical symptoms in animals and can only be distinguished by the fact that any one does not protect an animal against infection with the other two; nevertheless, each virus maintains its identity whether propagated in the cow, pig, guinea pig, rat or hedgehog. It is difficult to see how this could happen if the virus were produced by each species of mammal from its own tissues.

Another filterable agent, in many respects resembling the virus of an animal disease, is the bacteriophage, which was independently discovered by Twort and d'Herelle. The effect of a drop of a suspension of bacteriophage added to a young liquid culture of susceptible bacteria is that the latter are dissolved and a large amount of fresh phage is produced. The bacterium-free filtrate of the liquid culture may often be diluted ten million times and still the same effect be produced by a drop as by the original suspension.

D'Herelle and many other bacteriologists believe that the phage is a living agent which infects young growing bacteria, multiplies in their interior, and is set free when the bacteria die and break up.

Phage, though destroyed at a temperature of 70°–75° C., as a rule survives at 60°–65° C., when the bacteria with which it is associated are killed ; it also resists drying and is remarkably resistant to the action of alcohol, acetone and chloroform. D'Herelle considers that all strains of phage are really one, though different strains become adapted to different bacteria, but more probably many phages when first obtained are a mixture of distinct races, and most filtrates containing phage are in the first instance derived from sewage or fæces, containing a great variety of bacteria.

Some strains of bacteria harbour a phage although apparently insusceptible to its destructive action. The activity is only manifested when a filtrate is tested on another susceptible strain. Thus many bacterial cultures have been shown to produce phage, though the presence of phage is not apparent and may not even have been suspected. This phenomenon suggests the original production of the phage by an uninfected culture, but it may merely be another instance of an apparently normal organism 'carrying' a parasite ; many parallel cases are known of animals and plants 'carrying' infective agents whilst themselves unaffected. De Jong showed that cultures of certain sporing bacilli which produce a phage may still be 'lysogenic' after being heated at 100° C. for five minutes, whereas the free phage is killed at 70° C. for five minutes. When the spores germinate the phage is again liberated. This experiment suggests that the phage is preserved by its inclusion in the resistant spore, and this evidence of its derivation from the germinating spore *de novo* is not conclusive.

The chief reason for doubting the living nature of some phages and certain viruses is the very small size of their filtrable particles, which makes it very doubtful whether they can have a complex composition resembling that of other living things.

Different strains of phage are very unequal in their filterability ; some have relatively large particles with a diameter about half those of vaccinia, while others pass through very fine filters, like the virus of foot-and-mouth disease, for which the diameter is estimated at about one tenth of the coarser phages.

The uniform and carefully graded collodion membranes introduced by Elford, of which the average pore diameter can be calculated, enables much closer estimates to be made than formerly of the size of particles which just pass or are just withheld. The size of the particles of some viruses has also been calculated, especially by Bechhold, by their rate of deposition when centrifuged at 10,000–15,000 rev. per min.

It has been possible to purify virus particles by first filtering and then centrifuging at high speed, washing the deposit and again centrifuging, as has been shown by Ledingham.

By the new collodion ultra-filters the diameter of the particles of different viruses has been estimated to vary from 200 $m\mu$ to 150 $m\mu$ for vaccinia to about 8–10 $m\mu$ for foot-and-mouth disease (μ = mikron = 1 thousandth of a millimetre ; $m\mu$ = one thousandth of a mikron). It is difficult to understand how with such dimensions they can have a composition of sufficient complexity to consist of living matter. For comparison, the smallest bacteria have a diameter of 1·0–0·5 μ and the egg-albumen molecule has been estimated at 4·34 $m\mu$ diameter.

Doerr, in a recent treatise, while granting that some viruses have been shown to be living, denies the possibility of life in those of the smaller dimensions. It so happens that the viruses of foot-and-mouth disease and louping-ill, which are among those with the smallest particles, exhibit all the typical essential characters of viruses both *in vitro* and in the animal body, though causing very different diseases and having very different 'life-histories'.

The exact and quantitative experiments with filters have been made possible by the high concentration in which certain viruses occur, and by opportunities for determining the presence of the virus in different dilutions by inoculation of susceptible small animals. The dilution of some fluids containing virus from the animal body can be carried to 1 in 10^6 or even higher when dealing with foot-and-mouth disease, vaccinia and some other diseases without depriving them of infectivity.

The quandary arising from the very active and apparently vital functions of virus particles in spite of their small size raises the question whether the accepted definitions of life are universally applicable or whether some intermediate state between what is called living and dead matter may not exist, as has been suggested by Boycott.

Of the functions usually postulated for a living organism, assimilation appears to be the most characteristic and indispensable. It is reasonable to assume that the metabolism of an organism would be much simplified if it existed in a circulating medium which provided a constantly changing supply of materials resembling its own components, such as might be afforded for an obligatory parasite living inside the cells of its host. Such an existence would have very different requirements from a truly independent life.

Virus diseases are transmitted from one animal to another by very varied means. Some, like canine distemper and certain influenza-like diseases of man, by droplets in the breath, others like yellow and dengue fevers by the bites of insects, others like louping-ill of sheep by the bites of blood-sucking ticks or of mites ; again, the bite of the mammalian host is the usual mode of infection with rabies, but for many others the method of transmission is still uncertain. In these respects they do not differ from diseases due to bacteria.

It is characteristic of many diseases that, although the initial infection is caused by a virus, many of the symptoms and complications are due to secondary infections with bacteria, and this is notably the case in the influenza-like group in man, in swine fever, canine distemper and swine influenza.

A virus may become remarkably adapted and sometimes permanently attenuated, when transferred to a new host, as is well instanced in the change of the virus of small-pox to vaccinia in cattle and rabbits, and of the rabies virus in the rabbit.

The period of resistance shown by the host following an attack of disease is sometimes very prolonged, even lifelong, after small-pox, varicella, yellow fever and canine distemper, but in some other cases the protection afforded is of comparatively short duration, in foot-and-mouth disease usually for one to two years, whereas frequently recurring attacks due to the virus of *Herpes labialis* are common.

This immunity is to a great extent due to the production in the animal body of 'antibodies' which can be found in the blood serum of recovered animals, just as occurs after bacterial infection. These antibodies can often be demonstrated by the formation of a precipitate or by the agglutination of the virus particles when a suspension of the elementary bodies is mixed with the serum, or by the neutralisation of the virus by the serum when both are injected into an animal. These phenomena are of the same kind as the precipitation occurring when the blood serum of an animal which has been inoculated with a foreign protein (antigen) is mixed with the same protein *in vitro*, and are not peculiar to true infections.

It is not intended here to do more than refer to the enormous and increasing number of filterable viruses known to cause infective disease in plants and found in their juices. These, like mosaic disease of tobacco, spotted wilt of tomato, and crinkle and leaf-roll of potato, may cause very serious disease, or in other cases may be present throughout the plant without producing any visible effect, as in some infections of the potato.

There is good evidence that two viruses may co-exist in the same plant, and as a result the symptoms may be either much more or much less severe than when either virus is present alone.

Some viruses are transmitted by insects such as aphis or thrips, while others pass by unknown means. In some of these diseases of plants peculiar 'inclusion bodies' are found in certain cells, but their relation to the virus is undetermined. It is known that these 'bodies', as well as some of the symptoms due to a virus, can in special cases be imitated by the addition of certain inorganic salts to the soil, but the disease is not then transmissible. Some plant viruses are highly resistant to drying, chemical action and alcohol, and in many ways the viruses of plants resemble those of animals.

The problems which the behaviour and properties of viruses raise are of great practical and theoretical interest, and are by no means yet solved.

Heat Production of Muscle and Nerve

By PROF. A. V. HILL, O.B.E., F.R.S., Foulerton Research Professor of the Royal Society

THE first paper by the present writer on this subject was printed almost exactly twenty-five years ago in the *Journal of Physiology* : the coincidence reinforced the invitation of the Editor of NATURE to write an interim report.

The heat production of muscle had been investigated in the past by such scientific giants as Helmholtz, Heidenhain, Fick and Blix: and indeed it was with Blix's apparatus, purchased by the providence of Langley and set in order by the Cambridge Instrument Company in the days of Horace Darwin and Keith Lucas, that the present experiments began. For some time, apart from Blix's work on the relation between heat production and muscle length, little of importance had been done on the subject ; but, as Langley wrote in a letter dated November 11, 1909, "an especial problem" had been "suggested by Fletcher and Hopkins's work on the efficiency of the muscle working with and without oxygen. . . . Once started, there are plenty of further experiments to do". The indication was clear : and in 1912 it was shown that a considerable part of the heat set free by an active muscle "occurs in recovery processes—presumably in the oxidative removal of the lactic acid liberated during contraction". The recovery heat production of muscle has been a fruitful subject of investigation in the intervening years ; the most recent papers have pushed its analysis to the extreme case of a single twitch in which, in a muscle of about 0·1 gm., 0·0002 calorie is liberated in the fifteen minutes following contraction.

The 'initial' heat production—that which occurs during actual contraction—has been extensively explored. Its investigation has led to great improvements in technique, for not only its amount but also its distribution in time relative to the various phases of mechanical activity had to be determined. The former demanded calibration of the thermo-electric apparatus, together with the muscle, in absolute units of heat : the latter, great rapidity in recording. The heat had to be related to the force developed and maintained, to the work done, to the character, the duration and the frequency of the stimulus, to the temperature and to the physico-chemical condition of the muscle. It was shown quite early (1914) that the initial heat, and its relation to force developed, are independent of the presence of oxygen ; so that the chemical processes of contraction were presumably of a non-oxidative character. This fact has a fundamental bearing on the nature of muscular fatigue of the rapid 'athletic' type : as also has the behaviour of the delayed oxidative heat production on recovery from such fatigue : but that is another story.

In 1912 the first attempt was made to relate the heat associated with the process of muscular activity to the only chemical events then known to occur : the formation and subsequent removal of lactic acid and the production of carbon dioxide. It was clear at once, as has been abundantly verified since, that the lactic acid was not removed simply by oxidation—the heat was far too small. In 1913, Peters published the first direct comparison of the initial heat with the lactic acid set free, and from 1919 onwards Meyerhof and his colleagues have made full use of the relation between heat and chemical change in their exploration of the intermediate mechanism of contraction. Lactic acid is no longer the only chemical substance known to be liberated in activity : creatine-phosphoric acid breaks down, and a complex sequence of phosphate changes has been discovered. It is probable indeed that the primary energy change in muscular activity is not lactic acid formation at all, and that the latter process is really the first stage in restoration, a non-oxidative stage rather rapidly completed, and followed (if oxygen be present) by the oxidative processes of recovery referred to previously. Here again the heat has thrown light on the problem, since, even in the complete absence of oxygen, a significant amount of heat is set free in the first minutes following muscular activity.

From the general scientific point of view, apart from the details of chemical machinery, the following broad conclusions may be drawn :

(i) The muscle is not a heat engine, but a chemical engine working at practically constant temperature.

(ii) It possesses an 'accumulator' mechanism by which energy can be liberated very rapidly without oxidation, and a 'recharging mechanism' by which the *status quo* can be restored under the influence of, and at the expense of energy derived from, oxidation.

(iii) It is primarily a machine for developing and maintaining force, not for doing work : even if no work is done, the muscle contracting at constant length ; even if negative work is done as when a muscle is stretched during contraction (for example, in walking downstairs), considerable heat is liberated, more the greater the duration of contraction. It is true, as Fenn (1923) found, that there are significant relations between work and heat, but these do not disguise the fact that the primary relation between thermal and mechanical effects is one between heat and force developed and maintained.

(iv) The 'efficiency' of the muscle machine, considering the whole cycle of breakdown and recovery, that is (work done)/(total energy set free) could never be greater than about 50 per cent, since the recovery process frees about as much energy as the initial process, and the latter always shows a positive balance of heat, even when maximal work is done. Under actual working conditions in man the maximum 'efficiency' is about 25 per cent. The energy is derived ultimately from the oxidation of foodstuffs.

(v) Little is yet known of the means by which 'excitation' induces chemical change and the latter mechanical effects. The existence (in some muscles) of optical phenomena running parallel with the thermal and mechanical changes, and the alterations of apparent viscosity during contraction, strongly suggest that the ultimate cause of the mechanical effects is a reversible rearrangement in a system of large protein molecules, on which X-ray analysis, or the methods of surface chemistry, may ultimately throw light.

A not unimportant result of work on the heat production of muscle has been the enforced improvement of galvanometers and of thermopiles of the insulated type. This has had some interesting by-products; for example, (i) a sensitive method for measuring the slow resting heat production of a small object; (ii) a method of determining the vapour pressure depression of a small quantity of solution (down to 0·1 mgm.) to an accuracy considerably better than 1 per cent; (iii) the possibility of further progress in studying stresses in engineering structures by means of their thermo-elastic properties; (iv) a method of increasing galvanometer sensitivity by the use of a photo-cell.

Most important, however, from the point of view of physiology, has been the work on the heat production of nerve. It was formerly believed that a nerve transmitted its messages without loss of energy, that the nerve impulse was in some sense analogous to a mechanical or electromagnetic wave in which all the energy involved is put into the system at the start. Unsuccessful attempts to measure the heat production of stimulated nerve supported this point of view. As a matter of fact, it is quite wrong: the heat is very small, but it is measurable and it obeys certain quite definite rules. In the transmission of a single impulse in medullated nerve, there is an 'initial' production of heat of 2×10^{-8} to 8×10^{-8} calorie per gram of nerve, and a recovery heat production of ten to thirty times that amount. The time-course of the latter, occupying 10–30 minutes (at 20° C.), has been mapped out: the relation of the former to temperature, frequency of excitation and other factors has been determined.

The results have been confirmed by measurements of the oxygen consumption, and attempts have been made to determine the chemical changes underlying the transmission of the nervous impulse. These latter have not, as yet, had much success, owing to the extreme smallness of the quantities involved. It is probable that the first stage in nerve transmission is the building up at each point of a critical electrical potential, under the influence of the electric accompaniment of the impulse approaching from a distance. When the potential reaches its critical value at any point a state of instability of unknown nature results, the insulating properties of the nerve boundary change, and the potential difference normally existing at that boundary is now able to produce a current to neighbouring regions: these in turn are similarly activated and the wave is propagated. The nerve boundary then returns to its normal insulating state. The initial heat is presumably due to the chemical events associated with this cycle of membrane changes: as in muscle where, with 100,000 times as much heat, chemical changes are associated with contraction and relaxation. The recovery heat may be due either to an oxidative reversal of these chemical changes, or to the restoration of the ionic differences responsible for the resting potential difference across the nerve boundary.

For the moment, there is a lull in these measurements of heat in muscle and nerve: further progress is probably to be sought chiefly in other directions. Micro-chemical methods need to be greatly improved if the chemistry of nerve activity is to be understood; the physical chemistry of the active boundaries involved in nerve transmission requires an application of the new technique of surface chemistry; the electrical accompaniments of excitation and transmission need more accurate quantitative study. On the muscle side, owing to the greater magnitudes involved, the chemistry is not so difficult, and considerable light is being thrown, and a very complex system is being revealed, by biochemical methods. The newer methods, however, of optical and X-ray analysis need to be more fully tried before one can say how far alteration in complex molecular systems will be found responsible for the mechanical accompaniments of activity. The effects of high hydrostatic pressure on the behaviour of muscle and nerve, and the changes of volume accompanying contraction, also may throw light on the mechanism.

These researches have been due to the co-operation of many. Langley started them on the suggestion of Fletcher and Hopkins's work. Bürker and Paschen, in respect of thermopiles and galvanometers, gave fundamental help. R. A. Peters, Weizsäcker, Parnas and Lovatt Evans collaborated before 1914. Hartree for many years bore the brunt of the experiments (and the arithmetic!) on the analysis of muscle heat into its constituent phases. Downing similarly contributed his skill in the construction of delicate instruments. The work of Meyerhof, of Embden, of Parnas, of the Eggletons, of Lundsgaard and of many others brought light from the chemical side. Fenn's fundamental researches on the relation between work and heat have been, and Gerard's on the subject of nerve metabolism must be, recorded. Azuma, Ernst Fischer, Gasser, Parkinson, Cattell, Furusawa, Wyman, Bronk, Bozler, Feng, Levin, Cowan, Bugnard, Rosenberg, each furnished a characteristic contribution. The list is not exhaustive. In spite of the present lull, at any stage in further progress reference may have to be made once more to the so-called 'myothermic' and 'neurothermic' methods, which have so great an advantage in their quickness and sensitivity, and in the fact that they can determine so fundamental a quantity as the total energy without any injury to the experimental object. The usefulness of these methods will probably not end with the jubilee of their revival.

Therapeutic and other Applications of X-Rays and Gamma-Rays

By Dr. G. W. C. KAYE, O.B.E., National Physical Laboratory

WITHIN a period of fifteen years prior to the King's accession, Röntgen had discovered the X-rays and J. J. Thomson the electron, Becquerel had discovered radioactivity and the Curies had isolated radium. The new reign was to prove an era of X-ray and radium research no less fruitful than its predecessor. In particular, the X-ray crystal diffraction experiments of Laue in Germany in 1912, followed by those of the Braggs in England, opened up a new vista of research which has left its mark on physics, found diverse and important applications in industry and is beginning to acquire significance in the biological sciences. Röntgen, who had lived to see many of these developments, died in 1923 in his seventy-eighth year, poor in fortune, but consoled by the beneficent services which his discovery had rendered in the War.

The British Army entered the War relying entirely for its X-rays on induction coils and 'gas' tubes, both well-nigh obsolete now. About 1908, Snook developed the high-tension closed-core transformer with rotary-arm rectifier, and in 1913, Coolidge introduced the hot-cathode X-ray tube. Much development has since followed. The X-ray tube of to-day is self-protected and shock-proof, and is even claimed to be climate-proof! The complete equipment is earth shielded, permits precise control and is silent in operation. The high-tension transformer works in conjunction with one or other of the rectifying-valve and condenser circuits, which deliver either pulsating or constant high voltage to the X-ray tube. In routine medical radiology, these voltages range from 60 kv. to 200 kv., but 400 kv. and up to 1,000 kv. are now to be found in certain therapeutic centres.

In 1910, X-ray diagnosis was fairly well advanced, but radiation therapy was in its infancy. Protection for the worker was rudimentary or non-existent; and many injuries and deaths resulted. Not until 1921 were the British protection recommendations issued by a representative committee, and these, the first in any country, were used as a basis for international agreement four years later at Stockholm. These recommendations, which are revised triennially by an International Protection Commission, have been adopted throughout practically the whole civilised world. They have not only provided effective safeguards against the working dangers of X-rays, but also have contributed, as no other factor has, to the better housing and general well-being of the X-ray and radium worker. Most radiology departments in 1910 were deplorably housed, whereas the light, roomy and well-ventilated departments of to-day are often a source of pride to hospitals.

Another vital step in the progress of radiation therapy was the adoption of the röntgen (r.) as the international unit of X-ray quantity or dose. The röntgen, which is an air-ionisation unit, was the subject of an international intercomparison in 1931 by the national laboratories of the United States, Germany and Great Britain, a very satisfactory measure of agreement resulting. It is probable that the röntgen will be adopted internationally for gamma radiation also, though further measurements on both gamma and high-voltage X-radiation are required.

Radiography has found considerable application in the industries and arts, for example, in the examination for flaws and other defects in metal castings and forgings, welds and assembled components. Wooden aeroplane parts were examined radiographically in the War. Many millions of clinical thermometers under test have been expeditiously scrutinised at the National Physical Laboratory by the use of X-rays during the last ten years. Other industrial applications include the screening of electrical insulators and golf balls during manufacture. The National Gallery and the Courtauld Institute have recently installed X-ray outfits for the examination of pictures and objects of art. Gamma-rays are resorted to in the radiography of metal specimens too thick for X-rays to tackle.

It is, however, in the world of medicine and surgery that X-rays and radium have been turned to account most outstandingly. X-ray diagnosis has improved in the last twenty-five years to an almost spectacular extent, and radiation therapy, though of more recent growth, has now established its claim to an important place in the treatment of malignant disease. The use of radium for cancer treatment was given impetus in Great

Britain by the formation in 1929 of the National Radium Trust and Commission, which were constituted to distribute and administer some quarter of a million pounds worth of radium which, it will be remembered, was subscribed for as a national thanksgiving for the King's recovery from his illness. The Trust and Commission were given powers by their Charter not only to augment existing supplies of radium for the treatment of the sick, but also to advance existing knowledge of the best methods of rendering such treatment.

I would here mention that in what follows, I have had the advantage of the experienced and authoritative assistance of Dr. Constance Wood, whose responsibility for the medical opinions expressed I gratefully acknowledge.

While it is still the case that the whole of the gastro-intestinal tract and early carcinoma of the breast are best treated by surgery, X-ray and radium therapy is bidding fair to displace the knife in the treatment of certain other forms of cancer. The response of tumours to radiation demands wide study, each type of tumour having a different response, both clinically and histologically. Views on radiation treatment have changed and the single massive dose of X-radiation, formerly advocated at Erlangen, is now replaced by a sequence of smaller doses spread over a period of time.

As to the quality of radiation required, this depends on circumstances. In certain superficial forms of cancer, such as rodent ulcer, almost any type of radiation will produce healing, whether it be low-voltage X-rays (for which high-power close-proximity tubes are now available) or the beta- or gamma-rays of radium. Other types of cancer, such as squamous epithelioma of the skin and lip, are successfully treated by a few milligrams of heavily screened radium, the residual scar frequently being quite invisible.

The real problem of malignant disease lies, however, in the treatment of glandular metastases. Small quantities of radium or low-voltage X-rays are not capable of destroying cancer cells at a depth ; for the deeper lesions and gland areas we turn either to (*a*) X-rays which, excited by very high and ever-increasing voltages, tend to approach gamma-rays in quality, or to (*b*) large quantities of radium placed at distances remote from the skin in an attempt to obtain the large depth doses possible with X-rays. Both methods have their advocates. From a financial point of view, Regaud estimates that when the heavy initial cost and low maintenance costs of a large radium unit are balanced against the lower initial cost and higher running costs of a high-voltage X-ray plant, there is little to choose between them at the present price of radium, though the possibility of an induced radioactive element of sufficiently long life to make its use practicable may perhaps be envisaged. Adequate protective arrangements appear to be possible with either radium or high-voltage X-rays.

The early progress of 'teleradium' was slow, and its ultimate value is a matter on which opinions differ, but the growing belief in its efficacy by those who have had experience is reflected in the rapidly increasing number of large radium units being set up in the world. Paris, which has had a 4 gram unit for some eight years, now has an 8 gram unit. Stockholm has a 5 gram unit in addition to one of 3 grams which it has used during the last six years ; New York, Chicago, Buffalo and Toronto each has a 4 gram unit. Great Britain has lagged behind somewhat in its recognition of the value of 'bomb' treatment, partly because cases are not referred for radium treatment at as early a stage as in many parts of the Continent. There have, however, been 1 gram units at the Cancer and Westminster Hospitals in London since 1929, while the Radium Commission in 1933 allocated 1 gram units to both these hospitals as well as to Middlesex and University College Hospitals. Edinburgh and Leeds now have also 1 gram units. The Radium Beam Therapy Research Board, set up with State support in 1933, is working with a 5 gram unit since 1933.

In X-ray diagnosis, short-exposure radiography of any part of the human body offers no difficulties to the experienced. With improvement in apparatus and technique, less and less dense bodies can be distinguished, until now the soft tissues and even the extent of tumour growths in them can be depicted. Modern fluorescent screens enable digestive movements, heart beats or lung movements to be watched or cinematographed.

The physiology of the stomach and alimentary tract has been transformed. The presence and extent of internal cancerous growths or small ulcers in the stomach can be definitely established by swallowing barium salt preparations which are opaque to X-rays. Extraordinary anomalies, such as the presence of the stomach in the chest, have been so revealed. Much work has been done recently on the injection of opaque fluids into abnormal tracts, the radiographs clearly demonstrating to the surgeon what difficulties and dangers may be encountered in a projected operation. Some organs, for example, the gall bladder and parts of the kidney tract, have the property of concentrating certain administered liquids so that they presently become opaque to X-rays, and thus outline the organs and facilitate the diagnosis of deep internal disease.

The X-rays assist in demonstrating the extent of involvement and the type of disease in tuberculosis of the lungs. In the treatment of tuberculosis, when by the introduction of air into the chest cavity, the lung has been collapsed to allow it to rest and heal, radiography indicates the state of the lung and when it should be collapsed again. Pathological cavities in the substance of the lung are revealed by introducing into the chest lipiodol, which is an oil rendered opaque by iodising it. Radiography is a valuable aid in the study of heart disease. The heart is sometimes unexpectedly shown to be on the right side of the chest. In radiography of the brain, air may be introduced into the cavities of the brain, so locating and outlining in the radiograph the extent of a tumour and consequently indicating where the surgeon must operate.

The fine trabecular structure of the interior of bones is plainly revealed by the X-rays. Difficult fractures are set under the fluorescent screen, thus assisting in producing perfect restoration of the damaged bone. The development of the human embryo is better understood, and radiographs of the unborn child show the centres of the ossification of the bones before birth and are often of invaluable assistance to the obstetrician.

The X-ray localisation of foreign objects in the body is a routine matter in hospitals, which are called upon to deal with an amazing variety of objects, for example, coins and safety-pins swallowed by children, dental plates inadvertently swallowed, nails, screws, safety razors, etc., deliberately swallowed by prisoners and others, and legacies from the War in the shape of buried bullets and shrapnel.

Genetics Since 1910

By PROF. J. B. S. HALDANE, F.R.S., Professor of Genetics, University College, London

THE state of genetical knowledge in 1910 can be learnt from Bateson's "Mendel's Principles of Heredity", of which the first two editions were published in 1909 and 1913. The principles which Mendel had shown to hold for seven contrasted pairs of characters in *Pisum* had been extended to a very large number of characters in many plant and animal species, including man. The main additions to these principles were the pure line, multiple allelomorphism, partial linkage between genes, epistasy, and one of the four types of sex linkage now known. The latter discovery, along with cytological work, had made the genetics of sex determination fairly clear. At least one case of extranuclear inheritance had been recorded.

Mendel's theory was based on the hypothesis that a (diploid) heterozygote produced two kinds of (haploid) gametes in equal numbers. This has since been proved in cases where the haploid generation has a number of variable characteristics; notably by v. Wettstein in mosses, or where individual haploids can be bred from, as by Andersson-Kottö in ferns. In such cases it is found that the products of a single meiosis are always exactly two cells carrying one member of an allelomorphic pair and two carrying the other. When several pairs are segregating, four different haploid types may arise, and a further analysis shows that genetic segregation may be associated with either meiotic division.

The cytological basis of genetics was cleared up by Morgan and his colleagues Bridges, Muller and Sturtevant, working on *Drosophila melanogaster*. They were able to show that the genes were located at different points on the chromosomes. Adequate chromosome maps exist for several species of *Drosophila*, and, thanks largely to the co-ordinative work of Emerson, for *Zea Mays*. Less complete maps exist for *Lathyrus* (Punnett) *Pharbitis* (Imai) and other plants. By studying the giant chromosomes of the gland cells in *Drosophila*, Painter has been able to correlate the theoretically derived gene map with visible structure, and Muller and Prokofieva have detected visible changes associated with a difference affecting a single gene. Using chromosomes which were microscopically distinguishable owing to the attachment of sections of other chromosomes to them, Stern found that the visible changes in any individual could be predicted from its genetical constitution. Thus crossing-over is a physical fact as well as an explanation of genetical phenomena.

Similarly, Darlington has shown that there is a quantitative agreement between microscopically visible chiasmata and genetically detectable crossing-over, and has made it probable that these two events, which are really aspects of the same phenomenon, are both due to the relief of strains produced in the chromosomes by coiling. Equally striking is the cytological evidence that abnormal types of linkage are associated with cytologically visible exchanges of parts between different chromosomes (Muller and Altenburg, Hammarlund and Hakansson, Dobzhansky, McClintock, etc.).

Oenothera Lamarckiana and other forms which breed nearly, but not quite, true, have been shown to be examples of permanent heterozygosis. Here the organism forms two kinds of gametes, but only one of the three possible combinations is produced, owing to inviability or competition.

The genetical analysis of *Oenothera* is mainly due to Renner, while Cleland, Darlington and other workers have elucidated its cytological basis, on principles largely suggested by Belling's work. Meanwhile Muller built up and analysed a *Drosophila* which behaved like *Oenothera*, possessing balanced lethal genes in two homologous chromosomes.

The genetics of polyploids are now understood. Gregory studied the genetics of the autotetraploid *Primula sinensis*, which contains four similar sets of chromosomes, and Winge pointed out that hybridisation might lead to an increase in the number of chromosome sets. The distinction between autopolyploids with more than two similar sets of chromosomes, and allopolyploids with several unlike sets of pairs derived from different species, was made by Kihara and Ono; while R. E. Clausen and Goodspeed, Newton and Pellew, and many other authors analysed allopolyploids. Müntzing, by his synthesis of *Galeopsis tetrahit* from *G. pubescens* and *G. speciosa*, was the first to prove that Linnean species had arisen by hybridisation and doubling of the chromosome number. The gradual discovery that most cultivated plants are allopolyploids has given this work great practical importance.

The origin of new genes by mutation was a rare and uncontrollable process until Muller showed that it could be speeded up at least two hundred times by X-rays. Mutations generally lower the viability of an organism, but may raise it (Timoféeff-Ressowsky). They are generally recessive, but sometimes dominant. They are at least sometimes reversible by a further dose of X-radiation, and therefore cannot be regarded as mere injuries. They can also be provoked to a slight extent by heat, while the possibility of producing them by chemical agencies is still *sub judice*. The majority of mutant genes in animals appear to be lethal when homozygous. A proportion of these, including many so-called dominants, produce visible effects in the heterozygous condition.

In the normal type of sex determination one sex has two similar X-chromosomes, while the other has a single X, or more usually an X and a dissimilar Y. Besides genes carried by the X, the work of the last twenty-five years has disclosed others carried by the Y only (Schofield, Castle, Winge, Stern, etc.) or by both X and Y (Schmidt, Aida, Winge, de Zulueta, Philip, etc.). Genetical anomalies of sex linkage occurs in females with an added Y-chromosome (Bridges), with attached X-chromosomes (L. V. Morgan), translocations of sex-linked genes to other chromosomes, and so on. Bridges, by studying triploid *Drosophila*, showed that sex is determined not by the number of X-chromosomes but by the balance between them and the autosomes. Thus animals with three sets of autosomes are females if they have three X-chromosomes, and intersexes if they have two. Goldschmidt showed that in *Lymantria* the X-chromosomes contain genes making for maleness, the cytoplasm and perhaps other constituents making for femaleness. By crossing geographical races of different sex potency he was able to produce intersexes or complete sex reversal. In *Lebistes*, Winge has been able to shift the sex-determining mechanism to a different pair of chromosomes, producing XX- or YY-males instead of the normal XY.

In Hymenoptera and some other groups the male is haploid. Here Whiting and others have shown that all genes behave like the sex-linked (X-linked) genes in man. But in *Habrobracon* at least, Whiting has proved that there is a further complication, the female being XY, the male X or Y, while X eggs are normally only fertilised by Y sperm, and conversely. Thus genes in the X- and Y-chromosomes show a fourth type of sex-linkage.

Finally, the Thallophyta have shown an astonishing variety of sexuality. V. Hartmann has found that in some flagellates sex is purely relative, a given type of gamete functioning as male with a less male partner, and conversely; while Kniep found two complementary sex pairs AB and ab, Ab and aB, in certain fungi, determined by two pairs of allelomorphic genes. Still more complicated cases exist, and it is very difficult to draw the line between sexes on one hand, and exogamous groups of self-sterile hermaphrodite plants, which may be determined as in fungi (Correns) or by series of multiple allelomorphs (East and Mangelsdorf, Lehmann and Filzer, Sirks, Brieger, Crane, etc.).

Much work has been done on individuals composed of two or more genetically different types of tissue, including mosaics, gynandromorphs, and plant chimæras. They may arise from grafting, double fertilisation, loss of a chromosome, mutation and so on. Among the most notable work is that of Morgan and Bridges on *Drosophila*, that of Jörgensen and Crane on *Solanum* and that of Imai on variegated plants.

Besides inheritance due to genes, extranuclear inheritance undoubtedly exists. The earlier work of Correns on the inheritance of abnormal plastid type has been extended, and other characters transmitted only by the seed parent have been recorded in plants. Little finds that the tendency to spontaneous cancer is largely inherited from the mother. However, Michaelis showed that in one such case the cytoplasmic influence gradually disappeared in the course of ten generations, whereas genes in the nucleus show no such tendency. Jollos and Goldschmidt studied *Dauermodifikationen* in *Drosophila* and other animals. These are changes of colour and shape produced by heat, and inherited from the mother only. Unlike mutant genes, they gradually disappear. A good many supposed cases of Lamarckian inheritance of acquired characters have been investigated. Many have been disproved, and none has been conclusively proved. However, the work of McDougall on rats and Sladden on *Carausius*, which suggest inheritance of acquired habits, are still under investigation.

Apart from these rather aberrant cases, there is increasingly strong reason to think that all heritable variation is due to genes. The evidence is particularly strong in *Drosophila* and *Zea Mays*, where characters determined by genes in several different chromosomes can readily be investigated by linkage tests. Fisher showed that the data of the biometric school on inheritance of human stature were consistent with the view that stature is determined by a number of genes, and the work of Punnett and his colleagues on inheritance of weight in poultry and rabbits confirms this view.

Human genetics has consisted largely of the accumulation of pedigrees. Very many genes are known. Thus Cockayne listed more than a hundred affecting the skin, hair or teeth. In addition to abnormalities, the antigens of the blood cells were shown by Landsteiner, Bernstein, Schiff and others to exhibit Mendelian inheritance. In the economic field, sex-linkage has been applied by Punnett, Pease and Crew to determine the sex of young birds on hatching, and genetic principles are used to eliminate recessive lethals in cattle and horses, and to produce new varieties of various plants. But the main economic effect has been from the gradual permeation of genetical principles among practical breeders, which has shown itself for example in the grading of bulls by their daughters' milk yield.

The physiological side of genetics was particularly developed by Goldschmidt, who showed that genes determine the form of the adult by affecting larval growth rates. Kraffka, Huxley, Zeleny, Plunkett and others have investigated the same problem. On the chemical side, Onslow, Garrod, Scott-Moncrieff, Brink and others have shown that in many cases a gene is responsible for some particular chemical process such as oxidation or methylation. The mechanism of segregation is itself controlled by genes (Beadle, Gowen, Frost, etc.), so that a change in one gene may affect the distribution of all the others.

On the other hand, little is known of the nature of the gene. An analysis of multiple allelomorphism shows that different modifications of the same gene perform the same processes at different rates ; however, in many cases it is certain that the genes do not consist of a number of like parts. At present the most hopeful line of attack on the fundamental problem of heredity, "How does one gene produce two like itself?", is to be found in the study of mutation, either natural, as in the work of Demerec and Andersson-Kottö, or provoked by X-rays. Andersson-Kottö's work suggests the possibility of distinguishing between a mother and daughter, or model and copy, in the products of gene 'division'.

A possibly important clue to the nature of gene action lies in the fact that, whereas most characters, for example, presence of an organ or a pigment, depend on the interaction of many genes, the presence of an antigen has so far always been found to be due to a single gene. Hence, except possibly in species crosses, no organism contains an antigen not found in either parent (Todd).

The cause of dominance has been much discussed. Bateson and Punnett regarded it as due to the presence in the dominant gene of something absent in the recessive ; Fisher believes it to be an adaptive phenomenon due to modifying genes. Many workers take an intermediate point of view.

Naturally polymorphic populations have been investigated, especially by Nabours, Winge and Fryer. The genes concerned are often found to exhibit a surprising amount of linkage with one another. Tschetwerikoff, Dubinin, Spooner and others have shown that an apparently homogeneous population may include many individuals heterozygous for recessive genes producing very marked variations.

The species problem has been attacked from several sides. Vavilov pointed out that homologous variations in similar species generally show similar inheritance, but Harland has shown that there are exceptions to this law, and characters may occasionally be determined by different genes in related species. Sturtevant established a thoroughgoing parallelism in the action and arrangement in the chromosomes of genes in two allied *Drosophila* species.

The differences between some species appear to be mainly due to genes. In the rodents this is so for colour, and Green has located a gene responsible for part of the colour difference between two mouse species in a particular chromosome. Other species differ as regards the number and structure of their chromosomes, and here hybrids, if they exist, are often sterile. In particular, Blakeslee and his colleagues have compared the arrangement of the chromatin in a number of species of *Datura* from this point of view, while Babcock has done the same for *Crepis* and J. Clausen for *Viola*. On the whole, it may be said that while we are fairly clear as to the nature of the genetical differences between related species, and it has been possible to imitate them within a single species (for example, by producing races which differ morphologically and will not cross), we are only rarely able to say with any certainty how species have originated in Nature.

The study of populations has developed a mathematical theory, due largely to Wright, Fisher, Bernstein, Haldane and Norton. The most important problems studied have been the effects on a population of inbreeding, selection, and mutation, and the theory of estimation from samples. These involve among other things non-linear integrals and finite difference equations, and complex theorems in inverse probability. Their general result may be said to favour a modified Darwinian theory of evolution.

It must be emphasised that the main bulk of genetical research has been done by authors not named in this summary, and even where no new principles have been discovered, their work has shown that the general laws laid down by Mendel have as wide a validity for genetics as have Dalton's for chemistry.

Nuclear Structure and Chromosomes

By PROF. R. RUGGLES GATES, F.R.S., Professor of Botany, University of London

THE quarter-century of the King's reign has seen many striking advances in cytology, and particularly in our knowledge of the structure of the nucleus and its chromosomes. During the decade ending in 1910, the general theory of 'individuality' of the chromosomes had been established by the work of Boveri and others, the sex chromosomes had been discovered by McClung, and their general relation to sex determined, chiefly by the work of Wilson and his school. These remarkable beginnings definitely linked cytology with genetics and added strength to the view, already accepted in many quarters, that the chromosome reduction in meiosis furnished the physical basis for Mendelian segregation.

An equally notable line of research begun before 1910 was in determining the cytological basis of the mutations discovered by de Vries in *Oenothera*. This work laid the foundation for an analysis of mutations, so that by 1915 it was recognised that each mutation was in effect a cell change handed on by mitosis to every cell of the mutant. It was also recognised at this time that mutations could be classified into various types, which depended for their origin upon different kinds of chromosome change. The process afterwards known as non-disjunction had been discovered in the pollen mother-cells of *Oenothera rubrinervis* in 1908, and by 1912 it was proved that the mutant *Oe. lata* must have arisen by such a process, as it possessed an extra chromosome. Many other *Oenothera* mutations are now known to have an extra chromosome, and the conception of parallel mutations was founded upon the occurrence of *lata* and other mutations in different species.

These chromosomal mutations were regarded by many as convincing evidence of the chromosome theory of heredity. Recently (unpublished), trisomic ($2n + 1$) mutations have been found occurring on a large scale in a wild species of *Oenothera*. Similar conditions have been observed by Huskins (1927) in fatuoid oats and speltoid wheats, plants with 40, 41, 42, 43 and 44 chromosomes being found where 42 is the normal number, but the exact relation between fatuoidy and the extra chromosome is still undecided. Blakeslee and his colleagues have recognised the twelve trisomic mutants to be expected in *Datura*, which has twelve pairs of chromosomes, as well as a series of secondary forms derived from exchange of segments in the primary trisomics.

In 1907–9 the mutant *Oenothera gigas* was recognised as a cell giant which had doubled its chromosomes. This was the beginning of the enormous modern field of polyploidy, or plants with chromosome multiples. The mutant *semi-gigas* was found to have 21 chromosomes (triploid) by Stomps and Lutz independently in 1912. Triploidy was discovered in *Drosophila* in 1921 and in *Datura* in the following year. While rare in animals, polyploidy is so widespread in flowering plants that a genus which does not show at least one case of it may almost be regarded as exceptional. Nearly all our cultivated plants, such as wheat, oats, sugarcane, cotton, apples, cherries, tomatoes, potatoes and pineapples, are now known to have varieties or species which possess different multiples of a particular basic number. Among wild species of roses, chrysanthemums, maples, horse-chestnuts, docks, violets, primroses, clovers, ragweeds, strawberries and many others, similar conditions prevail, so that the evolution of many plant genera has clearly been accompanied by the development of higher chromosome multiples from an original basic number, such as $b = 7$, 9, 13 or 17, for the genus. Where $2b$ is the ordinary (diploid) condition, some species may have $4b$, $5b$, $6b$, $10b$, or occasionally even higher multiples.

Thus in the genus *Potentilla*, where $b = 7$, species with $2b$, $4b$, $8b$, $10b$, $12b$, $14b$ and $16b$ are known.

In the cottons, where $b = 13$, it was found (Denham, 1924) that the Old World species had $2b$ chromosomes while the cultivated American cottons have $4b$. More recently, several wild species in Lower California and the Galapagos have been found to be diploid. When and how the chromosome doubling in the cultivated cottons took place is at present unknown.

Wild species with an odd number of chromosome multiples reproduce apomictically, as, for example, the pentaploid roses, the tiger lily, which is triploid, and the triploid day lilies. In large genera there may be several basic numbers, as in *Primula*, where different sections or subsections of the genus have 9, 10, 11 and 12 respectively as basic numbers. Less is known as to how one basic number changes into another, but there is evidence that end-to-end fusion of certain chromosomes, fragmentation and non-disjunction as well as other changes have been at work. In *Drosophila* it seems clear that six pairs of chromosomes, which some species (for example, *D. virilis*) still have, was the original number, this number being diminished to five pairs in *D. obscura* and four in *D. melanogaster* and other species by fusion to form the long pairs. *D. Willistoni* has only three pairs, the small pair having disappeared. Changes in the relative lengths of chromosomes have also been taking place in various genera.

These discoveries regarding polyploidy are fundamental for an understanding of phylogeny, the results of crossing, and various other fields of genetics.

In 1922 Blakeslee discovered haploidy in *Datura*, that is, that an egg cell may develop parthenogenetically to produce a plant having a single set of chromosomes in its nuclei. Such a plant is usually much dwarfed and almost completely sterile, since the chromosomes have no mates and are irregularly distributed in meiosis ; but it is significant that it has the morphology of the sporophyte. Haploids have since been discovered in such plants as *Crepis*, tobacco, wheat, tomatoes, *Oenothera*, and in rice, where Japanese investigators have found them to occur with exceptional frequency.

Finally may be mentioned the remarkable cases of amphidiploidy, in which a sterile interspecific hybrid doubles its chromosomes and so becomes in effect a new fertile species with a higher chromosome number. The early case of *Primula kewensis* is now known to be of this character (Pellew and Newton, 1929). *Nicotiana digluta* was produced in this way by Goodspeed and Clausen in 1925 and *Digitalis mertonensis* at Merton in 1928. There is evidence that such cultivated plants as tobacco and the loganberry have originated by similar processes. Remarkable in this connexion is the history of *Dahlia variabilis*, which is native to Mexico and shows a double series of colours as well as the well-known striking morphological variations. It has been shown to be an amphidiploid, the two colour series being contributed by different species (Lawrence, 1929). It may well have originated under cultivation in Aztec gardens.

Even more striking has been the creation of the 'new genus' *Raphanobrassica* by crosses between the cabbage and the radish, each with $n = 9$ chromosomes (Karpechenko, 1924), and *Aegilotrichum* by crosses between *Aegilops* and wheats (Tschermak and Bleier, 1926). Amphidiploids between wheat and rye have also been obtained by Tumyakov at the Saratov station on the Volga, and recently by Lebedeff in the Ukraine, who claims that they reproduce apomictically. If so, this is a further similarity to some of our wild polyploid species in such genera as *Hieracium* and *Antennaria*. The fact that the tetraploid hemp nettle, *Galeopsis Tetrahit*, a well-known Linnean species in the British flora, has been synthesised by crossing two related diploid species, and that the rice grass, *Spartina Townshendii*, which spreads so rapidly in coastal waters, was found to be an amphidiploid hybrid between a British and an introduced American species, shows the importance of polyploidy in phylogeny and in connexion with taxonomic studies. The experimental amphidiploids are new species in every sense of the word, for not only do they breed true in the main, like other species, but they are partially sterile with the species which produced them. The two processes of doubling the chromosome sets and then differentiating them through gene mutations can be traced in many plant genera.

To return to 1910 : Morgan published his first mutation in *Drosophila*—red eyes to white—in that year, and in the following year found nine wing mutations and five mutations in eye colour. In 1912 the study of sex-linkage in *Drosophila* began, crossing-over soon came to be studied on an unprecedented scale and in this way more than five hundred mutations have been assigned their relative positions in the four pairs of chromosomes. By 1926 it was possible for Morgan to announce his law that the number of linkage groups corresponds with the number of chromosome pairs. This was confirmed by Punnett for *Lathyrus* in 1927 ; and in maize, where each of the ten pairs of chromosomes can be identified by its appearance, a map of the genes in each chromosome has been constructed by crossing-over experiments, chiefly by the Cornell school. In 1916, Bridges used cases of non-disjunction of the X-chromosomes in *Drosophila* to prove that sex-linked genes were borne in the X. Later, he also found individuals with a third member of the tiny fourth chromosome, as well as others having but one member of this pair.

Morgan's theory of crossing-over was founded upon Janssen's observations (1909) of chiasmata in meiosis, but exactly how chiasmata are formed and how they are related to crossing-over is still a matter of controversy on which many observations are being made and various views are held.

In 1922, L. V. Morgan found a strain of *Drosophila* in which the two X-chromosomes of the female had become permanently attached end-to-end. Before the condition was observed cytologically it had been predicted on the basis of the peculiar breeding results with this strain. The condition has since appeared independently in other strains.

Arrangement of the chromosomes of *Oenothera* in a chain at diakinesis was discovered in 1908, and in 1922 Cleland found that the number connected into a ring was characteristic of certain species. This condition, which is now known as catenation, is recognised as fundamental to the genetics of *Oenothera*, and the catenation in many species, hybrids and mutations, has been determined. It accounts for the usual absence or infrequent occurrence of ordinary Mendelian segregation, the occurrence of 'complexes' of characters, the twin hybrids of de Vries and the fact that heterozygous species breed true. In order to account for all these phenomena it is necessary to assume, not only that the chromosomes occupy fixed positions in the ring, but also that they have a fixed orientation. This has recently been shown experimentally to be the case. The 14 chromosomes of *Oenothera* may be all in a ring or in seven pairs or with various arrangements of smaller rings. The fifteen possible groupings (a few unpublished) have now all been observed in different forms of *Oenothera*.

Chromosome catenation has since been discovered in a number of other plant genera, including *Datura*, *Aucuba*, *Rhœo* and *Pisum*. It can be produced by crossing two Oenotheras each with seven free pairs, and also by crossing certain strains of *Datura* or *Pisum*. Of special interest is the cross between a Tibetan and a European variety of *Pisum* (Pellew and Sansome, 1931) in which a ring of four chromosomes arises. Catenation has also recently been produced in *Oenothera* by exposing the pollen to X-rays. The theory of segmental interchange was proposed by Belling and Blakeslee (1926) to account for the chromosome linkage arising in certain *Datura* crosses, and has since been shown to be widely applicable to *Oenothera* and all other cases in which ring formation takes place as a result of crossing.

In 1927 Muller announced that the mutation rate in *Drosophila* could be increased a hundredfold by subjecting the germ cells to X-rays. The exact nature of the effect on the chromosomes is still unknown, but in addition to gene mutations, many of which are lethal, chromosome fragmentations, deletions and segmental translocations are produced by this means. It has been applied to various plants, notably *Nicotiana*, barley, *Antirrhinum* and recently *Oenothera*. There are now many lines of evidence that translocation of chromosome segments can take place in Nature, and it has been shown, for example, by comparing the seriation of the genes in *Drosophila melanogaster* with that in *D. simulans*, that a segment of chromosome III in one of these species has been inverted.

Phylogenetic significance also attaches to the secondary pairing of chromosome bivalents in meiosis. This was first observed by the Marchals (1911) in mosses in which the chromosome number had been doubled experimentally. Hagerup (1927) noted it in a hermaphrodite tetraploid species evidently derived from *Empetrum nigrum*. Darlington (1928) used it in interpreting the history of the polyploid cherries. Secondary pairing appears to be due to a residual attraction, and indicates that the chromosome bivalents which show it are themselves more distantly homologous. In other words, it is an indication of polyploidy or similar processes in the more remote ancestry, and throws light on how chromosome numbers have changed from genus to genus. The Pomoideæ, a group of Rosaceous genera, have 17 chromosomes. They show secondary pairing and other multivalent associations (Darlington and Moffatt, 1930) which indicate how this number has been derived from an earlier 7, which is characteristic of many genera in the family, such as *Rosa* itself. Secondary pairing has been observed also in *Pyrus*, *Dahlia*, *Brassica*, *Gossypium* and many other cases, where it helps to throw light on nuclear phylogeny (Lawrence, 1931).

Important advances have also taken place in regard to chromosome structure, although in this fascinating field many points are still unsettled. Most investigators appear to be now agreed that the chromosomes are double in anaphase as well as prophase, from which it follows that the split occurs about the time of metaphase and that the chromosome is a double structure throughout the mitotic cycle. The chromonema theory, according to which the essential part of the chromosome is a thread of uniform thickness, dates from Vejdovsky, 1912. The chromomere theory, of granules aligned like beads on a string, is much older. Both views have strong supporters at the present time and it does not yet appear how their differences will be resolved. Wenrich (1916) found that in grasshoppers particular chromomeres could be identified by their size and position on the chromosome. Belling (1931) identified the chromomeres with the genes, and attempts at counting them in various plants have given values ranging roughly from 1000 to 2500. The chromosome threads become spiral in various stages of mitosis, and Kuwada has found indications of a spiral within the spiral. Others find the spiral chromonema splitting lengthwise in prometaphase.

In what may be called the external morphology of the chromosomes more marked progress has been made. In 1912, S. Navashin discovered that certain chromosomes in *Galtonia* have a tiny more or less globular satellite attached to one end by a thread. One or more pairs of satellited chromosomes have since been observed in many plants and animals.

The spindle fibre attachment constriction is now a well-recognised feature of all plant chromosomes, and 'kinetic bodies', 'knobs', 'heads', additional constrictions, vesicles and their special features have been observed. Levitsky, M. Navashin and others of the Russian school have been active in comparing the karyotypes of various plant groups.

The nature of the nucleolus has long been a mystery, but light has recently been thrown on this problem. Wenrich (1916) noted in the meiotic nuclei of a grasshopper that the nucleolus bore a constant relation to a particular pair of chromosomes. Later a definite 'nucleolar body' was discovered as a darker staining area of the nucleolus in pollen mother cells of *Lathyrus* (Latter, 1926), and it was shown that a loop of the chromosome thread was constantly attached to it. The same condition has since been found in *Lathræa*, *Oenothera*, *Malva* and rice, and frequently two such bodies rather than one are attached to the nucleolus. S. Navashin had observed a pair of satellites attached to the nucleolus, and in studies of maize, McClintock (1931) has shown that the satellited pair of chromosomes is concerned in producing the nucleolus in teleophase at a particular locus. When these chromosomes are widely separated, two nucleoli will be produced. Heitz (1931) has observed similar conditions in *Vicia* and other plants as well as in insects (1933), while Dearing (1934) shows in the amphibian *Amblystoma* the same relation between a satellited pair of chromosomes and the (usually two) nucleoli present. Thus it appears to be the function of a particular locus of one pair of chromosomes to produce the nucleolus, but this is not the whole story. In this, as in other fields of nuclear study, the results in animals and plants have been remarkably synchronised.

Lack of space prevents more than mention of the important method of micro-dissection, by which living cells can be dissected with glass needles under an immersion lens. Introduced by Kite and Chambers in 1912, it has led to many interesting observations of the physical condition of various cell constituents, including the chromosomes.

Finally, we may refer to the investigations of the chromosome structure in the salivary glands of insects. These giant chromosomes have long been known to show a banded structure, but its significance has only been brought out by the recent observations of Painter, Bridges, Koltzoff and others. The discs differ markedly in details of structure, but they are definitely spaced at varying intervals along the chromosomes, and from the evidence of their pairing and genetic behaviour it is clear that they must be identified in some way with the genes. Certain of the bands have been shown to vary according to the genetic make-up of the animal. Bridges has just published (*J. Hered.*, 26, No. 2) maps of the four chromosomes (significantly separated into six) in the salivary glands of *Drosophila melanogaster*, identifying each band and also pointing out many other structural features or landmarks at various loci of the chromosomes. These chromosomes total about 1180 μ, or 150 times the length of the meiotic chromosomes. The bands, which probably represent loci, number 2650, the little fourth chromosome having 34. This begins a new era in chromosome study.

Chemistry of the Anthocyanins

By PROF. R. ROBINSON, F.R.S., Waynflete Professor of Chemistry, University of Oxford

THE classical paper of Willstätter and Everest (1913), on the isolation of the pigment of blue cornflowers, heralded a dramatic transformation of the state of our knowledge of the blue and red colouring matters of flowers and blossoms, and the present position is that we not only know the molecular structure of the more important and widespread anthocyanins, but also that many of them have been made artificially in the laboratory. With the simultaneous growth of precise information about chlorophyll, the carotenoids, the polysaccharides and the terpenes, one may say that all the more obvious challenges of vegetative Nature to the organic chemist have been taken up, and taken up successfully. Deep mysteries there are still, it is true, but one must probe beneath the surface in order to find them. Willstätter owed his triumph largely to recognition of the fact that the anthocyanins, although non-nitrogenous, form salts with strong acids, and these salts can be purified by means of the technique appropriate to many ammonium salts, that is, solution in a hydroxylic solvent and precipitation with a non-hydroxylic solvent.

An early observation records the unconscious use of formic acid for the extraction of an anthocyanin. J. Wray (1670) wrote: "Bare an ant-hill with a stick and then cast the [chicory] flowers upon it, and you shall see the ants creep very thick over them. Now as they creep, they let fall a drop of liquor from them, and where that chanceth to light, there you shall have in a moment a large red stain". This was followed up and red extracts of blue chicory flowers were made with acidic solutions.

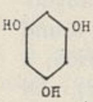
Willstätter and his colleagues extracted the anthocyanin salts by means of methyl alcoholic hydrogen chloride, acetic acid or other similar solvents, and precipitated a crude, often syrupy, product with ether. The process was usually repeated, perhaps with variation of solvent, and until the anthocyanin could be caused to separate from aqueous or alcoholic solution as a chloride or picrate. Purification was then possible by crystallisation, or a series of separations leading to eventual crystallisation. The different examples offered very divergent degrees of difficulty and indeed, in some cases, the skill of the florist in the breeding of deeply-coloured varieties has been such that the dried petals can almost be regarded as crude anthocyanin.

The blue cornflower and the red poppy represent the more difficult type, whereas the colouring matter is readily isolated from special deep red varieties of dahlias and chrysanthemums and from certain garden violas. The dried petals of the blue-black viola (*Viola tricolor*) employed by Willstätter and Weil (1916) for the isolation of violanin contained no less than 24 per cent of this pigment.

Willstätter was fortunate in the selection of material because among the first flowers studied were to be found representatives of the three main types in the group. From the cornflower, the rose and the dahlia he obtained cyanin chloride, $C_{27}H_{31}O_{16}Cl$, which splits up on hydrolysis into *cyanidin* chloride, $C_{15}H_{11}O_6Cl$, and two molecules of glucose; from the scarlet pelargonium he isolated pelargonin chloride, $C_{27}H_{31}O_{15}Cl$, which similarly yields on hydrolysis two molecules of glucose and *pelargonidin* chloride, $C_{15}H_{11}O_5Cl$, whilst the wild purple larkspur afforded delphinin chloride, $C_{41}H_{39}O_{21}Cl$, which gives, on hydrolysis, *delphinidin* chloride, $C_{15}H_{11}O_7Cl$, along with two molecules of glucose and two molecules of *p*-hydroxybenzoic acid. [Anthocyanins containing acyl groups, often *p*-coumaric acid (Karrer), are widely distributed and are termed *complex anthocyanins*. The true analogue of pelargonin chloride and cyanin chloride in the delphinidin series has recently been isolated from *Salvia patens* (Reynolds, Scott-Moncrieff and R. R., 1934); it is termed delphin chloride and has the composition $C_{27}H_{31}O_{17}Cl$.]

The aglucones were termed anthocyanidins, and in addition to the three already mentioned only certain of their methyl ethers have been encountered. The two or three exceptional cases serve merely to establish the rule that all the anthocyanins are derivatives of the three basic types. Further work showed that the aglucones may be combined with one molecule of glucose or of galactose, or with a rhamnoglucose or aldopentoglucose, and that isomeric diglucosides exist. Thus mecocyanin chloride (from *Papaver rhoeas*) is quite different from cyanin chloride, but like it has the composition $C_{27}H_{31}O_{16}Cl$, and it also furnishes cyanidin chloride and two molecules of glucose on hydrolysis.

The probable nature of the difference between pelargonidin, cyanidin and delphinidin is clearly indicated by the results of fusion with potash. All three give phloroglucinol (I) as one of the products,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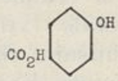
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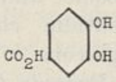
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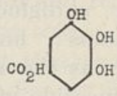
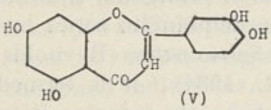

(IV)

but pelargonidin was in addition degraded to *p*-hydroxybenzoic acid (II), cyanidin to protocatechuic acid (III) and delphinidin to gallic acid (IV).

Taking into consideration the results of precedent investigations on natural flavones (luteolin, V) and flavonols (quercetin, VI) with which the names of Kostanecki, A. G. Perkin and Herzig are chiefly associated, and also the accumulated knowledge of the properties of flavylium salts (such as VII) (Collie, Werner, Bülow, Decker, W. H. Perkin and R.R.), it was apparent that the facts pointed to the formula VIII for cyanidin chloride. The formulæ for the other anthocyanidins would be derived by modifications of the group A in VIII to conform with the results of potash fusion as mentioned above.

This surmise was quickly justified by the discovery that flavones and flavonols could be reduced by metals in acid solution with the formation of oxonium salts having the reactions of anthocyanidins (Everest, Willstätter). In particular, Willstätter and Mallison showed that quercetin gives a small yield (0·6 gm. from 30 gm.) of pure cyanidin chloride when it is reduced in



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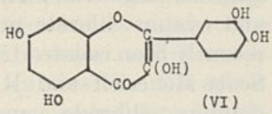

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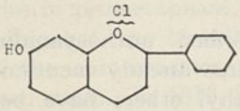

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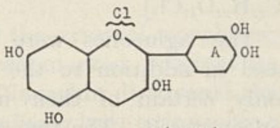
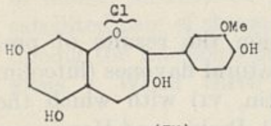


(VIII)

aqueous methyl alcoholic hydrochloric acid by means of magnesium (VI ⟶ VIII). This was followed up by a more formal synthesis of pelargonidin (Willstätter and Zechmeister), whilst the present writer and his collaborators have synthesised all the anthocyanidins, including the methyl ethers, by convenient and generally applicable methods.

The naturally occurring methyl ethers of the anthocyanidins are peonidin chloride (IX), the aglucone of peonin, a diglucoside, and oxycoccicyanin, a monoglucoside ; petunidin chloride (X), the aglucone of petunin chloride, a diglucoside ; malvidin chloride (XI), the aglucone of a monoglucoside, a monogalactoside, a diglucoside, and of complex anthocyanins ; hirsutidin chloride (XII), found only as the aglucone of hirsutin chloride, a diglucoside of *Primula hirsuta* (Karrer). Of these, malvidin, also called syringidin and œnidin, is of such frequent occurrence that it almost deserves recognition as a fourth fundamental type. Its monoglucoside is œnin, the pig-



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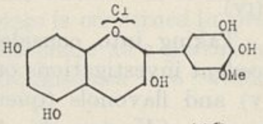

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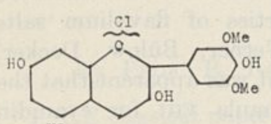

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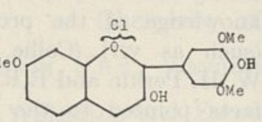
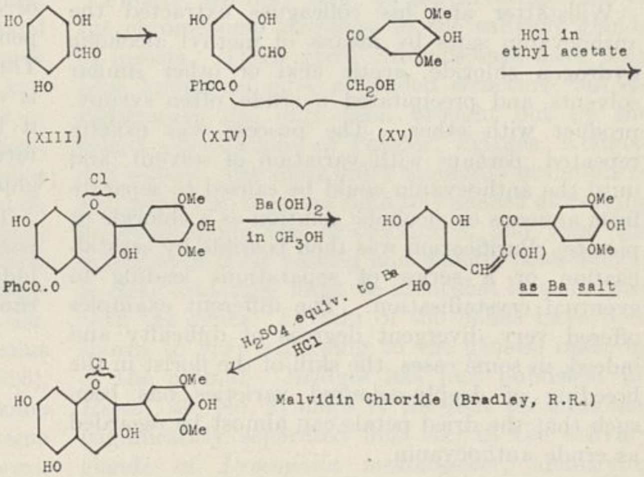


(XII)

ment of black grapes, one of the most frequently studied anthocyanins.

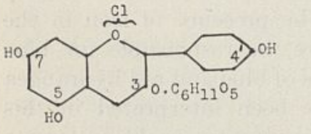
In the earlier work on anthocyanidin syntheses (Pratt, R.R.) it was thought necessary to protect the nuclear hydroxyl groups very completely, and the products were finally demethylated by means of hot hydriodic acid. Such a process could clearly not be applicable to the methyl ethers (IX–XII), and a technique has been gradually evolved that allows of the minimum of protection, and that by means of acyl groups only. The scheme below illustrates the stages of the synthesis of malvidin chloride by the best-known method.

Phloroglucinaldehyde (XIII) may be synthesised from carbon *via* five isolated intermediate stages, namely, acetylene, benzene, nitrobenzene, trinitrobenzene, phloroglucinol ; hydrocyanic acid is also used and may be obtained from carbon in two stages. The intermediate XV may be synthesised from carbon in thirteen isolated stages, namely, acetylene, benzene, benzoic acid (better in one more stage), disulphobenzoic acid, 3 : 5-dihydroxybenzoic acid, bromodihydroxybenzoic acid, gallic acid, trimethoxybenzoic acid, syringic acid, acetylsyringic acid, acetylsyringoyl chloride, diazodimethoxyacetoxyacetophenone, ω-4-diacetoxy-3 : 5-dimethoxy-acetophenone ; two carbon atoms are introduced by way of carbon monoxide, methyl alcohol, methyl sulphate, and one from carbon monoxide, methyl alcohol, methylamine, methylurea, nitrosomethylurea, diazomethane.



The monobenzoylphloroglucinaldehyde (XIV) has been found to be a particularly convenient first component in all syntheses of the above type, and its use (Robertson, R. R.) facilitated the synthesis of the anthocyanins themselves. Hints in regard to the site of the sugar residues in the anthocyanins had been obtained from a study of their colour reactions and other properties (Willstätter, Karrer, R. R. and their colleagues) in comparison with synthetic, analogous flavylium salts, but it is unnecessary, in this brief article, to recount the arguments, especially as none of them was conclusive. The case is one in which synthesis has been applied not merely to the confirmation but also to the determination of structure.

Nor is it necessary to mention the several stages of approach to the synthetic method, which is identical in principle with that already described. It was a question of applying the art of the organic chemist to the preparation of the various glucosidated intermediates of types XIV and XV. For example, by suitable modifications the four possible isomeric β-glucosides of pelargonidin were



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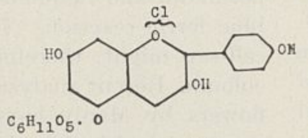

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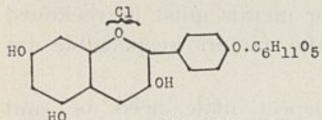

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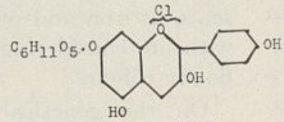


(XIX)

synthesised (XVI, XVII, XVIII, XIX) (Robertson, Léon, Seshadri, R. R.); XVI was found to be identical with Willstätter's callistephin and XVII with his pelargonenin, not a natural anthocyanin but the first product of the hydrolysis of the diglucoside, pelargonin.

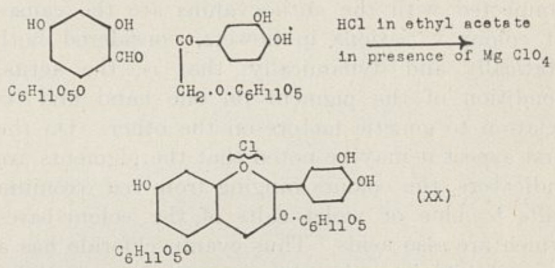
The natural monoglucosidic anthocyanins are all constituted like XVI. The naturally occurring mono-glycosides synthesised are callistephin (from the aster or red carnation), chrysanthemin (cyanidin 3-glucoside from the chrysanthemum and other flowers), oxycoccicyanin (peonidin 3-glucoside from American cranberries), œnin (malvidin 3-glucoside from purple-black grapes), fragarin (pelargonidin 3-galactoside from strawberries), idæin (cyanidin 3-galactoside from European cranberries), primulin (malvidin 3-galactoside from *Primula sinensis*). The last-mentioned case is of interest because it illustrates the value of one of the methods used for the characterisation of anthocyanins. The monoglucosides are distributed between dilute hydrochloric acid and *iso*amyl alcohol, but the distribution number varies with the concentration. By plotting the logarithms of the concentrations in the aqueous and alcoholic layers against each other, a straight line is obtained with a slope of 2; this indicates that double molecules exist in the water and single molecules in the *iso*amyl alcohol. The curves obtained in this way are much more reliable than single determinations of the distribution numbers because they afford evidence of homogeneity.

In connexion with work on the bilberry pigments, malvidin 3-galactoside was synthesised (Bell, R. R.), and its distribution properties were found to differ from those of œnin (malvidin 3-glucoside), so that a study of malvidin 3-glycosides containing unidentified sugar residues was feasible. Cyclamin (from cyclamen, Karrer) was found to be identical with œnin, but primulin (from *P. sinensis*), isolated by Miss R. Scott-Moncrieff, tallied with the galactoside. Closely related to the monoglycosides are the true biosides, and one example has been cleared up by synthesis. Cyanidin 3-cellobioside, 3-maltoside, 3-lactoside and 3-gentiobioside were synthesised (Inubuse, Grove and R. R.) and the latter was found to be identical with Willstätter's mecocyanin. The rhamnoglucosides have not yet been prepared in the laboratory but their reactions are closely similar to those of known 3-saccharides.

There remain the diglucosidic anthocyanins *par excellence*—pelargonin, cyanin, malvin, etc. At first regarded as biosides, these are now known to be di-monoglucosides, and the two sugar residues are attached to different hydroxyl groups of the anthocyanidin molecules.

The suggestion that they are 3 : 5-diglucosides was first put forward in a letter to the Editor of NATURE (G. M. R. and R. R.) and it was quickly confirmed by synthesis. The glucose rests must be introduced into both components. Normally and preferably these were acetylated, and the product was submitted to hydrolysis by alkali and reconstituted by the action of hydrochloric acid.

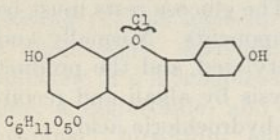
It is perhaps a matter of interest that cyanin chloride (XX) has been synthesised directly from unprotected components (Resuggan, R. R.).



(XX)

The naturally occurring 3 : 5-diglucosides synthesised include pelargonin, cyanin, peonin, malvin and hirsutin (Todd and R. R.); the additional case of delphin has been mentioned already.

The possession of pure synthetic specimens of the anthocyanins and anthocyanidins has made it possible to devise simple tests for the rapid recognition of the nature of the pigments in crude extracts of plant material, and a survey (G. M. R. and R. R.) has been made of a wide variety of flowers and other parts of plants in respect of their anthocyanin content. In general, we are able to specify the anthocyanidin and the position of the sugar groups, but the latter cannot be identified (except for rhamnose and the aldopentoses). This survey has made the dominating position of pelargonidin, cyanidin, delphinidin and malvidin even more clear, but it has also disclosed the occurrence in Nature of certain widely distributed anthocyanins not yet isolated in substance. As examples, the pelargonidin 3-bioside of the orange-red nasturtium and the pelargonidin 3-rhamnoglucoside of the scarlet gloxinia may be cited. The orange-scarlet flowers of *Gesnera fulgens* were found to contain a new anthocyanin termed gesnerin ; it is apigeninidin 5-glucoside (XXI) and has been synthesised (Todd, G. M. R. and R. R.) ; it is the only known anthocyanin related to a flavone rather than to a flavonol, although carajurin (XXII), a crystalline constituent of a cosmetic pigment used by the natives of the Orinoco, is a colour-base of such a substance (Chapman, A. G. Perkin and R. R.) Other special types of anthocyanins are the nitrogenous pigments of *Beta*, *Bougainvillœa*, *Amaranthus*, *Celosia*, etc. ; their nature has not been fully elucidated ; also the bright yellow water-soluble colouring matters of *Papaver alpinum* and *P. nudicaule*.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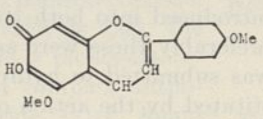
(XXII)

Among the matters of more general interest connected with the anthocyanins are the causes of colour variations in flowers, considered both statically and dynamically, that is, the actual condition of the pigment on one hand and its relation to genetic factors on the other. On the first aspect it may be noted that the pigments are indicators, the colours ranging from red oxonium salts to blue or violet salts of the colour-bases which are also acids. Thus cyanin chloride has a beautiful bluish-red colour, cyanin-base is violet and the potassium salt of cyanin-base is blue. Naturally, therefore, the colour of a flower is dependent on the *p*H of the cell-sap. But the range of *p*H is much smaller than experiments *in vitro* would suggest, and this is due to the combination of the anthocyanin colour-base with colloids tending to stabilise the anthocyanin anion at a *p*H which it could not survive in 'clean' solutions.

Another factor modifying the conclusions drawn from the indicator ranges observed in the laboratory is the presence of co-pigments in the flowers. These are organic substances, mainly flavonols and tannins, which have a blueing effect on the colour irrespective of the *p*H. The magnitude of the effect is, however, dependent on the *p*H and at a certain value becomes maximum. The phenomenon is the result of actual combination with the pigment and is accompanied by a marked change (diminution) of the distribution number.

A very characteristic reaction of cyanidin, petunidin and delphinidin derivatives is the deep blue ferric reaction. The presence of iron in the cell-sap might, therefore, be responsible for blue colours. Recent analysis of blue and red hydrangea flowers by Manly have been interpreted in this sense, and although this popular problem cannot be said to have been completely solved, the presence of iron and other metals must be reckoned with in considering the factors responsible for flower colours.

On the genetical aspect little need be said here ; the subject deserves a separate treatment. Obviously the anthocyanin approach to the study of heredity represents one of the most promising lines of investigation, and it will be greatly facilitated by the chemical advances here briefly summarised. Miss Scott-Moncrieff and her colleagues have recently completed an investigation of the dahlias (private communication) which goes far to show that the pelargonin, cyanin and flavone or flavonols occurring in these flowers are biogenetically complementary and are phytosynthesised from a limited supply of protoflavan material. The full details will be studied with interest, and this type of investigation is pregnant with possibilities in connexion with the elucidation of the mechanism of anthocyanin synthesis in the plant.

I consider that the identification of the anthocyanin-chromogen with the flavones was an unfortunate obsession of the plant physiologists, and that in a different form the oxidase hypothesis of Keeble and Armstrong will be revived.

The leuco-anthocyanins of Laborde, Rosenheim and others will probably be found to be much nearer the mark. These substances are even more widely distributed than the anthocyanins (G. M. R. and R. R.), and their constitution may be foreshadowed by an investigation of peltogynol recently carried out in these laboratories (G. M. R. and R. R.). This is a constituent of certain woods known as 'purpleheart', and it is essentially a dihydrodesoxycyanidin condensed with formaldehyde. It is thought that the leuco-anthocyanins as a class may be of similar nature, the sensitive partly reduced flavylium nucleus being protected in a semi-acetal sugar-like structure.

Adsorption Concepts in Chemistry

By PROF. ERIC K. RIDEAL, F.R.S., Professor of Colloid Science in the University of Cambridge

NO better perspective of the development of our knowledge concerning adsorption at surfaces can be obtained than by contrasting the contents of one of the many monographs published on this subject in recent years with the considered views of Nernst, as expressed in the sixth edition of his famous textbook in theoretical chemistry, which appeared twenty-five years ago. At that time the process of adsorption on surfaces was regarded essentially as due to the formation on the substrate of a dense atmosphere-like layer many molecules thick. Of this concept no vestige remains. Whilst the fundamental qualitative expressions of the more modern views are essentially simpler and more direct than the old, yet the detailed processes are undoubtedly complex and still await complete elucidation.

Two fundamental concepts introduced some twenty years ago, envisaged by the late Sir William Hardy, but most clearly presented and demonstrated by Irving Langmuir, have had the greatest influence in moulding our present views. The two ideas that the forces acting in the process of adsorption are to be recognised as identical with those operative in ordinary chemical processes, and that in molecules, especially in large organic molecules, certain portions are more reactive than others, form the basis of the modern concept of the orientated monolayer as the model of the adsorbed phase.

The reality of the existence of adsorbed materials in the form of orientated monolayers both on solid and liquid surfaces has now been demonstrated by chemical, optical, electrical and thermal methods. More detailed examination has revealed the fact that on liquid surfaces the material in the adsorbed monolayer can, like material in three dimensions, exist in various physical states akin to three dimensional vapours, liquids and solids, and that these phases can be transformed into one another each with its own definite change in free energy of transformation.

Examination of such monolayers on liquid surfaces by means of the Langmuir trough, and by determination of the phase boundary potential, now provides us with some information supplementary to the examination by X-rays as to the configuration of complex molecules like the sterols or proteins. It is also possible to measure the rate of reactions proceedings in these films, for example, such processes as enzyme reactions, chemical reactions involving hydrolysis, oxidation or two dimensional polymerisation. These reactions proceeding in monolayers at fluid interfaces are of great interest, in that not only may they be the prototype of a number of important biological chemical reactions which occur *in vivo*, but they also permit us to alter at will by mere compression or expansion the rate of reaction proceeding in the film, visual evidence of the reality of the factor termed the steric factor in homogeneous reactions.

A much greater variety of phenomena is met with when investigating adsorption at solid surfaces. Two distinct types of adsorptive processes are generally recognised, in one the forces holding the molecule to the surface originate in the mutual polarisation of the molecules and are frequently termed physical or Van der Waals' forces. In suitable circumstances an electronic switch occurs and a chemical reaction takes place between the adsorbed molecule and one or more molecules of the substrate, forming a chemi-adsorbed complex. It is customary to consider chemical compounds as belonging to one or other of the extreme types, one where the stability of the compound is due chiefly to the operation of coulomb forces between ions and the other where a bond or a valency force in the form of a pair of electrons is shared between two atoms in a binary compound. We may cite the adsorption of the rare gases on mica, of cæsium on tungsten and oxygen on tungsten as typical representatives of these three types of surface compounds existing in the adsorbed phase.

Whilst the molecules in a distended adsorbed phase on a liquid substrate can move freely over the surface by diffusion, such is not the case on a solid surface, where the adsorbed molecules must migrate *per saltum*, a process termed activated diffusion. Such activated diffusion is not always limited to the surface of the solid, for frequently the process of adsorption is complicated by penetration into the solid through fissures, along slip planes, into large molecular holes, as obtain in the zeolites, or actually into the lattice of the solid itself, and in some cases it is possible to trace the changes in the mode of gas flow inward from simple diffusion to activated diffusion as the fissures change in size and the temperature is varied. As we have noted, the elimination of forces other than Van der Waals' and chemical in adsorption phenomena, does not permit of the assumption of the existence of an atmosphere-like thick adsorption layer, yet thick layers can be built up under suitable conditions by the operation of these short-range forces alone ;

thus relatively thick layers of sodium can be deposited upon tungsten. It is possible that these are not intrinsically stable and may actually aggregate into drops embedded in a monolayer, as occurs when a relatively thick film of oleic acid is deposited on the surface of water. Evidence for the formation of a second layer on the top of a first has often been brought forward, and indeed this phenomenon may be of frequent occurrence ; thus a layer of oxygen molecules may be held on to the top of a layer of oxygen chemi-adsorbed on to tungsten. The second layer is of course 'held' less tightly than the first; in consequence the second layer may be but sparsely populated under conditions when the first is almost complete, and molecules in the second layer may be much more mobile than the atoms or ions in the first. It is indeed due to the surface mobility of the oxygen in this second layer that a tungsten wire becomes coated so rapidly with a chemi-adsorbed layer in oxygen at low pressures. The adsorbed oxygen in the second layer moves over the surface and drops into any vacant hole in the chemi-adsorbed layer beneath.

More recently, evidence has been brought forward that when gases, or more generally, vapours, are adsorbed by the operation of Van der Waals' forces, the adsorbed layer may exist under suitable conditions in more than one state ; thus it is possible to describe phase changes on solid surfaces as due to two dimensional liquefaction or solidification from a two dimensional vapour phase.

Similar phenomena are met with in cases of chemi-adsorption, but here the lateral attractive and repulsive forces between the adsorbed ions or dipoles, and their variation with the changes in the density of population, are great enough both to make a thorough study of the conditions of equilibrium in these two dimensional chemical systems on solid substrates an extremely complicated problem and to render the interpretation of the experimental data difficult.

Adsorption of gases by solids is not always an extremely rapid process but may, over suitable temperature ranges, proceed with measurable speeds. From the influence of temperature on the rate of the process, energies of activation may be calculated. In many cases this slow process, requiring a definite energy of activation, can be ascribed to the slowness of the process of conversion of the Van der Waals' adsorbed molecules into the chemi-adsorbed complex, and for this reason chemisorption is frequently termed activated adsorption, although in a number of cases the process of chemi-adsorption, like many elementary reactions, can proceed with a negligible energy of activation.

A closer analysis of the problem suggests that there are at least three distinct processes where energy barriers may be involved, that is, three different energies of activation may have to be distinguished. These are first, the transition of the Van der Waals' adsorbed molecule to the chemi-adsorbed state ; secondly, the transition of a molecule or atom of the exterior of the solid to a place just inside the solid ; and thirdly, the migration of this molecule farther into the interior.

In many cases where the process of adsorption is proceeding slowly, it is a matter of some difficulty to find out which of these three energy barriers is actually responsible for controlling the speed of the reaction actually being measured.

It seems certain that in many cases, where diatomic gases such as hydrogen, oxygen or nitrogen undergo the process of chemi-adsorption at metallic surfaces, a reaction occurs which is the preliminary stage in a number of heterogeneous catalytic reactions, some of these being of great industrial importance. The resulting chemi-adsorbed complex involves only one atom of the gas undergoing chemi-adsorption. Thus chemi-adsorption involves a process of dissociation of the molecule. The application of the principles of the wave mechanics to the theoretical aspects of this problem suggests that the energies of activation should vary with the spacing or distance apart of the atoms forming the substrate. Whilst the experimental evidence so far produced may be said to support this view, it has not yet been tested in a manner sufficiently rigorous to affirm the correctness of this important theoretical conclusion.

Twenty-five years ago, no distinct ideas as to the mechanism of catalytic reactions at solid surfaces could be said to have been formulated. The chemical view, which postulated the formation of intermediate compounds, could be found side by side with what might be termed a physical view, where it was supposed that the molecules in the condensed atmosphere not only collided more frequently but also the forces opposing reaction were in some mysterious way reduced to smaller magnitudes. At the present time, it may be said that the chemical view has been fully substantiated ; the catalyst provides by chemi-adsorption an alternative chemical path. Surface hydrides, oxides, nitrides, and more complex compounds—for example, such as are formed by chemi-adsorption of olefines on carbon—are known, and their properties have been examined. Much further work is required before the detailed kinetics of these processes can be said to be definitely established, but it is clear that during the last twenty-five years the crops from the field thrown open by Hardy and Langmuir have been good, and bumper harvests may be expected in the future.

Food Storage and Transport

By DR. FRANKLIN KIDD, Superintendent of the Low Temperature Research Station, Cambridge

THE state of affairs to-day with regard to the transport and storage of foods is very different from what it was twenty-five years ago. The bulk that is handled is very much larger and the variety is much greater, and transport and storage are conducted over longer times and distances.

Putting aside canning and drying as methods of preservation, and considering fresh foodstuffs only, this development has been due to the application of refrigeration over a wider and wider field.

The success that has attended this development is founded on the intelligent grasp that has been everywhere shown of the fact that the use of low temperature as such is in itself only the widest of general principles. Each type of foodstuff, be it fresh fish, meat, fruit or vegetable, is an infinitely complex material and subtly varying according to its growth and development. The last twenty-five years have seen a great extension of our knowledge of the laws governing the changes in these organisms in their living and post-mortem states. To-day, scientific attention is given not only to the question of temperature control and to the maintenance of low temperatures during storage; but also to every stage of the pre- and post-storage history, with the object of producing foodstuffs, after long storage and transport, indistinguishable in appearance, palatability, digestibility and physiological value from the original fresh material.

A single example may be interesting here in illustration. It must be generally known what a difficult fruit the William pear is to handle even when grown in one's own garden. It seems almost incredible that thousands of tons of this choice fruit should be successfully shipped in bulk to Great Britain from South Africa, California and Australia. This success could not be achieved unless in the first place an elaborate scientific technique existed for the proper production of the fruit, free from all blemishes : if the exactly right time for gathering the fruit based on a variety of tests had not been chosen : if the fruit had not been wrapped and systematically packed in cases by methods which have been evolved and standardised as a result of a long process of experiment and observation : if the fruit had not been rapidly cooled in special pre-cooling stores in the country of origin ; if afterwards it had not been carried, of necessity in bulk, but with the arrangements of stowage and refrigeration by forced air movement so adjusted as to maintain a uniformity of temperature throughout the hold to within 1° F. : and if finally, the fruit had not been properly ripened at a controlled high temperature after arrival in Great Britain in the winter months. Disasters occur even to-day through failure in one or other of the links in this chain.

Chilled beef is another good case in point illustrating this type of development. The degree to which the quality of imported chilled beef approximates to that of the best 'home-killed' depends not only on the maintenance of the low temperature, but also its maintenance to within 0·5° F. during shipment : upon the proper breeding, feeding, resting and watering of the cattle before slaughter : and above everything upon the utmost care in the maintenance of hygienic conditions during the dressing of the meat. Bacterial counts are now made at the time the beef is chilled, and from these the condition of the meat on arrival after transport can be almost precisely foretold.

One line along which much progress has been made is in the definition of the optimum temperatures for storage, and this is so principally with regard to fruit, and with regard to frozen fish and meats. As a general principle, all fruits and vegetables have what is termed a low temperature tolerance limit. They cannot of course be frozen without damaging the essential organisation of the fresh product. Even above the freezing point, however, they cannot be stored too long below their tolerance limit without suffering from some form of functional breakdown and disorganisation. Many types of breakdown of this class have now been detected and described in various fruits, and in a large number of cases the optimum temperature of storage has been accurately determined

In the case of frozen fish and frozen meats, scientific analysis has brought to light the fact that changes affecting solubility of the proteins occur most rapidly between − 2° C. and − 3° C., and it has become clear that the dry tasteless condition previously encountered in frozen fish and certain meats can be avoided and the fresh state almost completely preserved if, in freezing and thawing, the material is taken rapidly enough through a critical range of temperatures below the freezing point, and if during storage it is held at a temperature between − 20° C. and − 30° C.

One of the results of this discovery has been to open up a new source of fish supply to Great Britain. Large vessels equipped with rapid freezing equipment and large storage capacity are able to spend months away from port on the west coast of Greenland fishing for halibut and cod. An even more recent development, still in the experimental stage, is the preservation of a proportion of the herring harvest by quick freezing and low-temperature storage for subsequent, out of season, kippering and other uses.

So far we have dealt with what might be described as improvements in the technique of storage by the use of low temperature. A revolutionary development which has taken place within the last twenty-five years, a development which is probably even now only in its infancy, is the regulation of the composition of the atmosphere as an additional or accessory means of controlling biological change.

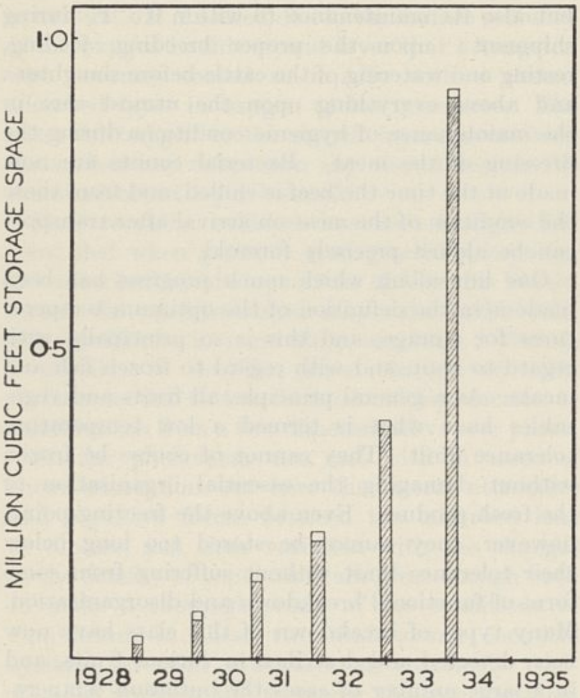

Fig. 1. Increase in the capacity of gas-storage for apples in England, since 1929.

The idea of using an inert gas for the better preservation of foodstuffs is, of course, an old one. Modern developments in Great Britain may be said to have started with a series of papers which appeared in the *Proceedings of the Royal Society* in 1914–15, dealing with the respiration and germination of seeds as affected by oxygen concentration and carbon dioxide concentration. The Food Investigation Board, founded in 1917, took up from the beginning a systematic study of the question of applying the principle of atmosphere control to the storage and transport of food. In the first place, investigations were confined to fruit and fruit-rotting fungi. The first commercial fruit store employing the combined control of the temperature, oxygen and carbon dioxide content of the air was installed in Kent in 1928, and since then the adoption of atmospheric control in fruit stores (gas-storage) has been rapid in Great Britain (Fig. 1).

The effectiveness of the method is due to several facts. The majority of English apples have a relatively high low-temperature tolerance limit, so that cold storage is not effective in the majority of cases for preservation beyond Christmas or January. The rate of ripening is a function of the rate of respiration, and this can be retarded not only by lowering the temperature, but also by reducing the oxygen content of the air and by raising the carbon dioxide content. There are, however, strict limits to which either operation can be safely carried without injuring the fruit. Carbon dioxide has a specific effect also in delaying the onset of what is known as the climacteric, a critical change of state which precedes the ripening changes of softening, and odour and flavour development.

Twenty-five years ago, owing to the length of the voyage, the transport of chilled beef from Australia to Great Britain was an outstanding and apparently insoluble problem. The limit for chilling was set by the activity of the micro-organisms—bacteria and moulds. Could the rate of growth of these organisms be sufficiently reduced by any concentration of carbon dioxide which could safely be used without itself spoiling the appearance of the meat ? Laboratory experiments on the types of micro-organisms concerned, at the temperatures of chilled beef carriage, indicated that the life of the beef would be approximately doubled by employing an atmosphere containing 10 per cent carbon dioxide. Simultaneous investigations showed that this concentration would be without appreciable effect upon changes in the fat leading to rancidity or those in the hæmoglobin leading to browning. In 1933, the first shipment of gas-stored chilled beef was brought from New Zealand, and to-day there is an established trade in good quality chilled beef from the antipodes to Great Britain.

The possibilities of atmosphere control are not limited to those dependent upon carbon dioxide and oxygen effects upon organisms—fruits, vegetables and micro-flora. As the result of the analysis of the critical part played by oxygen in the breakdown of unsaturated fatty acids and the production of certain types of rancidity, many types of dry foodstuffs containing fats are to-day packed in gas-tight containers from which oxygen is excluded. In the storage of bacon or cured pigs' flesh, this type of oxidative rancidity is usually the limiting factor, and storage in the chilled or frozen state does relatively little to retard these oxidative changes in fat. They can, however, be eliminated by the use of atmospheres free from oxygen and containing a high carbon dioxide content, and by this method bacon can now be successfully stored for months as compared with weeks previously possible.

Other improvements in the science and art of food storage and transport are dependent upon the use in special cases and for special purposes of atmospheres containing regulated traces of such gases as ozone, ethylene and ammonia. Ozone removes undesirable substances from storage atmospheres, such as the 'volatiles' of ripening fruit, which in too high a concentration are harmful to the fruits themselves or 'taint' other products stored afterwards or simultaneously in the same space. Ozone can also exercise a retarding effect on bacterial and mould growth. Ethylene is used specifically to stimulate in fruits the climacteric change alluded to above, so that large quantities can be brought uniformly to the optimum stage of ripeness at the time desired. Ammonia retards the germination of spores of decay organisms always unavoidably present to a greater or less extent on the surface of all kinds of fresh foodstuffs.

In broad retrospect, the past twenty-five years appear as an era in which scientific and practical skill has achieved remarkable results in extending the scope of storage and transport as regards the prevention of wastage. By a continuance of the same general methods—that is to say, progressive and intensive scientific analysis of the properties and behaviour of foodstuffs of all kinds and the close linking of practical application with new discovery—the next twenty-five years should see, I think, as great an advance in the quality of products as the past twenty-five years has witnessed in their quantity and variety.

Special Steels

By SIR ROBERT HADFIELD, Bt., F.R.S.

INTRODUCTION

THE author regards it as a privilege to be invited to review in these columns the general progress of special or alloy steels during the first twenty-five years of His Majesty's reign. His pleasure in accepting this invitation is further increased by the fact that he had last year the honour of being one of the deputation from the Iron and Steel Institute to present His Majesty with the Bessemer Gold Medal, which he graciously accepted. In doing so, His Majesty was following a precedent established by Queen Victoria and continued by King Edward VII, to whom in 1906 the author himself had the honour of presenting the Medal on behalf of the Iron and Steel Institute. Thus for three generations the Royal Family has demonstrated its concern and interest for the welfare and progress of the iron and steel industry, upon which the prosperity of our country and its position in the world so largely depends.

Within the limits of space here available, it is not possible to give anything approaching a complete survey of advances in the vast field of special and alloy steels during the past quarter of a century. The story is in fact one which begins much earlier and shows during this notable period of industrial activity the vigorous expansion of the era of alloy steels, which at its commencement had become well established but was then comparatively young. In 1929 the world's output of steel, then at its maximum production, was 120 million tons, of which no less than about 6 million tons represented alloy steels.

In reviewing progress in this period of twenty-five years it is necessary, therefore, to take account both of those newer alloy steels which it has seen initiated and also of the developments which have taken place in the use of those which had already found practical application.

The author's discovery and invention of manganese steel in 1882, as expressed by so many well-known metallurgists, marked the dawn of the age of high alloy steels. The extraordinary and valuable results then obtained led him to investigate in many other directions this hitherto practically unknown field, and later he was followed by numerous other investigators. To-day manganese steel, with modern improvements in manufacture, is used throughout the world in increasing quantities and for a greater variety of purposes than ever before. In addition, there have been developed corrosion- and heat-resisting steels, high-speed tool steels, special steels for armaments and ordnance, special structural steels, high tenacity steels, and steels with remarkable magnetic properties, whether as regards low energy losses in electrical machinery and apparatus, specially high permeability at low magnetisations, or special suitability for permanent magnets, as the case may be. The arts of peace have been served in no less measure than the needs of national defence, and progress has been astonishingly rapid in all the branches of metallurgical knowledge concerned.

Manganese Steel

Much progress has been made, and many difficulties overcome, in the production and applications of manganese steel since the original specimens of this material were exhibited by the author at the reading of his first paper on this subject before the Institution of Civil Engineers in 1887, that is, almost exactly forty-eight years ago. This alloy, now known throughout the world as the Hadfield manganese steel, consists of a non-magnetic alloy of iron with from 11 to 14 per cent of manganese and about 1·25 per cent carbon, and remains one of the most remarkable ferrous materials yet produced, whether from the point of view of practical application or scientific interest.

Whilst the general progress of metallurgy has brought about improvement in the actual manufacture of the material, as also its heat treatment which plays such an essential part in the full development of its qualities, this important alloy, manganese steel, remains exactly the same as when originally invented in 1882.

Silicon Steel

The history of the development of this remarkable steel, invented by the writer in the latter portion of the nineteenth century, and how the early difficulties attending its introduction and production, including the best and most suitable proportions to be used of the element silicon, also heat treatment, were surmounted, are given very fully in his book "Metallurgy and its Influence on Modern Progress".

Since its first employment early in the present century, silicon steel has become of the highest importance in the electrical industry by its use in transformers, generators, motors and many other purposes. Without the use of silicon steel, the efficiency of electrical generation and transformation would be seriously lower than at present and many modern designs of electrical plant would be physically impossible owing to the increased energy losses.

The hysteresis loss of this steel is initially about two thirds that of unalloyed iron, and actually decreases during a period of years in service. Its high electrical resistance, about six times that of iron, is also of great advantage in minimising losses due to eddy currents, while its maximum magnetic permeability is about 25 per cent higher than that of iron.

Corrosion-Resisting Steels

The remarkable developments in corrosion-resisting steels, as also in heat-resisting steels to be referred to later, have taken place entirely within the past twenty-five years. Several varieties of specialised types have been developed to meet different requirements. There are many applications in chemical and other industries for materials combining resistance to corrosion with the mechanical properties of steel, that is, apart from the use of some of these special alloy steels for domestic and ornamental applications. No single steel yet developed meets all possible requirements in this field, but many special steels have been perfected, and from these it is generally possible to choose one which is effective against any particular one or more of the many corrosive agencies encountered in industry.

The simpler and original type of corrosion-resisting steel, usually termed 'stainless' steel, established by Brearley, containing 12–14 per cent of chromium and from about 0·05 per cent up to about 0·40 per cent of carbon, also still higher percentages such as 16–18 per cent of chromium, according to the purpose for which they are intended, have valuable mechanical properties, and are specially suitable for applications in which the corrosive action is of the ordinary kind, that is, due to air and water. For chemical and other applications where a wider range of resistance to corrosion is required, the steels most generally used are of the nickel-chromium type, low in carbon and with from about 12–20 per cent of chromium and about 7–12 per cent of nickel, and in certain cases also small additions of elements such as tungsten, molybdenum and titanium, and other elements are being investigated such as columbium. These materials are now available in castings, forgings, rolled sheets or bars, tubes and wire ; also by machining, pressing, welding and other methods of assembly they can be fabricated into practically any form desired.

The development of non-rusting steel covers an exceedingly wide field and those specially interested in the history describing its origin and rise are recommended to refer to Chapter ix of the author's book "Faraday and his Metallurgical Researches" where the later development of alloy steels is dealt with.

Steels of this type are now used widely for tanks, pans and other parts of chemical or other manufacturing equipment exposed to corrosive media too numerous to be mentioned individually, including many of the most commonly encountered acids and corrosive salts. There is also large employment for these steels for decorative purposes where high polish is required. For other applications, further and more special types of corrosion-resisting steels have been developed.

One of these, for example, is useful in the sulphate house of coal and coke by-product recovery plants, owing to its resistance to dilute sulphuric acid. Also it finds many applications in sugar refineries owing to its resistance to acid calcium phosphate and other chemicals employed ; and it is specially valuable in food industries, being unaffected by the dilute solutions of phosphoric acid contained in chemical foods.

In a very different field, the use of a corrosion-resisting special steel for the reinforcements of the masonry in the preservation of St. Paul's Cathedral, London, suggests that such material will be employed to an increasing extent, ensuring the permanence of our historic buildings as necessity arises. It will doubtless be a satisfaction to all concerned with the metallurgy of iron that the special steels so employed and supplied by three Sheffield firms are associated in such an important capacity with the safety of the cathedral in which the Royal Silver Jubilee Thanksgiving Service is to be held.

In the construction of new buildings also, high tensile non-corrodible steel is being used, as in the case of certain structural members in the new library of the University of Cambridge.

HEAT-RESISTING STEELS

Almost contemporary with the development of corrosion-resisting steels has been the recognition and utilisation of the merits of heat-resisting steels. There are, in general, ferrous alloys with high nickel and chromium contents, variable in amount according to the properties required in the products. In some cases, the iron content barely exceeds 50 per cent.

The term 'heat-resisting', as applied to steels, implies resistance to oxidation and other forms of corrosion at high temperatures, while retaining a high degree of mechanical strength. Materials fulfilling these conditions find many important applications, including the valves of internal combustion engines, rotors of gas turbines, mechanical parts of furnaces of all kinds, reaction vessels for coal-hydrogenation, and many other uses requiring mechanical reliability combined with freedom from oxidation and scaling. Developments in this field have been so numerous that it is impossible here to do more than indicate their variety and importance. The following examples are, therefore, to be taken merely as representative and by no means exhaustive.

Cast iron parts formerly used in mechanical stokers in the Canadian Pacific Steamship Company's vessels of the *Beaver* class, operating with air preheated to 310° F., were found to require replacement after every second round trip. The parts exposed to the severest conditions, such as tuyères, grate plates, slicing bars and extension plates, were, therefore, made of heat-resisting steel, and the grates were then found to be in perfect condition after a year's continuous service. Similar examples are provided in many other directions and, to take one at the other end of the scale, claw bars of heat-resisting steel in a certain type of domestic hot-water boiler are still in perfect condition after two years service, where new cast iron bars were formerly required every three or four months. This is only one of many instances.

The exhaust valves of internal combustion engines are, specially where high efficiency is aimed for, exposed to most difficult conditions as regards temperature, mechanical stress and liability to scaling and erosion. Here again, special heat-resisting steels come to the rescue, and exhaust valves of such material have contributed to successive world speed records on land, water and in the air. Similar conditions apply in the case of the rotors of exhaust gas turbines, in which applications equal success has been attained.

For the vessels used in modern high-pressure high-temperature chemical processes, heat-resisting qualities must be combined with resistance to chemical action, and here again the conditions are being successfully met.

The applications of these new alloy steels are, in fact, so numerous and important that they will probably have as important an influence on the progress of engineering and the economics of industry as that exerted by the earlier alloys, manganese steel and silicon steel, in their particular spheres.

SPECIAL STEELS FOR ARMOUR AND ORDNANCE

Without ceasing for a moment to regret the waste and folly of war, it is impossible to ignore the important contributions to national defence resulting from the applications of special steels in armour, projectiles and other munitions during the War. Then, and, in fact, throughout the particular period under review, the rivalry between armour and projectile continued with steady improvement in each. However, the reference made here to this subject can only be brief, though without doubt our nation must continue to supplement its work by continued efforts if national security is to be preserved.

One of the most striking applications of alloy steel in the War, and one to which it is very appropriate to make present reference owing to its humanitarian aspect, was the use of manganese steel for the helmets of our soldiers and most of our allies. Though commonly known as 'tin hats', these helmets were of the much sterner material known universally as the Hadfield manganese steel, and there can be no question that very large numbers of our brave soldiers owed their lives to the remarkable toughness and resistance to shrapnel fire of this extraordinary material with its non-magnetic qualities most useful in many cases.

Special Steels for Other Purposes

At least a passing reference must also be made to high tenacity steels, large steel forgings of extraordinary weight and size, special steels for steam turbines and steam fittings, high-speed tool steels, in which great advances have been made, special magnetic steels and alloy steels for general engineering and constructional purposes. Nor should it be forgotten that there have been important advances in the quality of carbon steels, which are strictly speaking alloy steels, for, of all the elements alloyed with iron, carbon is in many respects the most powerful and remarkable in its effects.

Alloy steels possessing high breaking strengths up to 100 tons per sq. in. and above have been used by engineers for some time past, and there has been steady progress during recent years in the improvement of the quality of such high-tenacity alloy steels, specially as regards toughness and resistance to shock and vibration.

In many of the largest steam turbines on land and sea, and even in more ordinary installations where there may seem to be no special liability to erosion and corrosion, a special alloy of iron high in its nickel and chromium contents is used for the blading, with great advantage in the maintenance of high steam economy, this alloy being highly resistant to erosion and completely non-corrodible under all the conditions experienced by steam turbine blading. For example, already turbines of no less than 7 million horse power in total capacity are now bladed in whole or in part with such special steel.

One of the most interesting developments in modern high-speed tool steels, specially in view of the fact that manganese steel was formerly considered to be practically unmachinable, is the discovery of alloy steels which will drill and cut water-toughened manganese steel, thus making possible a further extension in the many applications of this exceedingly useful material.

Great progress has been made in special steels for permanent magnets and in steels of very high permeability at low inductions ; also in new non-magnetic alloys of iron. Again, there have been important developments in the use of alloy steels for general constructional purposes, for example in the hulls of large vessels where reduction of weight is an important consideration. Many other instances might be mentioned, if space permitted, of improvements in alloy steels which have greatly advanced engineering and industrial practice since the year 1910.

Importance of Research

If there is one outstanding lesson that has been brought out by metallurgical progress in general and made possible the rise of alloy steels in particular, it is the importance of continual research. Also this research, specially where alloy steels are concerned, must be over as wide a field as possible.

As an instance it may be mentioned that the laboratories of the author's firm, as well as those of most modern steel works, have for many years used for routine testing as well as original investigations, equipment for every kind of test—chemical, mechanical and physical—with special apparatus for carrying out tensile, bending, endurance, impact, hardness, electrical conductivity, magnetic permeability, hysteresis, measurement of temperatures from the lowest to the highest, the determination of thermal change points and other tests. In a single week as many as 12,000 pyrometric observations have been made, and equipment for the microscopic examination and photomicrography of steels at all powers up to 5,000 and even 8,000 diameters is continually in use.

In any appreciation of the great and increasing importance of metallurgical research during the past twenty-five years account must be taken of the part played by our universities in the training of metallurgical students, and in many instances conducting valuable research investigations. The special duties and responsibilities of the research laboratories maintained by firms, and working in direct touch with the conditions and requirements of commercial development, can never be fully undertaken by other institutions or organisations. At the same time, metallurgists owe a great debt of gratitude to the universities. As an example, it may be mentioned that the training and research work carried out in the laboratories of the Applied Science Department of the University of Sheffield are worthy of the highest traditions of the city, and the establishment of metallurgy as an independent faculty with, quite recently, a special founding course and degrees in foundry science is but one instance of the way in which the authorities are keeping in the forefront of metallurgical progress. The importance of research facilities is equally recognised at other universities, each in its own sphere, but in regard to ferrous metallurgy the University of Sheffield naturally occupies a special position and is second to none in the world.

Outside the many and valuable researches carried out at the various universities of Great Britain reference must certainly be made to the important work being carried on continuously by the National Physical Laboratory, originally under the able guidance of Sir Richard Glazebrook, and now that of Sir Joseph Petavel, to whom and his staff, composed of men of scientific eminence, great credit is due. This great national establishment is now supported by large annual grants, aided by Parliament through the Royal Society and the Department of Scientific and Industrial Research.

The Future

Finally, as will have been gathered in the reading of this article, the continued and increasing use of alloy steels in their many forms is most certainly assured. The great value of such products can almost be said to be beyond computation in view of the services they render, and modern civilisation could not be sustained by any other means ; they may, therefore, be justly said to be beyond any adequate expression in terms of money.

It is scarcely realised how largely further advances of present modern civilisation depend upon alloy steels. Take these away and our modern civilisation could certainly not exist, at any rate, on anything like its present high plane, and we should in many respects be cast back to the comparatively unsatisfactory conditions of more than a century ago.

It is entirely the production and use of alloy steels which have rendered practicable the bringing into being of engineering and other constructions which would not otherwise have been possible, whether in their employment on land or sea or in the air.

One useful alloy after another, new or improved, takes its place in the civilisation which it advances and thereafter it is indispensable unless indeed a still better material can be discovered. Progress far beyond the bounds which could be foreseen twenty-five years ago has already been achieved, and the rate of such advance appears likely to continue undiminished. Therein lie challenge, inspiration and encouragement for those of the younger generation.

Progress in Radio Communication

By Prof. E. V. Appleton, F.R.S., Wheatstone Professor of Physics, King's College, London

It is a matter worthy of note that the remarkable progress of radio communication during the last quarter of a century has proceeded largely from the exploitation of the properties of that late-nineteenth century discovery, the free electron. For it is no exaggeration to say that practically all the instrumental progress of the period is connected in some way with that wonderful device, the three-electrode electron tube, while we now realise that the spectacular annihilation of distances in round-the-world communication by wireless is only brought about by the beneficent influence of free electrons at high atmospheric levels. Another significant feature of the period is that radio developments have had an unusually marked influence on human intercourse for, through broadcasting, there has been introduced a new and permanent feature of social and cultural enlightenment while, by way of the oversea wireless telephone, the different parts of the Empire have been brought into a closer unity which from time to time has been sealed by personal messages of greeting from His Majesty the King to all his subjects throughout the world.

In 1910 the utility of wireless communication was regarded as being largely concerned with increasing the safety of life at sea. Public interest was, in 1912 for example, stirred by the case of the *Titanic* which, with some 3,000 people on board, struck an iceberg on her maiden voyage across the Atlantic. Several ships picked up her wireless distress signals and raced to the rescue. Unfortunately, the *Titanic* had sunk when help arrived, and only 900 persons were saved, though it is clear that without the aid of wireless all would have been lost. The first of a series of international conferences concerning the safety of life at sea was held in the following year, though it was not until after the War that stringent regulations concerning the provision of wireless equipment for ships of above a specified tonnage were put into force.

Technicians were, at first, slow to recognise the potentialities of the instrument which was to revolutionise the subject, for it was not until 1913 that Armstrong, Meissner and Round independently discovered that the three-electrode valve, which de Forest had invented so far back as 1907, was capable of generating continuous electrical oscillations, and not until after the War was general use made of it in wireless telephony. Rather was attention being paid at that time to the possibilities of the Poulsen arc, and the different types of alternators designed by Goldschmidt, Alexanderson and others. The general tendency before the War was, in fact, to use arcs and alternators for high-power sending stations and spark generators for short-distance communication between ships.

Meanwhile, the fuller utilisation of the three-electrode valve in reception (for detection and amplification) was limited by its inconstancy in operation, which was due to the imperfect vacuum then realisable. A notable improvement was effected in this direction by Langmuir who, in 1915, produced 'hard' valves from which all deleterious traces of gas had been removed. It thus came about that after the War there was to the hand of the experimenter a device, constant and reliable in operation, which, for sending, would produce sustained waves over a very wide range of lengths, and, on the receiving side, give, in cascade, magnifications of a million-fold. With such a generator, any form of information, whether concerning a sound or a picture, could be transmitted over a distance in the form of a modulation of the waves ; while with such an amplifier in use at the receiving end of a wireless circuit, the power required at the sender could be correspondingly reduced.

In the summer of 1922 some of the leading British manufacturers of wireless apparatus approached the Post Office for permission to begin an experimental service of broadcasting speech and music by wireless telephony in this country, and the result was the formation of the British Broadcasting Company. Under the direction of this Company and its successor, the British Broadcasting Corporation, which on January 1, 1927, was incorporated by Royal Charter, there has grown up a great service of sound broadcasting in Great Britain, while to provide listeners with the necessary apparatus for reception there has arisen a new and vigorous electrical industry. In the evolution of the modern wireless receiver, commercial research has led to the development of new types of valve filaments giving greater efficiency and to more elaborate types of electrode structures. In this connexion special mention must be made of the immediate derivatives of the three-electrode valve, namely, the screen-grid valve for high-frequency amplification and the pentode for distortionless amplification of strong signals.

Most histories contain a revolution, and the history of wireless communication is no exception to the general rule. At the end of the War, it was regarded as established that long waves were superior to short waves for long-distance communications. The superiority was, in fact, embodied in a transmission formula due to Austin, which was then much employed by radio engineers. It is generally thought that the first hint of the extraordinary possibilities of short waves for long-distance communication came from the experiments of amateurs in December 1921. Such experimenters were limited by law to use wave-lengths less than 200 metres but, though operating with very small power indeed, they were able to establish contact with other amateurs 7,000 miles away. During the winter of 1922–23, Dr. W. H. Eccles and H. Morris-Airby, using receivers tuned to wave-lengths lower than 100 metres, were able almost every night to pick up signals from American amateur stations, often as harmonics of the sending wave-length. In October 1924 the greatest distance of all was spanned when communication was established between F. Bell in New Zealand and C. W. Goyder, a Mill Hill schoolboy.

The revolution mentioned above came at a time when the problem of linking up the Empire by wireless was under discussion. In March 1923 the British Government announced the decision to erect a large wireless station at Rugby, capable of communicating with any part of the world. By the end of 1926 this station, working on long waves, as well as a wireless telephone long-wave link between Great Britain and North America, were in successful operation. The latter service, the details of which were worked out by the engineers of the British Post Office in collaboration with the engineers of the American Telegraph and Telephone Company, was the first long-distance commercial wireless-telephone link to be completed, and its inauguration constitutes a landmark in the history of electrical communication. In connexion with Empire telegraph communications by short waves the engineers of the Marconi Company did pioneer work. The most notable invention in this field is due to C. S. Franklin who showed how, by using a special array of aerial wires with a similar array behind, to act as a reflector, it was possible to confine the waves into a directed beam. Nowadays, for all point-to-point services, advantage is taken of such directional and economic projection of the waves.

To the short wave beam station built by the Marconi Company for telegraph communication to the Dominions, there have been added direct wireless telephone services to different parts of the Empire. In these cases also beam senders and receivers, built by the Post Office, are used, with corresponding stations oversea. The sending stations are all accommodated at Rugby, while the corresponding receiving stations are situated at Baldock. The result of these direct Empire services is that it is not an exaggeration to say that the whole of the Empire is 'on the telephone', with London as the exchange. A further experiment in Imperial communication has been the inauguration of Empire short-wave broadcasting by the B.B.C. in 1932. At first it was attempted to provide a two-hours' programme in each of five Empire zones between the convenient hours of 6 p.m. and midnight, local time, while the B.B.C. publication, *World Radio*, which is the official organ of Empire broadcasting, is published so far in advance that copies of it are available in different parts of the Empire at the appropriate time.

On the more purely scientific side, substantial progress has been made during the last twenty-five years, especially as regards the elucidation of electric wave propagation. For the propagation of waves along the ground the correctness of the transmission formula of Sommerfeld has been checked by signal intensity measurements made by Barnett and Ratcliffe and by B.B.C. engineers. Other quantitative experiments have been carried out to elucidate the structure and properties of the highly ionised region of the upper atmosphere (from 100 km. upwards) known as the ionosphere, which reflects wireless waves and makes long-distance radio communication possible. The existence of such a reflecting stratum was postulated so far back as 1905 by both Kennelly and Heaviside, but it was not until 1924 that its situation in the atmosphere was established. Further investigations have shown that above the Kennelly-Heaviside layer, as the region about 100 km. is called, there is a more intensely ionised stratum, the electrical density of which is the factor that limits the shortest wave-length which can be used for round-the-world communication. Experiments carried out by Henderson, Rose and others during the solar eclipse of 1932 in Canada have shown that the upper atmospheric ionisation is caused by the photo-electric action of sunlight. Due to the influence of the earth's magnetic field on the motion of the free electrons, the ionosphere is a doubly-refracting medium and resolves an incident wireless wave into two oppositely rotating components which experience absorption of different amounts. The result is that a reflected wireless wave of, say, 400 metres, is of predominantly left-handed polarisation in the northern hemisphere but of opposite rotation in the southern hemisphere.

The ionisation in the upper atmosphere is not by any means constant. It is usually denser by day than by night and denser in summer than in winter, but these normal variations are sometimes profoundly upset by manifestations of solar activity. The general effect of such activity has been found to be an alteration of the disposition of the electrification and thus of the properties of the ionosphere as a reflecting medium. One of the curious things noticed, in our latitudes, is the difference in the effects on long-wave and on short-wave transmission. With long waves a solar disturbance which produces a magnetic storm may often increase the daylight signal intensity, but in the case of short wave channels there is almost always a sharp reduction in signal strength. In the case of communication over a great circle which traverses high latitudes, the effects of a magnetic storm have been found to be specially marked, which explains why the short wave channels to Canada are more frequently interrupted in this way than are the services to South Africa.

On the purely technical side there have been, particularly since the War, many notable contributions to electrical circuit practice, quite apart from the thermionic valve and its derivatives. Selection is difficult, but perhaps the superheterodyne circuit of Armstrong and the quartz crystal oscillator of Cady may be chosen as outstanding. The superheterodyne receiver, in which amplification is effected after the conversion of the received signals to a lower frequency, is almost universally used nowadays in commercial practice and in the more elaborate broadcast receivers; while the quartz oscillator, particularly in the hands of Dye and his associates at the National Physical Laboratory, has been developed to provide high-frequency standards of a constancy and accuracy hitherto unattainable.

The Perfection of the Thermionic Valve

By B. S. GOSSLING, Research Laboratories, General Electric Co., Ltd., Wembley

THE past twenty-five years have seen the coming of a great change, both in human society and in the individual human life. Man has become able to speak to man, and man to mankind, directly and without obstacle of distance. Next week, King George will speak, not for the first time, to all his people wherever they may be, and his hearers may well ponder this new aspect of the many-sided relation between Crown and people.

For the ordinary man the change is that he is now in ready touch with his fellows, whether actively and personally through the long-distance telephone, or passively and with others through broadcasting. As His Majesty has implied in his broadcast words, this means that the tragedies of enforced loneliness and anxiety will soon be erased from the lot of man. Music is now within reach of all who will, and whatever there be between learning and laughter that the spoken word can bring to our ears.

The principal instrument that has enlarged on this vast scale, and yet without artificiality, the scope of our most natural mode of communication —by voice and ear—is the thermionic valve. The attainment by this instrument of its present large measure of perfection—so much even those who best know its faults can allow it—falls easily within the period under review, but springs from the efforts of so many workers in so many countries that it can here be presented only in the briefest of outlines.

To begin with, making our start from somewhat less than thirty years ago, there were then two well-recognised and eagerly pursued problems in the art of communication. The first quarry in the hunt was a delicate device capable of controlling energy from a local source in faithful response to an incoming signal, such as the attenuated speech-waves on a telephone line the length of which it was desired to extend, or alternatively a weak wireless signal. The second aim was a means of generating continuous high-frequency oscillations adaptable to similar faithful control by a microphone for wireless telephony. It was already realised that whatever should solve the first of these would also, when allowed to react on itself, go a long way towards solving the second. There was also in existence a device, the simplest, or diode, form of thermionic valve, in which current passed between electrodes in an evacuated glass bulb ; this offered a means of detecting high-frequency signals by regular rectification, but it was biding its time in face of other temporarily approved alternatives.

Ideas had arisen too, in more minds than one, of making such devices more responsive to an incoming signal, but these ideas were as yet vague in the extreme.

To complete this outline of the conditions of incubation of the valve as we now know it, we should note the technical position at the time. Amongst makers of electric lamps the production of high vacua in glass vessels, already well advanced as an art in daily practice, was being raised to the higher pitch demanded by the tungsten filament, and was ahead of corresponding practice in the laboratory in some respects at least. Acquaintance with pumps in great variety, and the use of many of them, the choice of suitable glass, its fabrication in conjunction with small metal parts, the method of outgassing by 'baking' under vacuum, the use of phosphorus as 'getter' for improvement and maintenance of vacuum, the choice again of suitable metals in addition to tungsten, all these alike were well understood, so that when the need came, any well-equipped lamp works could launch out into valve-making.

About the opening of our period, valves, thus incubated, hatched out in various places, and the excitement attending the demonstration of their working was proportionate to the interest of the double problem which they solved. A clear explanation of what was going on in them did not, however, come at once. The little that was known was reflected in their construction. The addition of the third or intermediate electrode left a controlled stream of moving particles as the obvious main connexion between input and the output circuits, but much time was spent, by some at least, before the essential simplicity of the valve and the comparative unimportance of the differences between early types were realised. It is interesting that, before these fascinating devices were turned into reliable tools, a blind eye had to be turned on those factors which need not be taken into account in explaining their action. The first of these inessentials was gas ionisation ; it had to be realised that, since even the simple diode would work at voltages below the ionisation point, some other agency must be sought. Once this was appreciated a newly-fledged graduate in physics could acquire sound ideas of the main current-voltage relation by working out the solution of a

Poisson's 'space-charge' equation. Given this luxuriously simple basis, or even still simpler qualitative ideas on the same lines, the other less important factors could be viewed in proper perspective, and the inherent limitations of the valve could be defined, even thus early, in terms of natural constants. In the triode, again, the main point to be appreciated was that one was not required to trace out the motions of particles in transit through the intermediate grid, but only to regard this member as behaving chiefly as a somewhat leaky Faraday screening cage which defined for the region near the cathode a residual field controlling the strength of the current of escaping electrons. The German term *Durchgriff* survives as a happy illustration of this point.

So much for the valve itself. Its action in the circuit had to be deduced by the application of alternating current theory to the relative variations of the voltages applied to the various electrodes and the currents led to or from them. Here, contrariwise, the range of relevant premises had to be enlarged by including the displacement currents in minute and at first disregarded stray capacities before laborious algebra bore full fruit in explaining the observed phenomena of amplification and spontaneous oscillation. From this work arose, as a kind of shorthand, the array of technical terms such as 'amplification constant' (as compared with its reciprocal synonym *Durchgriff*), 'anode impedance', 'reaction' and so forth now heard out of the mouths of schoolboys.

All this work was spread out, with much duplication and overlapping, over the first quarter of the period. The effect of the War, sometimes spoken of as a time of great advance, is dubious. It seems in retrospect that intrinsic development may actually have been retarded by the isolation and distraction of those who would in any event have carried on that work. The real benefits of this period were indirect; improvement of technique was stimulated by the making of large numbers of valves, and the number of those conversant with the use of them increased with abnormal rapidity. After the War, however, the expansion thus made possible did not come at once. The valve as a perfected tool had to establish its position, and that on a world-wide scale, by the resumption of the normal exchanges of scientific and technical intercourse, and by further demonstrations arising from free experimental activity. In regions outside the United States, preparations had to be made for the insertion of valve amplifiers or 'repeaters' in telephone lines, and over the oceans the extension of direct wireless telegraphy and the introduction of telephony had to be arranged.

It was, then, at about the middle of our period that the valve came into its own. For the specialised conditions of long-distance telephony on land-lines the necessary requirement of reliability was early satisfied. In wireless the word 'system' dropped out of common parlance; the time for alternative methods was past. The discovery of the peculiar transmission possibilities of 'short' waves, for the generation of which valves were uniquely adaptable, brought world-wide range almost as a gift. At the same time came broadcasting, with, on the technical side, the need of new standards of faithfulness imposed by the nature of the matter transmitted, particularly music, and of reliability at both ends of the unilateral transmission. The waste of energy by thermal radiation from the cathode was progressively reduced. The implicit possibility of using free electronic projectiles as the sole connexion between circuit elements was exploited in 'screen-grid' tetrodes and later more complicated types. Amplification was carried to the limit set by those disturbances, the 'Shot effect' and the like, arising from the discontinuous structure of matter itself, a real limitation at present. The power handled by valves has, however, since the conversion of the anode into a water-cooled metal portion of the envelope, no near upper limit, even without resort to continuous evacuation. Uses have also at length been found for thermionic devices employing ionisation in the forms of heavy-current rectifiers of great efficiency, occupying a position midway between the high-vacuum rectifier and the rectifying arc, and of trigger devices which make a virtue of the formerly troublesome discontinuity in current-control in presence of a lavish supply of ionisable material.

In the field of communication, the second half of our period has thus been a time of technical consolidation and expansion and of the rise of great social implications. During this time also the valve has influenced the course of scientific research as an instrument generally adaptable for use wherever there is a need for delicacy and nimbleness beyond what is conveniently possible for purely mechanical devices. Thus, physiologists have been using valve amplifiers for the study of nerve action as revealed by minute electrical changes; valves, sometimes of special design, have replaced sensitive voltmeters and electrometers; thermionic relays have come into use for counting the minute discontinuous occurrences of atomic disintegration; metallurgists have used valve-generated high-frequency currents in furnaces for melting experimental specimens.

The position at the present day and the immediate prospect have now to be outlined. One point of arrest is to be noted. The deliberate design of valves by calculation has progressed but little, although the physical principles being known this work might be held to have passed into the province of the engineer. However, the mathematical functions are generally intractable, and engineers may be excused for their reliance on methods of trial and error. As valves get larger, however, such methods are becoming expensive. The evolution of the valve is not yet by any means complete, although sometimes, as in television, the valve is an accepted tool and interest centres on other devices at either end of the train of valves.

There is still, however, the new field where the periods of electrical oscillation are so short that electron inertia is no longer negligible, but has itself to be brought into service as a main principle of action. Here early history has been repeating itself, but the period of groping is now past; theoretical study is difficult but is well advanced. Indeed, in contrast to the early days, development has been somewhat in advance of demand. There are also novel devices using free electrons which are not of thermionic origin but are ingeniously obtained by photo-electric or secondary emission.

Other new developments may be expected now that valves have made their appearance in the laboratory as appliances built and operated by continuous evacuation in the laboratory for the purposes of research without recourse to the valve maker, for example, for obtaining continuous high-voltage supplies by rectification and very recently also by short-wave oscillation. It is not in general to be supposed that valves manufactured by the thousand for engineering purposes or by the million for domestic use are really those best suited for special problems, and it is well that the experimental physicist should take the initiative in meeting his own needs.

Finally, new prospects are beginning to open in yet other directions associated rather with the material needs of the human body than with man as an intelligent and social being. For some few years high-frequency electrical oscillations of wave-lengths from a few metres downwards generated by valves have been coming into use for purposes as yet perhaps of practical medicine rather than of physiological study, first for surgery, and later for the reinforcement of the *vis medicatrix naturæ*, in part, it would seem, by some kind of inward fomentation, and in part, perhaps, by some more specific action dependent on the existence of natural frequencies in molecules of various sizes or in small bodies of greater than molecular size. The achievement of direct specific action on such structural elements would open up wide fields of application to chemical and biological processes far removed from the problems of communication from which the development of the essential instrument took its origin.

Developments in Aeronautical Science

By PROF. F. T. HILL, Assistant Professor of Aeronautics, Imperial College of Science and Technology, London

THERE can be few applied sciences able to compare with aviation in the rate at which purely academic physical conceptions have been first translated into actual accomplishments and then industrialised, to the extent of the aircraft industry in the short space of a quarter of a century. Although the mechanics of flight have been investigated by certain mathematicians practically since the Middle Ages, continuous sustained flight for heavier-than-air machines, or even a useful degree of controlled flight in lighter-than-air craft, was not possible until some device capable of giving out power in the form of a propeller thrust was available, with reasonable weight. The internal combustion engine made this possible, and in 1903 the first power-driven flight in a heavier-than-air machine was made by one of the Wright brothers in the United States. The dirigible balloon antedated this achievement by a few years for lighter-than-air craft, although it is not possible to be precise about the date of the first flight owing to the difficulty of specifying exactly what constituted a power-driven flight, as distinct from having merely floated from one spot to another. It is certain, however, that at the commencement of the period under review, achievement in either school did not consist of much more than having succeeded in flying for a reasonable period of time, with a very small margin of safety. Little attention had been paid to progress towards any severely utilitarian aspects of the problem of flight.

In the spring of 1910, Cody, Dunne, Roe and Short were flying aeroplanes of their own design and building in Great Britain. Mr. J. T. C. Moore-Brabazon (now Lieut.-Col. and at present president of the Royal Aeronautical Society) was granted the R. Ae. C. Club pilot's certificate number one, for making the first officially observed flight in the British Isles, under certain specified conditions. The power used varied from a 50 horse-power Antoinette in Cody's machine to a 9 horse-power J.A.P. engine used by Roe. Speeds appear to have been about 50–55 miles per hour, and somewhat uncertain, but Cody held one definite record then of having remained in the air for a little more than one hour.

With lighter-than-air craft, the pressure type of envelope was in use then. This was either non-rigid, using the gas pressure to maintain its elongated form, or semi-rigid, with the shaped balloons partly stabilised and supported by a longitudinal framework. Airship activity in Britain was almost entirely confined to the British Army Balloon Factory at Farnborough. A few small airships were built by Messrs. Willows and Co. during the years 1905–12, an outstanding feature of these being the introduction of swivelling propellers as an auxiliary to the normal controlling surfaces, a device still often used on modern airships. The Army airships of early 1910 were capable of about 35 miles per hour speed, with a 35 horse-power Green engine, and carried a crew of three.

The period 1910–18 can logically be considered to be one of the development of war machines. Previous to 1914, the production of machines directed towards a military outlook was stimulated by a War Office competition held in the summer of 1912, and as no equal incentive towards any form of civil aviation existed, the military requirements predominated in design then. The year 1912 thus crystallised the attainments of the machines of that day in the military competition, and helped to give definite ideas upon possible lines of improvement. A top speed of 75 miles per hour, a lowest speed of 50 miles per hour necessarily accompanying it, a rate of climb of about 400 ft. per minute, and a ratio of descent to forward travel with the engine stopped (gliding angle) of 1 in 8, can be taken to be the best performances then. Military requirements demanded increase in top speed and climb for fighting purposes, an increased gliding angle for enlarging the area over which the pilot could land in the event of engine failure, and a reduction, if possible, in the already dangerously high landing speed. The development during the whole War period can be summed up by saying that the required improved performances were obtained by the use of greater and greater powers, as these became available from contemporary improvement in the internal combustion engine designed specifically for aircraft work. By 1918 these average values (excluding a few freaks for special purposes) can be said to have reached 130 miles per hour for top speed without any corresponding increase in landing speed, 2,000 ft. per minute for initial rate of climb, and a gliding angle, although varying considerably with the type of machine, greater than 1 in 8. Size had also increased from a two-seater, say, 500 lb. total useful load, to one carrying a load of about 9,000 lb.

During this same period the most marked advance in the lighter-than-air craft was that of size, which brought about the necessity for a different construction, the 'Rigid' or Zeppelin type. In this a number of separate gas bags are encased in a rigid framework of elongaged cylindrical form, the whole of the load being taken by this structure. This construction is used for all large airships to-day. The smaller airships were by no means superseded, but they made no great strides in development, being suited to the naval and military duties allotted to them without any drastic alterations. By 1918, British rigid airships had reached a speed of 70 miles per hour, carried 1,250 h.p. in power, with a disposable load of about 27 tons. The most outstanding point in performance, in which the airship is still ahead of the aeroplane, was its range. At a reduced speed of 45 miles per hour, the rigid airship of that day had a cruising range extending over nearly nine days.

The reconstruction period in 1919 allowed attention to be paid to the more scientific side of aircraft design, when the immediate urgency of increased performance at all costs was removed. The study of aerodynamic theory produced rules for design resulting in less resistance to motion, both from drag and interference, the net result of which was either increase of speed, greater carrying capacity or wider range, for a given engine-power output. Progress in engine development itself gave that power with less engine weight, smaller fuel consumption, and reduced drag for cooling purposes, and concurrently engines of greater power were produced. A better understanding of the problem of aerodynamics and theory of structures, added to the increased engine-powers available, led heavier-than-air craft design into specialised channels, and types tended to become, and have remained, with different characteristics depending upon their design criterion. To-day the records stand at 440·67 miles per hour maximum speed, 5,654 miles non-stop distance, and more than 57,000 lb. useful load carried. In none of these cases are such machines of any general use, but the figures indicate the magnitude of the progress made during the post-War period. A fair estimate of how far practical requirements modify these figures is obtained if the results of the England-

Australia race of October 1934 are taken. This was won by a De Havilland Comet which, although built specially for the race, is of a type that could be used for ordinary everyday commercial flights. The flight to Australia, a distance of 11,300 miles, occupied 60 hours 50 minutes flying time, an average not far short of 200 miles per hour. Certain military types have normal speeds somewhat higher than this.

That such progress should have been made without setbacks is scarcely to be expected, and it is almost paradoxical that such failures, resulting in a train of investigations into their causes, have probably been the greatest help to ultimate success. The investigation of accidents and the subsequent building up of design laws that shall avoid a repetition of them, has been one of the responsibilities of the Aeronautical Research Committee in Great Britain throughout the whole of the period under review. For example, the gradual increase in speed has produced aerodynamic forces on the wings the precise extent of which had not been anticipated from the experience available at lower speed flight. The current theory of structural design was not always adequate to deal with such cases, and wings and control surfaces, lacking stiffness, have developed 'flutter' which has sometimes led to the collapse of the structure of the aircraft. It can be safely said that to-day the scientific aspect of this question has now been worked out.

Another similar outstanding scientific development is that of landing a machine with maximum safety. As the top speed of flight began to increase, it became necessary to investigate the aerodynamics of increasing the speed range, otherwise the landing speed became dangerously high. Even with this as low as possible, pilots are tempted into approaching too near it, and with no margin in hand, they allow the machine's speed to fall below the minimum, and 'stall', usually with serious results. This problem has been defeated in two distinct ways: the use of aerodynamical devices that delay the occurrence of the 'stall' to a slower speed, or giving the pilot that extra control over the orientation of the machine by which he can neutralise the most dangerous result of a 'stall', the loss of his normal control actions. A combination of these two ideas to-day can make the actual flying of a machine as nearly 'fool-proof' as can ever be needed. One attempt at dealing with this question has resulted in the creating of a novel type of aircraft—the autogiro. The supporting wings of this machine are rotated in a horizontal plane, windmill fashion, instead of being fixed to the body, as in the normal form of aeroplane. Thus, their lift, which supports the machine, depends primarily upon their speed of rotation and not upon the forward speed of the craft. This latter may be reduced very greatly by the pilot, but as long as the wings are kept rotating above the minimum speed necessary, the machine will retain its full support.

The post-War history of lighter-than-air craft is unfortunately not so happy a tale. The rigid airship has grown in size, and has been developed towards the idea of a long-distance transport machine. A new German Zeppelin, just about to be launched, will carry eighty-five passengers, ten tons of freight, in addition to accommodation almost comparable with an Atlantic liner. Its engines total 5,000 horse-power, and its range without refuelling will be about 10,000 miles. This ship, together with a somewhat smaller sister, the *Graf Zeppelin*, now flying regularly, will be the only large rigid airships in commission in the world. The generally accepted principle of any vessel that obtains its lift from buoyancy—that its efficiency as a load carrier increases with its dimensions—means that the accompanying increase in cost makes the experiments more susceptible to the difficulties of replacement in the case of failures. Both Great Britain and the United States have discontinued experiments upon large rigids, largely because of the political aspect that has arisen as the result of accidents costly both in lives and material.

To sum up the situation to-day, after twenty-five years development, in heavier-than-air craft any speeds, up to those that the ordinary human being can stand without special training, can be flown, provided that the price in power required for it can be paid. This price will probably be reduced gradually as more efficient machines are produced, but there does not appear to be any very revolutionary change in sight. Sizes of machines such as will give a reasonable degree of comfort are already in existence, and will probably increase, although in theory there should be a limit to this, as the ratio of the structural weight of the machine to the total flying weight must increase. This limitation is not serious so long as the size necessary for comfort has been attained. In range it is still uncertain as to whether the direct route across the Atlantic and Pacific Oceans can be flown under unfavourable conditions, at least as an economic proposition. Except for these two cases, the range of any normal aeroplane can be such that it is well within reach of organised aerodromes all over the civilised world. In this last case lies the principal hope for the future of the large airship. Its capacity is such that the longest possible journey necessary, that is, half-way round the earth, is probably within its attainments even to-day.

Progress in Turbine Machinery

By Eng.-Capt. Edgar C. Smith, o.b.e., r.n.

IN March 1776 in the reign of George III, Johnson and Boswell spent a few days in Birmingham, and the latter, accompanied by Johnson's old schoolfellow Hector, took the opportunity to see the famous Soho Manufactory of Boulton and Watt. During Boswell's tour through the shops where parts of the engines of Watt were being constructed, Boulton with pardonable pride remarked to him: "Here, Sir, I sell what all the world desires to have—Power". Only half a century had passed since Newcomen, in the reign of George I, by the invention of the atmospheric pumping engine, had ushered in the age of steam power, but already steam engines were being erected in mines, factories, breweries and works on an increasing scale, and five years later Boulton wrote to Watt, "The people of London, Manchester and Birmingham are steam-mill mad". Great pioneers as they were, neither Watt nor Boulton, however, visualised the important part steam was destined to play in industry and transport, or that before the death of George III steam would be applied to ships and locomotives. Year by year the demand for power grew; by 1840 the steam engines of the world were estimated to have an aggregate of more than 2,000,000 horse-power, and a century after Boulton had spoken of London, Manchester and Birmingham as being steam-mill mad, the total horse power of stationary and marine steam engines and steam locomotives in the world was estimated at about 30,000,000.

However remarkable these figures may appear, they are comparatively insignificant when placed beside those of the world's power plants to-day. With the passage of time have come improvements in hydraulic turbines, the introduction of oil, gas and spirit engines, the invention of steam turbines and also the construction of power-driven electric generators from which electricity for power purposes can be transmitted over long distances. Any review of the mechanical progress of the reign of H.M. King George V must therefore necessarily have as its central feature the development of prime movers and electric generators. Of the prime movers, the reciprocating steam engine is still the most important unit on our railways, the petrol engine is practically without a rival on the roads and in the air, the oil engine has spread all over the world and has successfully challenged the steam engine for certain classes of ships, the hydraulic turbine coupled to electric generators is used where sufficient water power is available, but for the propulsion of fast vessels, such as warships and liners, and for driving electric generators in steam power houses the steam turbine is supreme. About 96 per cent of the electricity generated in Great Britain is produced in steam stations, the majority of which contain turbo-generators. It is acknowledged that the construction of the first turbo-generator by Parsons in 1884 is as great a landmark in engineering history as the invention of the separate condenser by Watt in 1765, but it is only within approximately the last twenty-five or thirty years that the steam turbine has surpassed in size and power the great reciprocating engines which were the direct descendants of the rotative engines of Watt.

When shown at the Inventions Exhibition of 1885, the first turbo-generator of Parsons, with its high speed of rotation (18,000 r.p.m.) and its extravagant steam consumption (129 lb. per kilowatt hour) excited no great interest and raised no great hopes. It contained, however, all the essential elements for success, and ten years later Parsons was building his first 350-kilowatt turbo-generator and also the 2,000 h.p. turbines for the famous *Turbinia*.

Six years later a great advance was made by the construction of the 1,250 kw. machines for the city of Elberfeld in Germany. These machines had a steam consumption of only one seventh that of the original turbo-generator, and their success paved the way for further developments. One of the finest and most efficient machines running at the time of the accession of King George V was a 5,000 kw. turbo-generator at the Carville power station of the Newcastle-upon-Tyne Electric Supply Company. Supplied with steam at a pressure of 200 lb. per sq. in. superheated to 508° F., this machine revolved at 1,200 r.p.m. and had a steam consumption of 13·19 lb. per kwh. The record set up by this machine was surpassed by that of a far larger turbo-generator of 25,000 kw. ordered in 1911 from Messrs. C. A. Parsons and Co., Ltd., for the Fisk Street Station of the Commonwealth Edison Company of Chicago, U.S.A. In this case the speed was 750 r.p.m., the steam pressure 200 lb. per sq. in., the steam temperature 588° F. and the steam consumption 10·42 lb. per kwh. or about one twelfth of the original machine. Ever since then, by improvements in design, the utilisation of many inventions, the employment of superior materials, by increasing steam pressures and temperatures and by many other means, it has been possible to construct turbo-generators still more efficient and of greater and greater capacity, the present limit in size being marked by the 208,000 kw. machine of the State Line Power Station, Chicago.

In Great Britain, the limit of size is marked by the 105,000 kw. turbo-generator now being erected in the Battersea Power Station of the London Power Company by the Metropolitan-Vickers Electrical Co., Ltd. The installation of such machines is one of the outcomes of the extended use of electricity for industrial and domestic purposes, brought about partly through the work of the Electricity Commissioners and the Central Electricity Board, which have been responsible for the erection of the National Grid. In the latest report of the Central Electricity Board, it is stated that the production of electricity in Great Britain during the past five years has increased by 50 per cent. Co-ordination in the electric supply industry, too, has led to the closing down of uneconomical stations and the erection of many new stations, of which Battersea is but one. Full descriptions of these stations have appeared from time to time in the technical press and from these have been taken a few particulars of turbo-generators which illustrate current practice. In various countries stations have been or are being erected, with steam pressures far in excess of those mentioned below, but these stations are comparatively few.

It was perhaps but natural, as the Parsons steam turbine was developed on the banks of the Tyne, that some of the most historic turbo-generators should be found in the Newcastle area. Mention has already been made of the Carville station. The latest and most up-to-date station in the district is the new Dunston power station of the North-Eastern Electric Supply Company. This station has an ultimate capacity of 300,000 kw., but at present it contains three 50,000 kw. machines. The steam is supplied at 625 lb. per sq. in. and at a temperature of 825° F. The turbines are of the two-cylinder tandem type and run at 1,500 r.p.m. Current is generated by the alternators at 13,500 volts and a frequency of 50 cycles. An interesting feature is that the steam leaving the high-pressure cylinder is taken at a pressure of 115 lb. per sq. in. to re-heaters and is then passed to the low-pressure turbine at a temperature of 800° F.

One of the most important stations in the Midlands is the Hams Hall station of the Birmingham Corporation, the first part of which was opened by the Duke of York in November 1929. It is designed for an ultimate capacity of 240,000 kw. but there is ample room for its expansion to 1,000,000 kw. if required. Steam is supplied from pulverised-fuel fired boilers at 375 lb. per sq. in. and 710° F. to 30,000 kw. turbo-generators running at 1,500 r.p.m., generating current at 11,000 volts and a frequency of 25 cycles. In the north-west, the Clarence Dock power station of the Liverpool Corporation has the highest thermal efficiency of any station in Great Britain, namely, 26·06 per cent. It is unique in being built on the floor of a disused dock. Designed for an ultimate capacity of 400,000 kw., with eight 50,000 kw. turbo-generators running at 1,500 r.p.m., it has at present three machines generating current at 7,250 volts and a frequency of 50 cycles. The steam pressure is 450 lb. per sq. in. and the steam temperature 750° F. The station began work in 1931, and tests of the steam-raising plant showed an efficiency of 86·45 per cent, while the thermal efficiency of the turbines was 30·4 per cent. In the construction of the generators, advantage was taken of electric welding. By using welded frames for the stators instead of cast frames, no less than 16 tons weight was saved.

It would be possible to trace the development of power station practice from the power houses in the London district alone, for it was in Holborn in 1882 that the first central station in the Old World was opened, while at Deptford, Ferranti built what has been called the "forerunner of modern power stations". Several big companies to-day serve the metropolitan district, and the London Power Company has six 'selected' stations for the purposes of the Electricity Act of 1926. Of these, Deptford West took the first place for thermal efficiency among British stations in 1931, while at Battersea is being installed the 105,000 kw. turbo-generator referred to above. The Battersea station is designed for an ultimate capacity of 400,000–500,000 kw. The machines at work at the present time consist of two 69,000 kw. three-cylinder turbines driving generators delivering current at 11,000 volts. The boiler pressure is 625 lb. per sq. in. and the highest temperature of the steam is 875°–900° F. This station is equipped with an elaborate plant for preventing the emission of sulphurous fumes from the chimneys. Lastly, brief mention may be made of the Barking power station of the County of London Electric Supply Co., the first part of which was opened by H.M. the King ten years ago. The largest set at that time was a 35,000 kw. turbo-generator, but the station now possesses two 75,000 kw. machines using steam at 625 lb. pressure and 825° F. temperature. In these turbines steam is 'bled' from four different points for the purpose of feed heating. The station has at present a capacity of 390,000 kw.

From the first, the steam turbine had one particular advantage over the reciprocating engine for driving electric generators, inasmuch as it was most efficient at high speeds. When, however, it was applied to marine propulsion, owing to the inefficiency of propellers at high speeds, a compromise had to be made. Yet its inherent qualities led the marine steam turbine quickly to surpass the turbo-generator in point of size, and only ten years elapsed between the debut of the *Turbinia* at the Diamond Jubilee review of 1897 and the construction of the 70,000 h.p. turbines of the *Lusitania* and *Mauretania* and the adoption of steam turbines for all classes of warships except submarines. When referring to the steam turbine in his Gray Lecture to the Institution of Mechanical Engineers in 1930, Eng. Vice-Admiral Skelton said : "Its application is one of the few important marine changes which were made without any setback, and the initial success and the rapid extension of the system is undoubtedly attributable to the experience gained in its long and gradual development under proper conditions on shore, no less than to the soundness of the conceptions of the inventor and his thorough exploratory work in connexion with the marine application".

It had been realised quite early that in ships it would be an advantage to have some form of reduction gear between the turbine and the propeller, and the development of steam turbines afloat during the last twenty-five years presents several aspects, first the progress with direct driving turbines, secondly the use of turbines coupled to the propeller shafts with either mechanical, hydraulic or electric transmission gear and thirdly the combined use of reciprocating engines and turbines. The most notable direct-driven turbine ships of the last quarter of a century include the *Aquitania* (62,000 h.p.), *Berengaria* (65,000 h.p.), *Majestic* (84,000 h.p.) and the *Leviathan* (82,000 h.p.) ; and large warships such as the *Iron Duke* (31,000 h.p.), *Malaya* (75,000 h.p.) and *Repulse* (112,000 h.p.). Helical-toothed reduction gear, tried out by Parsons in the *Vespasian* in 1909, was adopted in turbine-driven cross-channel vessels and destroyers in 1911 and quickly came into favour. By September 1919 the total horse-power of geared marine turbines completed or under construction was about 18,000,000. The use of gearing enabled the efficiency of both turbines and propellers to be increased, turbines of 20,000 h.p. with gearing being equal to turbines of 30,000 h.p. without gearing. H.M.S. *Furious* (90,000 h.p.), H.M.S. *Hood* (144,000 h.p.) and H.M.S. *Nelson* (45,000 h.p.) all have geared turbines, as also have the modern Atlantic liners *Bremen*, *Europa*, *Conte di Savoia* and *Rex*, while the machinery of the *Queen Mary* will be of this type.

Hydraulic transmission between the turbine and the propeller has never been extensively used, but electrical transmission, first used on a large scale in the United States Navy, has made rapid strides. The French liner *Normandie* is fitted with electric drive, and will have four main turbo-generators of 34,200 kw. delivering current to the motors on the propeller shafts, the whole plant rivalling in size and interest the machinery of a big power station.

Marine engineering practice has sometimes forged ahead of and sometimes lagged behind land practice, but to-day it tends to run on parallel lines. Progress during the last twenty-five years has been due to many eminent engineers, among whom the inventors of steam turbines, such as Parsons, De Laval, Curtis, Zoelly and Rateau, hold the place of honour.

News and Views

Prof. P. Kapitza and the U.S.S.R.

IT is common knowledge in scientific circles that Prof. P. Kapitza, director of the Royal Society Mond Laboratory at Cambridge, and Messel professor of the Royal Society, has been detained in Russia since last September by order of the Government of the U.S.S.R. Kapitza came to England as a member of a Russian scientific commission in 1921. He soon started to work as a research student at Cambridge under the supervision of Lord Rutherford, and after some preliminary work on radioactivity he commenced work on the production of intense magnetic fields, and in 1925 a new laboratory, financed by the Department of Scientific and Industrial Research, was opened for the work. By the use of a special alternator, Kapitza was able to produce fields up to 300,000 gauss, and to carry out experiments showing the existence of new phenomena in conduction and in magneto-striction. Since most of these phenomena are more pronounced at low temperatures, a hydrogen liquefaction plant was added in 1929, and in 1930 the Royal Society made a special donation of £15,000 to enable a new laboratory to be built to house the original apparatus, together with a helium liquefaction plant. It was characteristic of Kapitza that he was not satisfied to take over existing designs of helium liquefiers, but began immediately to work on the construction of a new type of liquefier which required no liquid hydrogen. This liquefier is an illustration of Kapitza's special technical gift, for it incorporates a piston type engine, which works down to the temperature of liquid helium. This liquefier, which was described in NATURE of May 12, 1934 (p. 708), was perfected last summer, and Kapitza was able to carry out preliminary experiments using strong magnetic fields combined with helium temperatures before leaving for Russia in September to attend the Mendeléeff Congress.

THROUGHOUT these years of developmental work, Kapitza had visited Russia almost every summer. During these visits he gave lectures and advised on the construction of new institutes, and it was known that he had at one time been offered the directorship of an institute in Russia, but Kapitza himself considered that conditions in the U.S.S.R. were not favourable for the development of his work. It came, therefore, as a shock to his colleagues to learn in October that Kapitza's return passport had been refused, and that he had been ordered to begin the construction of a new laboratory in Russia. The reasons underlying this action may be inferred from the following statement from the Soviet Embassy which appeared in the *News-Chronicle* :—"Peter Kapitza is a citizen of the U.S.S.R., educated and trained at the expense of his country. He was sent to England to continue his studies and research work . . . Now the time has arrived when the Soviet urgently needs all her scientists. So when Prof. Kapitza came home last summer he was appointed as director of an important new research station which is being built at Moscow". This commandeering of Kapitza's services on behalf of the U.S.S.R. ignores the personal and psychological factors involved, as was pointed out by Lord Rutherford in a letter to *The Times* of April 29. A man of Kapitza's highly-strung type must inevitably be profoundly disturbed by a sudden frustration of years of work ; and it comes as no surprise to his friends to learn from reliable sources that his health has already been seriously impaired by anxiety and strain. The right of the Soviet to retain Kapitza in his native country can scarcely be questioned, but from the point of view of international science we venture to express the hope that he may be permitted to return to Cambridge to complete the investigations with the remarkable plant designed by him and installed in the Royal Society Mond Laboratory at the University.

Retirement of Sir Peter Chalmers Mitchell

LAST summer it was announced that Sir Peter Chalmers Mitchell was to retire from the post he had held for more than thirty years as secretary of the Zoological Society of London (see NATURE, Aug. 25, 1934, p. 280). At the annual meeting of the Society held on April 29, Sir Peter formally vacated the secretaryship and his successor, Prof. Julian S. Huxley, took his place. Sir Henry Mahon and Prof. J. Stanley Gardiner presented Sir Peter with his portrait, painted by Mr. William Nicholson, on behalf of some 1,250 members of the Society ; very appropriately, the background of the portrait includes a map of the Whipsnade estate, with the development of which Sir Peter's name will always be associated. The response to the appeal for the portrait was so generous that it has been possible to send each subscriber a reproduction in colour of the portrait and also to present to Sir Peter a personal memento. The Duke of Bedford, president of the Zoological Society, in moving a resolution of thanks to Sir Peter for his many years of active and inspiring service to the Society and to science, stated that whereas in 1902 the Society's Gardens in Regent's Park had 69,500 visitors, in 1934 the number had increased to 1,690,000, while the Society's high reputation as a scientific body has been similarly enhanced. The Society has been a pioneer, under the guidance of Sir Peter Chalmers Mitchell, in the improvement of the conditions under which animals are kept in captivity. On the more strictly scientific side, mention should also be made of the valuable investigations carried out by the succession of anatomists, pathologists and other workers who have been encouraged by Sir Peter to study the Society's collections.

King George's Jubilee Trust

No social change of our time is more significant than the way in which leisure has ceased to be the privilege of a few and become the concern, if not indeed the lot, of the many. In the problems which leisure now presents, there is none more serious and pressing than those which it presents in adolescence. The Jubilee Trust inaugurated by the Prince of Wales at St. James's Palace on March 1 is designed specially to deal with such problems, and a further reference to its objects was made in an appeal broadcast by His Royal Highness on April 12. The main objects of the Trust are to provide more and better facilities for the recreation and guidance of the younger generation, to encourage the cultivation of abilities, craftsmanship and all those outdoor interests and activities which make for mental and physical fitness. The Trust will assist, strengthen and extend the work of the many voluntary organisations in existence, the work of which is to promote the welfare of the boys and girls of Great Britain. It will enable similar movements to be started in places at present untouched, particularly through lack of local resources and the need of help from a central source. It should encourage co-ordination of effort and prevent the waste of money and effort in overlapping.

APART altogether from its direct activities, the existence of the Trust should encourage a more enlightened and generous attitude to the many problems which arise in regard to juvenile employment and leisure. It should lend powerful moral support to all agencies which are concerned with the education and recreation of young persons, whether in relation to industry or to citizenship. It may provide a focus from which powerful support will be forthcoming for all efforts to deal wisely with the tragedy of juvenile unemployment, with excessive hours of work or with any other matters which hinder the normal development of citizens possessing the qualities of physical, mental and spiritual fitness and ideas of service which make a people great. The Jubilee Trust aims at dealing with the most crucial educational task of the time—that of guarding from the worst dangers of unemployment or unsuitable work at the most critical time of their physical, moral and mental development that large section of our young people between fourteen and eighteen years of age who are drifting into manhood and womanhood with little guidance, and it should inspire not merely protective or remedial measures but also courageous efforts to deal with the root causes.

Chemical Industry at the Brussels Exhibition

PUBLICITY is a kind of vitamin or hormone essential for the proper growth of an industry. Like those accessories, it needs to be used constantly, judiciously and in appropriately small doses; an excess may do more harm than good, and the different varieties are more or less specific in their action. After a period of unrestrained enthusiasm, during which we sought rapidly to restore supposed deficiencies in vitamins of every alphabetical designation, we have learned to submit our requirements to the examination and prescription of experts; likewise we are learning that the best publicity is that which is well planned and well informed, that which is presented through the right channels by those best qualified, and that in which reality and literal truth are the corner-stones. The British chemical industry has been represented at many exhibitions, but for many years no demonstration of its ramifications and of the excellence of its products has been so comprehensive as that which has been arranged for the Brussels Universal and International Exhibition, 1935, opened by King Leopold on April 27. The exhibit, which is located in the British Government Pavilion, has been organised by the Association of British Chemical Manufacturers on a national basis; all sections of the industry have co-operated in its organisation and industrial firms have sunk their identity in order that the display might be truly national. It has been designed to show, by a series of tableaux, the modern applications in industry of selected chemicals. There are six main sections: heavy chemicals, agricultural chemicals, dyestuffs, coal-tar products, fine chemicals, and pharmaceutical chemicals; there are also exhibits of rayon and of the products of the new plastics or synthetic resin industry.

EVERY other industry depends to-day on the chemical industry, whether in the raw material, in the means of manufacture, in testing and control, or in the finished product. New industries have been created by the application of discoveries and inventions relating to chemical substances; old industries, such as agriculture, have been given a helping hand, as in the form of fertilisers and sprays. A clear impression of the degree to which industrial chemistry and chemical industry play their part in national life and in individual well-being is offered by the booklet which the Association of British Chemical Manufacturers has prepared in connexion with the Brussels Exhibition. The English edition—others in French, German and Spanish are being prepared—is of much interest apart from the exhibits which it describes; it is a waistcoat-pocket guide to the British chemical industry rather than the programme of a show. It gives a brief account of the part which Great Britain now plays in supplying with its chemical products not only its own needs and those of the Dominions and Colonies, but also the wants of foreign countries less happily placed. The booklet contains a list of firms and organisations which have contributed to the exhibit, together with statements of their principal products. This is the right sort of publicity; dignified, informative, accurate and interesting. The exhibitors deserve their due reward.

Aborigines and Australia

A CABLE from Adelaide in *The Times* of April 26 announces the composition of a Federal Board of Inquiry, which has been set up to investigate the treatment of the Australian aborigines. The Board will consist of three members, Prof. J. B. Cleland, professor of pathology in the University of Adelaide, Mr. White, acting Federal Chief Protector of Aborigines, and the Rev. J. H. Sexton, secretary of the Aborigines Friends Association of South Australia. The responsibility of the Federal Government of the Australian Commonwealth is limited to the aborigines of the Northern Territories, including the Arunta of the Alice Springs area, famous in the annals of anthropology as the tribes among whom the late Sir Baldwin Spencer and F. J. Gillen made their epoch-making investigations. Although a liberal policy has been pursued by the Federal Government in the protection of these aborigines, especially in the matter of endeavouring to ensure that they should have free access to their hunting grounds and to the springs and water-holes, allegations have been made recently that the aborigines are being forced off the land necessary to their livelihood. Attention has also been directed in a recent report of a Commission in West Australia, to which we hope to refer later, to the inadequacy of the arrangements for dealing with leprosy among aborigines. This is a Federal responsibility, a leprosarium being provided at Darwin, at which cases from the various States are received. The accommodation, it is stated, is inadequate, causing serious delay in evacuating cases from their point of origin, while, notwithstanding an agitation which has been proceeding for ten years, no steps have been taken towards a systematic examination of the aboriginal populations for the disease.

Broadcasting in Great Britain

THE Postmaster-General recently appointed a committee to consider the constitution, control and finance of the broadcasting services of Great Britain, including broadcasting to the Empire, television broadcasting and the system of wireless exchanges which will be conducted after December 31, 1936. He appointed as chairman Viscount Ullswater, and everyone will agree that this was a happy choice; but we were surprised to see that the committee did not include any men of science. We do not believe that any other country in the world would have appointed such a committee without a representative of science. Mr. Whitley was very proud of the new research department of the B.B.C. and was looking forward to it being a great help in the future. Already it has done valuable work, but little reference is made to it in the *B.B.C. Annual* for 1935. In our opinion, the addition of two or three scientific and technical men to this committee is necessary. So far as we can see, none of the committee has any real knowledge of the scientific principles underlying the problems its members will have to discuss. We hope that this will soon be remedied. It is necessary to consider the instructional and entertainment values of broadcasting, but it would be foolish to neglect the scientific development of the art. We have tried to find out from the *Annual* the amount expended in 1934 on research. Unfortunately this does not appear ; it is apparently included in the general sum of £334,959 mentioned on p. 91 for maintenance, salaries, development and research, etc.

Science and Social Responsibility

IN the April number of *State Service*, the journal of the Institution of Professional Civil Servants, Prof. H. Levy contributes an interesting article on this topic. The social consequences, he says, that have flowed in the wake of technical advance stand now in such clear outline that even scientific men, traditionally concerned only with the internal content of their work and not with its external repercussions, are beginning to lose their complacency. In the past, the scientific method excluded from its scope all matters involving prejudice, desire, bias or purpose, and was purely objective in character. In the logic of the physical sciences, human desires play no part, but in the social sciences they are fundamental. The pursuit of science is essentially a co-operative activity and is therefore socially conditioned. It is directed to an end, and that end is its social purpose, but since the direction which scientific investigation takes is in this way socially determined, science itself becomes one of the determining factors of society. It improves the technical level of production ; it introduces new factors into the way of living for the population ; it affects their cultural interests ; it creates new needs and therefore arouses new hopes and desires. In almost every walk of life, laws of detailed social behaviour on which action is based are already recognised. Is it too much to suggest that here in small detail are the kinds of regularities and recurrences that make a science possible ? Are we not therefore entitled to expect corresponding regularities, perhaps deeper and more far-reaching, on a large scale, and as a consequence, since society is dynamic, a logic of social change ? Since science is itself a motivating factor in that change, its study is a scientific responsibility.

British Trust for Ornithology

FIELD ornithologists in the British Isles are making an experiment in co-operative research which, if successful, may have far-reaching implications. They have a peculiar problem to deal with, partly because the great majority of them are not trained men of science, and yet are being led on to territory where an advanced scientific technique is essential. Some of the combined operations recently carried out have been on an impressive scale. The census of heronries in 1928 needed some five hundred observers before it was completed, while the great crested grebe inquiry of 1931 and the two-year woodcock inquiry now in progress have each enlisted more than a thousand observers. Naturally such work calls for a high degree of organisation, but until very recently British field ornithologists as such possessed no national organisation whatever. Irreplaceable manuscripts, field-notes, photographs, maps and collections of literature or bibliography were got together and dispersed according to the hazards of individual existence. A number of prominent ornithologists, including Mr. H. F. Witherby, president of the British Ornithologists' Union and editor of *British Birds*, Prof. Julian Huxley, the Rev. F. C. R. Jourdain, secretary of last year's International Ornithological Congress, and Dr. P. R. Lowe of the British Museum, combined to fill this gap by forming the British Trust for Ornithology as a permanent national trustee for the interests of field ornithologists. The Trust itself holds capital funds and assets in kind, such as a library, and collects subscriptions, which enable it to make grants for ornithological research. These grants, which at present are only on a very small scale, are being used to develop the nucleus of an Institute of Field Ornithology at Oxford, recognised and administered by the University. A national planning committee for the ornithological programme as a whole has been set up jointly by the Trust and the University.

THE Trust's first report just issued shows that, in spite of very cramped finances, a wide range of research has already been undertaken with marked success. Special reference should be made to the enterprise of the Trust in starting an experimental annual index of heron numbers, based on a twenty-five per cent sample of the breeding heron population of England and Wales. The index for 1934 is given as 102, 1928 being taken as 100. Another interesting point is the linking up of census work on swallows with a study of the size of broods, association with domestic animals at breeding places and occurrence of certain lethal parasites. The inquiries into short-eared owl habits during a vole plague on a Forestry Commission estate, and into the effect of the recent drought on great crested grebes, are further examples of the broad range of research which this comprehensive and flexible type of organisation makes possible. The Trust is still in an experimental stage. Inquiries and offers of help should be addressed to the Honorary Secretary, Mr. E. M. Nicholson, 61 Marsham Street, London, S.W.1.

Earthquakes in Persia

DESTRUCTIVE earthquakes have recently visited the Persian province of Mazanderan that lies along the southern border of the Caspian Sea. The first shock occurred on April 12, and was followed by others of greater severity during the next few days. It is stated (*The Times*, April 24 and 27) that 28 villages have been destroyed and about 600 persons killed. The province is one that is seldom disturbed by great earthquakes, though it lies near the important centres of Teheran and Resht. Sir Arnold Wilson, in his valuable paper on earthquakes in

Persia (*Bull. Sch. Oriental Studies*, 6, 103–131 ; 1930), records two earthquakes in Mazanderan, in 1802 and 1820, that have hitherto escaped the attention of seismologists. By the earlier shock, 70 towns and villages were destroyed, while the towns of Semnan and Damghan, to the south of the province, were seriously damaged.

Rockefeller Medical Fellowships

THE Rockefeller Medical Fellowships for the academic year 1935–36 will shortly be awarded by the Medical Research Council, and applications should be lodged with the Council not later than June 1, 1935. These Fellowships are provided from a fund with which the Medical Research Council has been entrusted by the Rockefeller Foundation. Fellowships are awarded by the Council, in accordance with the desire of the Foundation, to graduates who have had some training in research work in the primary sciences of medicine, or in clinical medicine or surgery, and are likely to profit by a period of work at a university or other chosen centre in the United States or on the Continent of Europe, before taking up positions for higher teaching or research in the British Isles. A Fellowship held in America will have the value of not less than £350 a year. Full particulars and forms of application are obtainable from the Secretary, Medical Research Council, 38 Old Queen Street, Westminster, S.W.1.

Announcements

HIS MAJESTY THE KING has conferred his patronage on the fifty-fourth annual meeting and conference of the Society of Chemical Industry to be held in Glasgow on July 1–6. Among the subjects to be discussed are the transport of food by road, rail and sea, problems of water supply, and chemical engineering in the Navy.

WE regret to announce the death, on April 27 at the age of seventy-three years, of Prof. H. B. Baker, F.R.S., lately professor of general chemistry in the Imperial College of Science and Technology.

DR. GEORGE SARTON, editor of *Isis*, the quarterly organ of the History of Science Society and of the International Academy of the History of Science (Harvard Library, 185, Cambridge, Mass., U.S.A.), has been elected a corresponding member of the Academia de la Historia of Madrid.

THE Ramsay Memorial Fellowships Trustees will consider at the end of June applications for a Ramsay Memorial Fellowship for chemical research, of the value of £250 a year. Particulars of the award can be obtained from the Secretary of the Ramsay Memorial Fellowships Trust, University College, London (Gower Street, W.C.1).

THE Linacre Lecture at St. John's College, Cambridge, will be delivered by Mr. P. P. Laidlaw, pathologist to the Medical Research Council, National Institute for Medical Research, on Tuesday, May 7, at 5 p.m. in the new lecture-room of physiology. The title of the lecture will be "Epidemic Influenza : A Virus Disease".

A COURSE of eight lectures on pathological research in its relation to medicine is being given on Thursdays, commencing May 2, at the Institute of Pathology and Research, St. Mary's Hospital, W.2. The lecturers are Sir Almroth Wright, Prof. E. D. Adrian (electrical activity of the brain), Dr. I. N. Asheshov (bacteriophage), Dr. C. H. Andrewes (cancer), Dr. R. G. Canti (cultivation of living tissue), Sir Henry Dale (active substances of ergot), Mr. J. Henderson Smith (virus diseases of plants and animals) and Dr. J. Needham (chemical embryology). The lectures are open to members of the medical profession and medical students, without fee.

THE seventh Natural Science Congress of the Dutch Indies will be held at Batavia on October 23–26. The agenda will include addresses by Prof. R. Remmelts and Dr. L. J. C. Van Es as well as meetings of sections. Further information can be obtained from the Secretariat, Koningsplein Z11, Batavia.

A SPECIAL exhibition of welding has been arranged at the Science Museum, South Kensington, and will remain on view until May 15. The exhibits include a wide range of machines used in welding by the oxy-acetylene, resistance, atomic hydrogen and arc processes, and a representative selection of examples of welded work. Demonstrations of the first three processes are being given daily at 11–1 and 3–5, and films illustrative of welding are being shown every afternoon in the Lecture Theatre at 4. The exhibition is supplementary to the symposium on welding on May 2–3 organised by the Iron and Steel Institute in co-operation with a number of other technical societies and institutions.

APPLICATIONS are invited for the following appointments, on or before the dates mentioned :—An assistant (II) for research in aero engines and accessories at the Royal Aircraft Establishment, South Farnborough, Hants—The Chief Superintendent (May 7). A laboratory research assistant in the Glamorgan County Mental Hospital, Bridgend—The Medical Superintendent (May 15). An assistant (Grade III) for abstracting scientific and technical papers in the Department of Scientific and Industrial Research—The Establishment Officer, 16 Old Queen Street, Westminster, S.W.1 (May 15). A head of the Mechanical Engineering Department, Central Polytechnic, Croydon—The Education Officer, Education Office, Katharine Street, Croydon (May 15). An inspector of agriculture in the Department of Agriculture and Forests, Sudan Government—The Controller, Sudan Government London Office, Wellington House, Buckingham Gate, London, S.W.1 (June 10). A lecturer in mathematics in Huddersfield Technical College—The Director of Education, Education Offices, Peel Street, Huddersfield. A principal of the Swansea Technical College—The Director of Education, Swansea. An assistant for soil survey work at Harper Adams Agricultural College, Newport, Shropshire—The Principal. A lecturer in geography in Armstrong College, Newcastle-upon-Tyne—The Registrar.

Letters to the Editor

The Editor does not hold himself responsible for opinions expressed by his correspondents. He cannot undertake to return, or to correspond with the writers of, rejected manuscripts intended for this or any other part of NATURE. *No notice is taken of anonymous communications.*

NOTES ON POINTS IN SOME OF THIS WEEK'S LETTERS APPEAR ON P. 765.

CORRESPONDENTS ARE INVITED TO ATTACH SIMILAR SUMMARIES TO THEIR COMMUNICATIONS.

The Green Flash at Sunset

OBSERVATIONS of the green flash have frequently been recorded in NATURE, and Lord Rayleigh[1], by simple and beautiful experiments with an artificial source of light and a prism the dispersion of which was equal to atmospheric dispersion, has imitated the chief phenomena of the coloured flash observed at sunset. This experimental imitation strongly supported the generally accepted view that the green flash is primarily due to atmospheric refraction, dispersion and differential scattering. The discussion following Lord Rayleigh's paper read before the Physical Society indicated, however, that before a satisfactory explanation of all the observed phenomena could be given, further observations were required.

The phenomenon is probably by no means so infrequent as is generally supposed, and may even be the rule rather than the exception when the horizon is clear and the observer at a sufficient altitude. The rarity of the green flash at sea-level is possibly due to the horizon being too near for the dispersion to be perceptible.

Recently I had an opportunity of making a number of observations of the coloured flash on the west coast a few miles north of Auckland from a hill about 180 feet high. On one occasion Mr. H. B. Lusk, who had observed the green flash with me from the hill on the two previous evenings, was on the beach at sunset and reported that no green flash was visible, though it was clearly seen by me and by other observers from the hill.

On several occasions I observed the setting sun with an ×30 army pattern telescope. One evening there was obvious stratification of the atmosphere. At the moment before sunset the sun appeared orange-red through the lowest stratum, which was about a third of the diameter of the sun in thickness, orange through a second stratum of about the same thickness and light yellow above. The marked turbulence of the rim of the sun appeared to have a horizontal tendency. When about a fifth of the diameter of the sun remained above the horizon, the sun appeared orange through the telescope and the turbulent rim was fringed with green, which became more evident as the sun sank. Just before the sun disappeared, a small narrow horizontal strip appeared to become detached from the top of the sun. During detachment the ends and upper edge of this fragment were green. The green rapidly invaded the strip, which at the moment of detachment was completely grass green in colour, the much larger mass of the remaining sun appearing orange. As the sun disappeared below the horizon, the last narrow edge turned bright green before disappearing.

On another occasion when the sky was unusually clear, the setting sun was almost too bright to observe with the naked eye. Through the telescope it appeared yellow with the lower part tending to orange. When the sun had set to about four-fifths of its diameter, the turbulent edge of the sun appeared to have a narrow fringe of brilliant violet. As the sun set, this changed gradually to a bright spectrum blue. A small fragment became detached as in the previous case, but instead of being green was a brilliant blue at the moment of separation. The last tiny portion of the sun to disappear became bright blue-green before sinking below the horizon.

Although the primary cause of the coloured flash may be atmospheric dispersion, simultaneous colour contrast may very considerably modify the subjective colour effect. I had the privilege of seeing Dr. J. S. Haldane's experiments referred to by Lord Rayleigh and have seen other remarkable simultaneous colour contrast effects. Some years ago in Auckland the nearly full moon shortly after sunset appeared grass green. I telephoned to a neighbour asking him to look at the moon and tell me its colour, and was not a little relieved when he reported that it was green. I concluded at the time that the effect was due to colour contrast, the sky being highly coloured. In the case of the setting sun, the contrast is between the coloured edges or fragments and the more luminous remainder of the sun, not the background.

F. P. WORLEY.

Auckland University College,
Auckland, N.Z.
March 1.

[1] *Proc. Roy. Soc.*, A, **126**, 311; 1930. *Proc. Phys. Soc.*, **46**, 487; 1934.

I HAVE read Prof. Worley's letter with interest, and can agree with him that the green flash is by no means a rare phenomenon. On a recent trip to the West Indies, I saw it three times out of a total of five sunsets observed, using a field glass ×7. It was just about as conspicuous as the experimental work would lead one to anticipate. Circumstances unfortunately prevented my observing further sunsets, as had been hoped.

RAYLEIGH.

Terling Place, Chelmsford.
April 5.

Striated Muscles of an Amber Insect

IT is well known that arthropods found in Baltic amber are unusually well preserved, so that even the minutest features of their chitinous structures are plainly visible under considerable magnification. The internal organs, however, are usually completely disintegrated, nothing but the amber mould of the chitinous skeleton remaining. It was therefore something of a pleasant surprise to discover a specimen of an amber fungus-gnat in which the flexor and extensor muscles of the tibia, located in the femur, are so well preserved in all legs, that not only their outlines, but also the transverse striations of the fibres, may be clearly seen under the microscope at a linear magnification of 300 : 1 (see Fig. 1).

The specimen belongs to the British Museum (In. 18753, 92.74) and is in the same piece of amber with a spider, forming part of a collection loaned to me for study through the courtesy of the Department of Geology. Unfortunately, the wings of the fly are broken off at their base, making identification of the species and even of the genus impossible except by matching with specimens in some other, identified collection. Presumably it is a species of *Sciara*, this genus being extensively represented in the Baltic amber. The small insert in the photograph shows the fly at a magnification of 15. The femora with the muscles had to be photographed at a magnification of 300 : 1 with the aid of a low-power objective and a high-power ocular, the combination being necessitated by the thickness of the amber. [In reproducing the photograph, it was reduced to $\frac{3}{5}$.] The best results were obtained with infra-red rays.

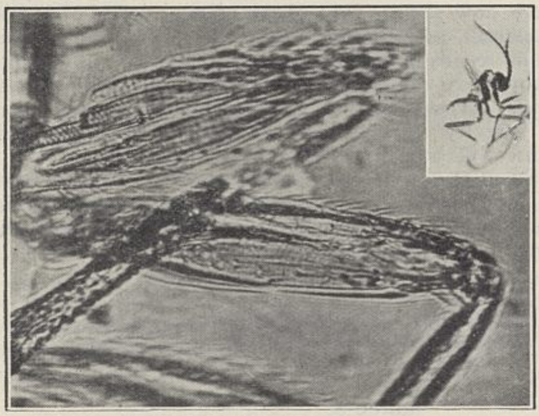

FIG. 1. Infra-red photograph of a Baltic amber fungus-gnat (*Sciara* sp. ?) showing transversely striated flexors and extensors in the legs (× 180). Inset (× 15). Photographed by Prof. Petrunkevitch.

The reason why the striations do not show nearly as well in the photograph as when the specimen is examined directly under the microscope, lies in the fact that one cannot change the focus during exposure, or increase its depth sufficiently to show all lines at the same level.

So far as I know, this is the first instance of striated muscles found in fossil insects. In 1902, Bashford Dean[1] described and figured transversely striated muscles in a Devonian shark. Vertebrate muscles, unprotected by anything but an easily perishable skin, are quick in deteriorating, yet for the same reason, under favourable conditions, may be penetrated by soluble salts serving as a preservative. Not so in arthropods. Only rupture of the outer skeleton admits fluids to the inner organs. This particular gnat must have been injured at the time that it was caught in the still fluid gum, which oozed through the wound, entering the legs and embalming the muscles before they had time to decompose.

ALEXANDER PETRUNKEVITCH.

Osborn Zoological Laboratory,
Yale University,
New Haven,
Connecticut.
March 15.

[1] Bashford Dean, "Presence of Muscle Fibres in Sharks of the Cleveland Shale", *Amer. Geol.*, **30**; 1902.

Nature of the Thermal Agitation in Liquids

THE accompanying photographs (Fig. 1) represent the analysis by a Fabry-Perot étalon of the structure of the 4046 A., 4078 A. and 4358 A. radiations of a low-density water-cooled mercury arc, after they are scattered through an angle of 180° by a column of carbon tetrachloride liquid. In each case, two different temperatures of the liquid column (30° C. and 70° C.) were employed, the exposures being as nearly as possible otherwise under identical conditions.

The choice of a Fabry-Perot étalon as the high resolving power instrument and of carbon tetrachloride as the scattering liquid were both determined by experience gained in this particular field of research[1]. It will be seen that a 40° rise of temperature produces a most remarkable change in the structure of the scattered radiation. The two Brillouin components having a Doppler shift determined by the velocity of sound in the liquid, which are well-defined at the lower temperature, broaden greatly when the liquid is heated, and move in towards the central component, practically closing in upon it. The central component at the same time increases in intensity. The conception that ordered wave-trains of sound constitute the thermal energy in a liquid therefore departs more and more from the actual facts as the temperature of liquid is raised.

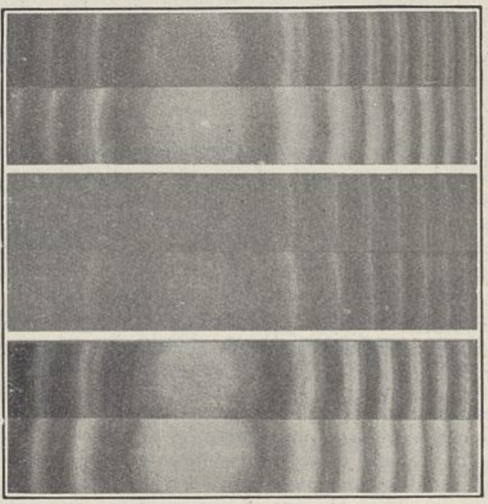

FIG. 1.

C. V. RAMAN.
B. V. RAGHAVENDRA RAO.

Department of Physics,
Indian Institute of Science,
Bangalore.
March 24.

[1] B. V. Raghavendra Rao, *Proc. Ind. Acad. Sci.*, **1**, 261 and 473; 1934–35

Use of Hydrogen Cyanide in Fumigation

THE recent tragic death of two children from hydrogen cyanide fumes following the fumigation of their home in Aldershot has directed attention to the need for stricter control of the practice of fumigation and to the need for fuller knowledge of it. For some years past I have strongly urged the need for the licensing of fumigators, and the question has, I believe, received consideration by officials of the

Ministry of Health and of the Home Office. While one fully appreciates the difficulties which the licensing of fumigation presents, the dangers to which innocent members of the community are exposed justifies a serious effort to overcome them. One firm which supplies the greater part of the hydrogen cyanide used for fumigation purposes in Great Britain is playing its part by restricting supplies to fumigation firms and fumigators of known repute and competency.

Fumigation of houses, warehouses and mills, and of foodstuffs and other materials, is much more widely practised than is generally known. The recent formation by the Medical Research Council of a committee charged with the investigation of the bed-bug problem as an important factor in slum clearance, and the promotion by that committee of research on fumigation as applied to houses, is an important step in the right direction. Until the formation of that committee, research on fumigation and fumigation methods in Great Britain was dependent for financial support almost solely on firms manufacturing insecticides, or on firms directly interested in the fumigation of food-stuffs and other consumable stores, such as tobacco.

The use of fumigants for the destruction of rats on ships has long been recognised, and is indeed insisted on as part of an international campaign against plague, but the use of fumigants against insects infesting food-stuffs and other consumable stores is still in some circles regarded with disapproval; and although tolerated is not encouraged. A main argument for this attitude is that if foodstuffs were stored and transported under proper hygienic conditions, there should be no need for fumigation, and that just as preservatives in foodstuffs have been dispensed with by food manufacturers, so should fumigants be unnecessary. The two cases are not comparable for a number of reasons. The habits and behaviour of insects are more complex and far less well understood than the biology of bacteria. Then the use of preservatives was naturally applied to food-stuffs just prior to marketing and packed in small bulk; in other words, preservation was a factory process. Now infestation of food-stuffs by insects may occur during harvesting and at any stage thereafter until the factory is reached, and the quantity of material to be treated may amount to thousands of tons. It is impracticable to ensure absolute protection of such a large bulk of produce from insect infestation in our present state of knowledge of the insects' biology; and, however desirable it may be that sterilisation of food-stuffs by fumigation should be dispensed with, that is no more practicable at present than to dispense with fumigation practice in slum clearance.

Meanwhile, it is surely better that the need for fumigation in the marketing of food-stuffs should be recognised; that those firms concerned which are enterprising enough to inaugurate and support researches designed to make fumigation safer and more efficient should be encouraged in their work; and that every effort should be made to prevent fumigation falling into disrepute, mainly because it is not sufficiently recognised as a scientific process and its application is not restricted to those adequately trained in its theory and practice.

J. W. MUNRO.

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Mechanism of Respiration

UNDER the above heading, Prof. A. Szent-Györgyi makes the wide statement[1] that respiration consists mainly of a reversible oxidation of succinic and malic acids to fumaric and hydroxy-fumaric (oxaloacetic) acids. Succinic and malic acids are activated by specific dehydrases and "only these two dehydrases seem to be connected immediately with the Warburg-Keilin system".

These conclusions are probably accounted for by the fact that Szent-Györgyi used minced tissues. It has been shown by Elliott and Schroeder[2] that, while slices of kidney tissue will carry out a cycle of reactions in the oxidative removal of lactic and pyruvic acids, on mincing the tissue, only the power to oxidise succinate to fumarate and to convert fumarate to malate remains; all the other oxidising agencies concerned in the cycle, as well as various other mechanisms, are completely destroyed.

In collaboration with Z. Baker and M. Benoy, I have now shown that slices of two types of transplantable rat tumour, a sarcoma and a carcinoma, while respiring at a rate equal to that of many other tissues, are quite unable to oxidise succinic or malic acid. These acids, therefore, cannot be the centre of activity in this type of tissue. Details of this work will be published shortly elsewhere.

Szent-Györgyi also appears to overlook the work of Harrison[3], who has shown that glucose with its dehydrogenase and co-ferment can react with the cytochrome-indophenol oxidase system.

K. A. C. ELLIOTT.

Cancer Research Laboratories,
Graduate School of Medicine,
University of Pennsylvania,
Philadelphia.
March 8.

[1] NATURE, **135**, 305; 1935.
[2] *Biochem. J.*, **23**, 1920; 1934.
[3] *Biochem. J.*, **25**, 1016; 1231.

Phenosafranine as an Anticatalyst of the Pasteur Effect

ALTHOUGH since Pasteur it has been recognised that in a wide variety of animal and vegetable cells the respiration is able to suppress the appearance of products of fermentation, the mechanism of this effect is still obscure. At present, the use of reagents which specifically interrupt this link between the two main energy-liberating reactions of cells appears to offer the principal means of its investigation. In the course of work on the action of reversible oxidation-reduction systems on tissue metabolism, I have found that the dyestuff phenosafranine proves to be the most vigorous specific inhibitor of the Pasteur effect yet described.

The active concentration of phenosafranine is with brain tissue 10^{-5} molar; it is therefore some hundred times as active as ethyl *iso*cyanide (Warburg[1]), aminonaphtholsulphonic acid (Krah[2]), glutathione (Bumm and Appel[3]) or phenyl hydrazine (Dickens[4]), and is active in one ten-thousandth of the concentration of potassium chloride recently used by Ashford and Dixon[5]. When slices of rat brain are suspended in Ringer solution containing glucose, in the Warburg apparatus, and phenosafranine in $10^{-5}M$. concentration is added, the essentially carbohydrate respiration (Q_{O_2} in table) of brain continues unimpaired, the respiratory quotient (*R.Q.*) remains at the carbohydrate level, but the aerobic acid formation ($Q_G^{O_2}$) rises to a value near or equal to that normally found only under anaerobic conditions. The acid formed, estimated by Clausen's method, proves to be lactic acid.

Expt. (min.)	Medium	Control			Phenosafranine 10^{-5} *M*.		
		Q_{O_2}	$Q_G^{O_2}$	*R.Q.*	Q_{O_2}	$Q_G^{O_2}$	*R.Q.*
100	Bicarb.	− 11·5	+ 2·0	—	− 14·9	+ 15·2	—
90	Phosphate	− 12·8	—	1·01	− 11·6	—	0·98
120	Bicarb.	− 13·2	+ 1·7	1·02	− 14·4	+ 11·1	0·98

Thus the complete separation and simultaneous occurrence of carbohydrate oxidation and fermentation is demonstrated in intact animal cells under conditions closely approximating to the physiological.

In tumours, unlike most normal tissues, the respiration is inadequate to suppress the lactic acid formation (Warburg[6]); the carbohydrate oxidation is defective (Dickens and Simer[7]). Phenosafranine specifically inhibits the Pasteur mechanism in tumours also:

	Expt. (min.)	Medium	Control		Phenosafranine 3×10^{-4} *M*.	
			Q_{O_2}	$Q_G^{O_2}$	Q_{O_2}	$Q_G^{O_2}$
Jensen sarcoma	60	Bicarb.	− 10·8	+ 28·3	− 9·7	+ 44·9
Walker carcinoma	30	,,	− 12·1	+ 20·9	− 8·8	+ 39·5

Thus whilst in both normal and tumour tissue a widespread correlation between carbohydrate oxidation and carbohydrate fermentation normally exists (Dickens and Simer[7]), phenosafranine in both groups of tissue is able, when present in extremely low concentration, to break down specifically and completely the coupling reaction between these two fundamental routes of carbohydrate katabolism in the living cell.

F. DICKENS.

Cancer Research Laboratory,
North of England Council of the
British Empire Cancer Campaign,
Royal Victoria Infirmary,
Newcastle-on-Tyne.
March 8.

[1] *Biochem. Z.*, **172**, 432; 1926.
[2] *ibid.*, **219**, 432; 1930.
[3] *Z. physiol. Chem.*, **210**, 79; 1932.
[4] *Biochem. J.*, **28**, 537; 1934.
[5] *ibid.*, **29**, 157; 1935.
[6] "Stoffwechsel der Tumoren", Springer, Berlin, 1926.
[7] *Biochem. J.*, **24**, 1301; 1930. **25**, 985; 1931.

Application of Low Temperature Calorimetry to Radioactive Measurements

IT is often of importance to determine in absolute measure energy changes connected with radioactive transformations, but only in a few cases has it been possible to employ calorimetric methods for this purpose, since in general the amounts of energy liberated in unit time are too small. The sensitivity of calorimetric measurement can be increased, however, by many orders of magnitude by working at very low temperatures, and it may be worth while to point this out, as low temperature technique is now within the reach of non-specialised laboratories.

Consider a calorimeter consisting of lead. At a temperature of 1·3°, which can easily be obtained with liquid helium, its specific heat is 3,000 times smaller than at room temperature. So the calorimetric sensitivity is increased by this factor if we take the temperature sensitivity as constant. Using a substance like tungsten, with a higher θ_{Debye}, one can increase this factor still further by one power of 10. If one wishes to measure the heat developed with an accuracy of 1 per cent, the temperature must be allowed to change by 1/10°, assuming that the measuring sensitivity is 1/1,000°–1/10,000°. The effects can be accumulated over a period of at least ten minutes, as at very low temperatures the thermal insulation can be made nearly perfect, owing to the lack of radiation. Thus, using a calorimeter consisting of 1 cm.^{3} of tungsten, one could measure 10^{-9} cal./sec., which is about 1,000 times more sensitive than in the calorimeter of Meitner and Orthmann[1]. So, for example, the total heating effect of 10^{-8} gm. of radium situated within the calorimeter could be determined, or the heating caused by the γ-rays from a source of 0·1 millicurie of radon placed 3 cm. away from the calorimeter.

Cooling the calorimeter below 1° by the magnetic procedure, one can diminish still further the specific heat of the absorbing substance, and at the same time the sensitivity of the temperature measurement is considerably increased by basing it on the susceptibility of the paramagnetic salt, for, in the region where the Curie law holds, the accuracy of temperature measurement is proportional to $1/T^2$. With a substance obeying the T^3 law for the specific heat, therefore, the sensitivity of this method increases with falling temperature with T^{-5}.

The specific heat of a paramagnetic salt, however, does not follow the T^3 law, as its specific heat must necessarily be anomalous in this temperature region[2]. No great increase in sensitivity could therefore be achieved below 1° by working with a calorimeter consisting of the salt alone. But, of course, this does not apply to an appropriate combination of the paramagnetic salt and an absorbing substance of non-anomalous specific heat.

In some preliminary experiments carried out during the past few weeks, Dr. Kürti and I nevertheless worked with the unfavourable case of the salt alone in order to be able to use our ordinary apparatus for magnetic cooling[2]. We took 1 gm. of iron ammonium alum and cooled it down to 0·05°, which in this case was an advantage solely because of the improved thermal insulation[2]. In spite of the very small absorption coefficient of the substance for γ-rays, and the comparatively low thermometric sensitivity of this particular apparatus, a sharp rise of temperature set in immediately after the substance had been exposed to the γ-radiation of 100 millicuries of radon at a distance of 2·5 cm. (This turned out to be a very convenient way for measuring the specific heat of the salt and we will report soon on the results.) Even in this unfavourable case, we could measure 10^{-8} cal./sec., and it should be possible to measure, in a volume of about 1 cm.^{3}, an evolution of heat of the order of 10^{-11} cal./sec., by using a suitable absorbing substance in combination with the paramagnetic salt and improving the sensitivity of the temperature determination.

With such increased sensitivity, various problems can be attacked, and experiments in this direction are in progress at the Clarendon Laboratory.

F. SIMON.

Clarendon Laboratory,
Oxford.
March 28.

[1] L. Meitner and W. Orthmann, *Z. Phys.*, **60**, 143; 1930.
[2] N. Kürti and F. Simon, *Proc. Roy. Soc.*, A, **149**, 152; 1935.

Internuclear Distance and Vibration Frequency for Diatomic Molecules

THE equilibrium internuclear distance r_e and the vibration frequency ω_e for diatomic molecules were connected by Morse in the formula $\omega_e r_e^3$ = const. = $3{\cdot}000 \times 10^{-21}$ cm.^{2} for many molecules. This, however, does not hold accurately, and in fact the constant shows a periodic error. Douglas Clark has proposed a modified formula, $\omega_e r_e^3 \sqrt{n}$ = const., where n is the 'group number', and is the number of 'shared electrons', usually the sum of the valency electrons in the atoms composing the molecule. This constant varies for each molecular period, and appears to be quite arbitrary. Neither of these formulæ is capable of fitting the case of isotopes, for which r_e has the same value, while ω_e depends on the reduced mass.

We have considered a formula involving the reduced mass μ, namely, $\omega_e r_e^3 \sqrt{\mu}$ = const., and examined it with relation to experimental data for non-hydride molecules. Using Clark's nomenclature, it is found that for the molecular periods KK, KL and KM which he discussed, the agreement is very nearly as good as with his formula and almost certain to be within the limits of observational error. In addition, it gives identical constants for the isotopes $B^{10}O$ and $B^{11}O$, and for H_2 and HD.

The formula also gives consistent results for the LL and MM periods, and it is found that the constant for the KL period is the mean of the constants for the KK and LL periods, and that for KM the mean of KK and MM. Finally, the constant for each period is no longer arbitrary, but is approximately proportional to the number of completed electronic shells in the molecule, the value for the KK period being $10{\cdot}6 \times 10^{-33}$ gm.$^{\frac{1}{2}}$ cm.^{2}.

We hope to publish a fuller account of this work shortly.

H. S. ALLEN.
A. K. LONGAIR.

Physical Laboratory,
University,
St. Andrews.
March 20.

Raman Spectra of some Deuterium Compounds

USING a high intensity glass spectrograph with a dispersion of 15 A. per mm. we have measured the Raman frequencies of tetrachlordeuterium-ethane and *cis-trans* deuterium-dichlorethylene prepared from heavy water. The results are briefly given below, together with mean values of the Raman frequencies (cm.$^{-1}$) of the corresponding light hydrogen compounds taken from earlier measurements[1] for comparison. Intensities are given in brackets.

$C_2D_2Cl_4$: 174(4), 240(3), 287(4), 352(8), 399(1), 532(2), 623(6), 701(2), 739(5), 947(3), 2240(6).
$C_2H_2Cl_4$: 171(4), 236(6), 286(4), 351(5), 395(2), 544(2), 644(4), 761(2), 802(5), 1212(2), 2984(6).
$C_2D_2Cl_2$ (*cis*) : 176(6), 368(3), 515(1½), 689(6), 850(3), 1570(6), 1507(2), 2325(6).
$C_2H_2Cl_2$ (*cis*) : 173(6), 406(4), 565(2), 714(5), 806(¼), 878(½), 1182(4), 1587(5), 1687(1), 3080(7).
$C_2D_2Cl_2$ (*trans*) : 346(4), 657(1), 759(2), 992(6), 1570(6), 1547(3), 2325(4).
$C_2H_2Cl_2$ (*trans*) : 351(7), 763(2), 846(3), 1271(5), 1578(3½), 1625(¼), 1694(½), 3077(4).

The isotope effect is in many cases clearly determinative and indicates the participation of the hydrogens in the different oscillations. Thus the alteration of the C–H frequency is specially strong; in tetrachlorethane, for example, we have:

CH : = 2984 cm.$^{-1}$ and CD : = 2240 cm.$^{-1}$ in dichlorethylene :
CH : = 3080 cm.$^{-1}$ and CD : = 2325 cm.$^{-1}$.

An approximate estimate of the bond strength, using elementary vibration theory, gives a greater value for deuterium than for light hydrogen in these compounds.

We intend to discuss these new results further elsewhere in conjunction with earlier polarisation measurements[2].

B. TRUMPY.

Geophysical Institute,
Bergens Museum,
Bergen.
March 26.

[1] K. W. F. Kohlrausch, "Smekal-Ramaneffekt".
[2] B. Trumpy, *Z. Phys.*, **90**, 133: 1934. **93**, 624; 1935.

X-Ray Study of Recovery and Recrystallisation of Aluminium Single Crystals

To study recovery and recrystallisation after deformation, we have adapted the rotation method of crystal analysis with flat films placed in front of and behind the specimen.

The aluminium single crystals were deformed by extension by 5–16 per cent. It is well known

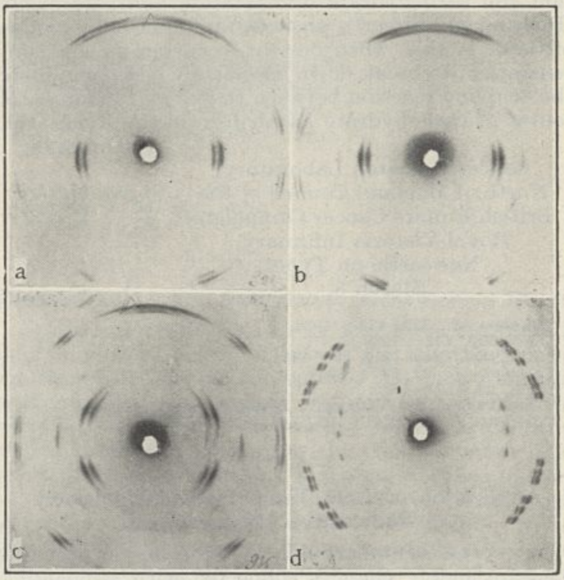

FIG. 1. X-ray analysis of single crystals of aluminium. (*a*) Deformation texture and (*b*) recovery after 2 hours at 300°. (*c*) Deformation texture and (*d*) texture after recrystallisation.

that the asterism in the process of recovery does not change. Distinct changes in the distribution of intensity among the spots, sometimes accompanied either by their shortening or elongation, with simultaneous increase in their sharpness could be seen on some elongated spots on the X-ray pictures taken by back reflection (see Fig. 1, *a* and *b*).

We consider this phenomenon to be the result of the removal of stresses and straightening of the elastically bent separate parts of the deformed single crystal.

Some of the deformed single crystals (10, 12 and 16 per cent extension) have again become single crystals after recrystallisation at temperatures coinciding with those of Karnopp and Sachs[1], but with an orientation absolutely different from that of the deformed crystal (see Fig. 1, *c* and *d*).

N. Seljakow.
E. Sows.
Institute of Metals,
Leningrad.

[1] R. Karnopp and J. Sachs, *Z. Phys.*, **42**, 283; 1927.

α-β Transformation of Muscle Protein *in situ*

In a recent letter[1] we described the prediction and discovery by X-rays of an α-β intramolecular transformation on stretching myosin, and pointed out the close analogy in molecular configuration and elastic properties between myosin and the labile ('supercontracting') form of hair keratin. We are now able to report that we have at last succeeded in bringing about the transformation by stretching muscle itself. Details will be given elsewhere: at the moment, the change has been demonstrated both in frog's sartorius muscle and in the retractor muscle of the foot of *Mytilus edulis*.

Shortly after writing our previous letter, we became acquainted with an almost simultaneous paper by H. H. Weber[2], describing independent optical and elastic experiments on myosin threads. It is interesting to note that Weber's results also indicate, as is shown directly and unambiguously by X-ray analysis, that the myosin molecule is normally in a folded configuration endowed with inherent long-range elasticity.

W. T. Astbury.
Sylvia Dickinson.
Textile Physics Laboratory,
University of Leeds.
April 11.

[1] Nature, **135**, 95, Jan. 19, 1935.
[2] *Pflüg. Arch. Physiol.*, **235**, 205; 1934.

Points from Foregoing Letters

The green flash at sunset is a common occurrence when overlooking the sea from a certain height, according to Prof. F. P. Worley, of Auckland, New Zealand. In one instance fringes of violet and of blue preceded a final blue-green. From this and from the fact that on one occasion the full moon shortly after sunset appeared green, Prof. Worley concludes that while atmospheric dispersion may be the primary cause of the coloured flash, the contrast between the coloured edges and the non-luminous remainder of the setting sun may modify considerably the subjective colour effects.

The structure of the softer parts of fossil animals is relatively seldom maintained. Prof. A. Petrunkevitch submits a photograph of the transversely striated muscle of a fungus-gnat (probably *Sciara*) which had been embalmed some thirty million years ago in a piece of amber, now in the British Museum.

From the change in the structure of the light scattered by carbon tetrachloride when the temperature of the liquid is raised, Sir C. V. Raman and Mr. B. V. Raghavendra Rao infer that, as the temperature increases, the thermal energy of liquids becomes less like that of ordered wave-trains of sound.

Prof. J. W. Munro appeals for stricter control of the practice of fumigation and for support of research to make fumigation safer and more efficient, so that it may also be applied in the case of insects infesting foodstuffs and other consumable stores.

Dr. K. A. C. Elliott finds that cancer tissue of the rat, while respiring at a rate equal to that of many other tissues, cannot oxidise succinic or malic acids. He therefore disagrees with Prof. Szent-Györgyi's generalisation that respiration consists mainly in the reversible oxidation of those acids and believes that Prof. Szent-Györgyi's findings apply mainly to minced tissues.

Living cells derive their energy largely from the oxidation or break-up of sugar-like substances. In the absence of oxygen, lactic acid is formed (fermentation). If oxygen is present the sugar is completely oxidised to carbon dioxide, and the lactic acid disappears (Pasteur effect). Dr. F. Dickens finds that in the presence of traces of the dye-stuff phenosafranine, the respiration of brain tissue produces both carbon dioxide and lactic acid, so that the Pasteur effect is apparently inhibited.

At temperatures near the absolute zero, the amount of heat necessary to produce an appreciable change in temperature is very much smaller than at ordinary temperature. Taking advantage of this fact, Dr. F. Simon has constructed a low-temperature calorimeter which registers 10^{-8} cal./sec. He discusses the means for increasing the sensitivity a thousand-fold so as to be able to measure by means of the heat emitted the absolute energy connected with many radioactive transformations.

Prof. H. S. Allen and Mr. A. K. Longair point out that the simple formulæ which, in a diatomic molecule, connect the vibration and the internuclear distance (magnitudes deduced from the band spectra of the light emitted by such molecules) do not hold accurately. They propose to introduce another factor, the 'reduced mass' (equal to the product of the masses of the atoms divided by their sum). This makes the formula fit better and renders the 'constant' for each period approximately proportional to the number of completed electronic shells in the molecule.

The spectra of the light scattered by certain compounds of carbon, chlorine and heavy hydrogen ($C_2D_2Cl_2 : C_2D_2Cl_4$) have been compared by Prof. B. Trumpy with those of the corresponding compounds containing ordinary hydrogen (di- and tetrachlorethane). From changes in the wave-length of some of the spectrum lines, he deduces how the hydrogen atom participates in certain intra-molecular oscillations.

Messrs. N. Seljakow and E. Sows submit photographs showing the changes taking place in the shape and intensity of the spots of X-ray defraction patterns, when single crystals of aluminium are deformed by extension and then allowed to recover. They consider the changes to be due to the removal of stresses and straightening of the elastically bent separate parts of the deformed single crystal.

Science News a Century Ago

Work of the Cambridge Observatory

According to the *London and Edinburgh Philosophical Magazine*, at a meeting of the Cambridge Philosophical Society held on May 4, 1835, "Prof. Airy gave an account of recent results obtained at the Observatory; namely, 1st, That the discrepancy of the observations of the obliquity of the Ecliptic at the summer and winter solstices formerly noticed, had disappeared on using the refraction corresponding to a new barometer which stands 1-10th of an inch higher than one formerly used. 2nd, That the mass of Jupiter, as determined by observations of the 4th Satellite in 1834, is almost exactly the same as that obtained in 1832 and 1833, namely 1–1048th of the Sun's mass. 3rdly, That the time of rotation of Jupiter, as determined by a spot, is 9h, 55m, 21s: the spot from which the determination was obtained made 225 revolutions in 93 days."

Marine Meteorology at the Royal Society

At a meeting of the Royal Society held on May 7, 1835, at which Sir John Rennie presided, five papers were read, including three on marine meteorology, communicated by Capt. Beaufort, R.N. They were entitled "Hygrometrical Observations made on board His Majesty's surveying vessel Ætna", "Meteorological Register from the 1st of January to the 1st of November 1834" and "Meteorological Register kept on board His Majesty's Ship Thunder, between the 1st of January and the 30th of June 1834". This last 'register' had been kept by R. Owen, Commander, while the other, from January 1 until November 1, 1834, had been kept by Edward Barnett and contained observations made during a voyage across the Atlantic.

Cooking by Gas

On May 7, 1835, a correspondent, "M. P.", writing from Hitchin to the editor of the *Mechanics' Magazine*, began his letter: "If any of your long list of readers are smitten with the desire of diffusing useful knowledge, and are in possession of the information I seek, they will thank me for affording them an opportunity of indulging that laudable and fashionable propensity." A gas works had just been erected in Hitchin, and attempts were being made to use the gas for cooking. "M. P." said they had tried an apparatus described in the fifteenth volume of the *Mechanics' Magazine*. "It consists," he said, "of nothing more than a cylinder of thin sheet iron, twelve inches high, six inches wide at the bottom and three at the top. The bottom is open and the top is covered with a piece of thin wire gauze." The gas pipe being carried up two inches into the cylinder, the gas jets mixed with the common air and ascended together through the gauze and were set fire to at the top. Results of experiments, "M. P." said, showed that two quarts of water could be boiled by the application of three feet of gas, and as the price of gas was 12*s*. 6*d*. per thousand feet the expense was only a halfpenny. He was, however, desirous of having further information on the subject.

Wheatstone on Speaking Machines

At the Royal Institution on May 8, 1835, Wheatstone delivered a lecture on speaking machines. Mr. Wheatstone, said the *Record of General Science*, gave an account of the different attempts which had been made to invent speaking machines from the time when the oracular responses were delivered at Delphi, through the period when a speaking head was exhibited by the Pope towards the end of the tenth century, and others afterwards by Roger Bacon and Albertus Magnus, with the impositions which were practised upon the credulous, to the present time when the principle of a speaking machine had been developed by Mr. Willis. Van Helmont was one of the first to write upon the adaptation of the organs of voice to the articulation of the letters. He considered that the letters of the alphabet constituted the order in which articulate sounds were naturally produced, by the structure of the tongue and the larynx; that when one letter is uttered the tongue is in the proper position for the pronunciation of the subsequent one. Wheatstone gave a demonstration with a copy of a speaking machine which had been invented in Germany, the words 'mamma', 'papa', 'mother', 'father' and 'summer' being distinctly pronounced. The instrument consisted of a pair of bellows, to which a tube was fixed and which ended in a bell, the aperture of which was regulated by the hand so as to produce the sounds.

Societies and Academies

DUBLIN

Royal Irish Academy, March 16. W. B. MORTON: Vortex polygons. A revision and completion of the classical investigation of J. J. Thomson on the stability of the rotation of a set of equal straight vortex-filaments at the angular point of a regular polygon. It is found that the period of rotation is that also of the most rapid oscillations about steady motion, the shorter periods given in the former work for five and six vortices being spurious, and arising from an unjustifiable step in the analysis. The motion of seven vortices is on the border line between stability and instability, one of the oscillations having vanishing frequency, to the first order of approximation. The modes of motion in each case are examined in detail.

PARIS

Academy of Sciences, March 18 (*C.R.*, **200**, 993–1076) GEORGES CLAUDE: The campaign of the *Tunisie*. AUGUSTE LUMIÈRE and MLLE. SUZANNE SONNERY: The mode of action of suspensions of carbon introduced into the circulation. Intravenous injections of carbon induce hyperleucocytosis, roughly doubling the proportion of white corpuscles. SAMUEL EILENBERG: Invariance with respect to small transformations. CLAUDE CHEVALLEY: The definition of Betti groups of closed ensembles. GEORGES VALIRON: The Borel directions of meromorph functions of zero order. M. LAVRENTIEFF: A class of continued representations. CHARLES LEDOUX: A stroboscopic torsiometer for the determination of the power of a motopropulsive group of a ship. PIERRE SALET: The velocity of light deduced from measurements of stellar radial velocities. The difference between the velocity of light deduced by the spectroscopic method from stellar radial velocities and that of Michelson is not due to a systematic error depending on the hour angle in the star observations. ANDRÉ GOUGENHEIM: The accuracy obtained in determinations of latitude by means of the prism astrolabe.

LOISEAU: The rational mechanics of the Euclidian connexions and a necessary form of all physical laws. PIERRE JOLIBOIS: A new arrangement of the diffusion pump. Description, with diagram, of a combined Sprengel pump and mercury vapour pump. PIERRE AUGER, ALBERT ROSENBERG and FRANÇOIS BERTEIN: The characters of two corpuscular components of the cosmic radiation. Experiments confirming the view given in an earlier paper, that there are two groups of primary corpuscular cosmic rays, both of great energy, but absorbed differently by matter. MARCUS FRANCIS and TCHENG-DA-TCHANG: The preparation of thin layers of uranium oxide, U_3O_8, by electrolysis. Deposits of less than 0·2 mgm. per square cm. are adherent, even after ignition. LÉONARD SOSNOWSKI: The artificial radioactivity of bismuth. The excited radioactivity was very weak, but its variation of intensity followed an exponential law. The capture of a neutron by the bismuth nucleus is accompanied neither by emission of a proton nor by the emission of an α-particle. MAURICE DE BROGLIE: Remarks on the preceding communication. JEAN PERREU: The tonometry of saline solutions. VICTOR HENRI and PIERRE ANGENOT: The ultra-violet absorption spectrum of pyridine. Three frequencies, 600 cm.$^{-1}$, 1,029 cm.$^{-1}$ and 1,488 cm.$^{-1}$ are found in Raman, infra-red and ultra-violet spectra. MLLE. CÉCILE STORA: Contribution to the physico-chemical study of photosensitive electrodes with colouring matters. JEAN J. TRILLAT and M. PAIĆ: The annealing of pure aluminium. The results of an X-ray study of commercial (99 per cent) and refined (99·993 per cent) aluminium. PAUL LAFFITTE and PIERRE GRANDADAM: The nitride formation of some metals. The production of nitride was studied by measuring the changes in electrical resistance of a wire heated in nitrogen or in ammonia. M. LEMARCHANDS and MLLE. D. SAUNIER: The reaction of the metalloids on the basic oxides. Study of the substance obtained by grinding iodine with mercuric oxide in a mortar: its constitution is $HgOI_2$. PAUL JOB, MME. MARIE FREYMANN and RENÉ FREYMANN: Absorption spectra in the near infra-red of organic and mineral derivatives of ammonia. ARMAND MARIE DE FICQUELMONT: The action of ammonia on the tetramer of phosphorus bichloronitride. The final product is always phosphorus nitride, P_3N_5. P. P. BOUDNIKOFF: The heat of hydration of mortars. JACQUES PARROD: The oxidation products of (*d*-arabino) tetrahydroxybutyl.4.imidazol by nitric acid. LÉON PALFRAY: Some new mineral salts of urea. ROBERT LEVAILLANT: The action of methyl chlorsulphonate on methyl acetate: the action of dimethyl sulphate on acetyl chloride. MLLE. SIMONNE CAILLÈRE: The signification of the phenomenon of incandescence shown by certain antigorites. VALÉRIEN AGAFONOFF: Some considerations on the colloidal part of French soils. MARCEL PICHOT: The imbibition and swelling of the clay of arable soil and their relations with the solids in rivers. DANIEL BARBIER, DANIEL CHALONGE and ETIENNE VASSY: The effect of the temperature of the stratosphere on the spectrum of ozone. CHARLES FABRY: Remarks on the preceding paper. ST. JONESCO: Pollination in certain ephemeral flowers. RENÉ LERICHE and RENÉ FONTAINE: Demonstration by aortography at the thorotrast of the vasodilating effect of peri-arterial sympathectomy. Analysis of this effect. MLLE. JEANNE LÉVY: Experimental alcoholism. Cellular hypersensibility due to acidosis. JAMES BASSET, EUGÈNE WOLLMAN, MME. ELISABETH WOLLMAN and MICHEL A. MACHEBOEUF: Studies on the biological effects of ultrapressures. The action of very high pressures on the bacteriophages of spores and on autolysins. MICHEL WEINBERG and JEAN DAVESNE: The antitoxic titre and anti-infectious power of therapeutic sera.

LENINGRAD

Academy of Sciences (*C.R.*, 1, No. 1; 1935). M. LAVRENTJEV: Some properties of univalent functions. O. ZHITOMIRSKIJ: Classification of cubic forms. A. IVANOV: Perturbations in the movement of the minor planet (122) Gerda during the period 1904–35, and the ephemeris of the planet for the opposition in 1935. B. NUMEROV: The problem of the determination of the geoid on the basis of gravity observations. S. RODIONOV, M. PAVLOVA, N. REJNOV, N. STUPNIKOV and A. JUZEFOVICH: The short ultraviolet in the solar spectrum. N. ANDREJEV: Measurement of the amplitude of vibration by a finger. O. LEIPUNSKIJ: The steric factor in the equation of the rate of activated adsorption. E. BRUMBERG: A new sensitive polariscope. V. DUBOV: Local tides of the Baltic Sea and their connexion with inundation at Leningrad. F. LOEWINSON-LESSING: Two kinds of correlation between the atomic numbers and atomic weights of chemical elements. J. KERKIS: Does the irradiation of the soma produce mutations in the germ cells? M. TIMOFEJEVA: Frost resistance of winter cereals in connexion with the phasic development and hardening of plants. N. PETINOV: Methods of controlling the grain quality of irrigated wheats. While watering by flooding reduces the protein content of grain, spraying increases both the amount of grain and its protein content. E. SLASTENKO: The *Scorpaena* of the Black Sea.

VIENNA

Academy of Sciences, Feb. 28. MARGARETE HOFFER: Determination of the polonium content from salts of thick layers. HERBERT HABERLANDT, BERTA KARLIK and KARL PRZIBRAM: Fluorescence of fluorite (4). Detection of uranium in fluorites and low-temperature fluorescence. After intense ignition, fluorites show a green uranium band, which serves in estimating the uranium content. The nearer the fluorite is to acid eruptive rock, the more frequent and the more dominant is the yellowish-green fluorescence of the ytterbium. Varying relative concentrations of ytterbium and europium in fluorites from different sources are indicated. R. BRINCKMANN: Comparative researches in the Gosau Basin of the north-eastern Alps. ADOLF MÜLLER and MAURICE DORFMAN: Photochemical behaviour of pyridine, 2-benzylpyridine, papaverine and various derivatives. When irradiated with a quartz lamp in the air, 2-benzylpyridine undergoes two main reactions. In the short-wave ultra-violet, a yellow aldehydic compound is formed, the pyridine ring probably being ruptured. In the long-wave ultra-violet, photo-oxidation to 2-benzoylpyridine and 1:2-di-α-pyridyl-1:2-diphenylethane occurs; papaveraldine is formed similarly from papaverine. F. HESS: Reply to Arthur Wagner's "Critical Remarks on the Daily Course of Cosmic Ultra-radiation". The reality of the daily course of ultra-violet radiation indicated earlier by Hess, Steinmaurer and Graziadei is confirmed. JOSEF A. PRIEBSCH: Statistical determination of the effect of barometric pressure on ultra-radiation. By a modification in the method of calculating, errors involved in the statistical method of ascertaining the air-pressure coefficient of ultra-radiation are taken into account. ARMIN DADIEU and HANS KOPPER: The Raman spectrum of liquid deuterium chloride. This spectrum consists of a wide, diffuse band of low intensity and with a maximum at 2041 cm.$^{-1}$. Under analogous conditions, ordinary liquid hydrogen chloride furnishes a band at 2822 cm.$^{-1}$. GUIDO MACHEK: The action of aromatic hydroxy-sulphonic acids on hippuric acid (1). The interaction of hippuric acid and the three isomeric cresols, phenol and β-naphthol yields salt-like molecular compounds of the hydroxybenzene (or naphthol) with glycocoll (liberated from the hippuric acid) in equimolecular proportions. LEOPOLD SCHMID and CHARLOTTE KEMENY: Investigation on *Flores verbasci*. The identity of the acid found, together with the colouring matter crocetin, in these flowers with *n*-1 : 14-tetradecandicarboxylic acid is confirmed by the synthesis of the acid from sebacic acid, by way of decandiol. HANS PRZIBRAM: The life of the water-beetle, *Hydrocus piceus*, L. (Col. Hydroph.), without antennæ. The feelers are not unconditionally necessary to the breathing of *Hydrocus* in water.

Forthcoming Events

[*Meetings marked with an asterisk are open to the public.*]

Sunday, May 5

BRITISH MUSEUM (NATURAL HISTORY), at 3 and 4.30.—M. A. Phillips: "Birds".*

Tuesday, May 7

UNIVERSITY COLLEGE, LONDON, at 5.—Dr. E. W. Fish: "The Physiology of the Teeth" (succeeding lecture on May 14).*

INSTITUTION OF CIVIL ENGINEERS, at 6.—Prof. O. T. Jones: "Geophysics" (James Forrest Lecture).

Wednesday, May 8

INSTITUTE OF METALS, at 8.—(at the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W.1). —Prof. W. L. Bragg: "Atomic Arrangements in Metals and Alloys" (Annual May Lecture).

Thursday, May 9

ST. MARY'S HOSPITAL, LONDON, at 5.—Prof. E. D. Adrian: "The Electrical Activity of the Brain".*

KING'S COLLEGE, LONDON, at 5.30.—Hugh Braun: "The Development of the Castle in England and Wales" (succeeding lectures on May 16, 23 and 30).*

Friday, May 10

ROYAL INSTITUTION, at 9.—Dr. C. S. Myers: "The Scientific Approach to Vocational Guidance".

ELECTRICAL ASSOCIATION FOR WOMEN, May 8–11.—Annual Conference to be held in Manchester and Salford.

Margaret, Lady Moir: President.

Official Publications Received

GREAT BRITAIN AND IRELAND

Reports of the Council and Auditors of the Zoological Society of London for the Year 1934, prepared for the Annual General Meeting to be held on Monday, April 29th, 1935. Pp. 103. (London: Zoological Society.)

The Scientific Proceedings of the Royal Dublin Society. Vol. 21 (N.S.), No. 22: Investigations on the Control of Seedling Diseases of Sugar Beet. By William Hughes. Pp. 205–212. (Dublin: Hodges, Figgis and Co.; London: Williams and Norgate, Ltd.) 6*d*.

Bristol Museum and Art Gallery. Publication 19: Explanatory Guide to the Geological Relief Map of the Bristol District. By Prof. S. H. Reynolds. Second edition. Pp. 24. (Bristol: Bristol Museum and Art Gallery.) 3*d*.

Imperial Agricultural Bureaux. Fifth Annual Report of the Executive Council, 1933–1934. Pp. 51. (London: H.M. Stationery Office.) 4*s*. net.

Agricultural Progress: the Journal of the Agricultural Education Association. Vol. 12, 1935. Pp. 204. (Cambridge: W. Heffer and Sons, Ltd.) 5*s*. net.

Brussels Exhibition 1935: British Chemical Exhibit. Organised by the Association of British Chemical Manufacturers. Pp. 87. (London: Association of British Chemical Manufacturers.)

OTHER COUNTRIES

U.S. Department of Agriculture. Circular No. 334: Characters Useful in distinguishing Larvæ of *Popillia japonica* and other introduced Scarabæidæ from Native Species. By Robert J. Sim. Pp. 20. (Washington, D.C.: Government Printing Office.) 5 cents.

Comptes rendus de la septième séance de la Commission Géodésique Baltique réunie à Léningrad et Moscou du 12 au 19 Septembre 1934. 1e partie: Procès-verbaux et rapports. Redigés par Ilmari Bonsdorff. Pp. iii+182. 2e partie: Communications. Redigés par Ilmari Bonsdorff. Pp. ii+429. (Helsinki: Commission Géodésique Baltique.)

Obras completas y Correspondencia cientifica de Florentino Ameghino. Vol. 14: Investigaciones de morfologia filogenética en los molares superiores de los Ungulados. Edicón Oficial ordenada por el Gobierno de la Provincia de Buenos Aires. Dirigida por Alfredo J. Torcelli. Pp. 619+271 plates. (La Plata.)

Carnegie Endowment for International Peace. Annual Report for 1934 of the Division of Intercourse and Education. By Nicholas Murray Butler. Pp. 68+8 plates. (Washington, D.C., and New York: Carnegie Endowment for International Peace.)

Field Museum of Natural History. Report Series, Vol. 10, No. 2: Annual Report of the Director to the Board of Trustees for the Year 1934. (Publication 336.) Pp. 137–280+plates 13–24. (Chicago: Field Museum of Natural History.) 1 dollar.

New York Academy of Sciences. Scientific Survey of Porto Rico and the Virgin Islands. Vol. 14, Part 2: Insects of Porto Rico and the Virgin Islands—Homoptera (excepting the Sternorhynchi). By Herbert Osborn. Pp. 111–260. (New York City: New York Academy of Sciences.) 2 dollars.

Imperial College of Tropical Agriculture: Low Temperature Research Station. Memoir No. 1: The Storage of Avocado Pears. By C. W. Wardlaw and E. R. Leonard. Pp. 20. (Trinidad: Imperial College of Tropical Agriculture.) 2*s*. net.

Bulletin of the American Museum of Natural History. Vol. 68, Art. 4: Wallace's Line and the Distribution of Anglo-Australian Mammals. By Henry C. Raven. Pp. ii+179–293. (New York: American Museum of Natural History.)

South Australia: Department of Mines. Mining Review for the Half-Year ended June 30th, 1934. (No. 60.) Pp. 72+2 plates. (Adelaide: Government Printer.)

Journal of the Faculty of Agriculture, Hokkaido Imperial University. Vol. 36, Part 2: Mycological and Pathological Studies on the Downy Mildew of Italian Millet. By Makoto Hiura. Pp. 121–284+plates 9–14. (Tokyo: Maruzen Co., Ltd.)

Bernice P. Bishop Museum. Occasional Papers. Vol. 10, No. 18: New Nemerteans from Hawaii. By W. R. Coe. Pp. 9. Vol. 10, No. 19: Taxonomic Studies of Raiatean Plants. By John William Moore. Pp. 8. Vol. 10, No. 20: Anatomy of Hawaiian Peperomias. By T. G. Tuncker and William D. Gray. Pp. 19. Vol. 10, No. 21: Revised List of Hawaiian Ants. By William Morton Wheeler. Pp. 21. Vol. 10, No. 22: Check List of the False Scorpions of Oceania. By J. C. Chamberlin. Pp. 14. Vol. 10, No. 23: Indo-Pacific Terrestrial Talitridae. By K. Stephensen. Pp. 20. Vol. 10, No. 24: New and Rare Polynesian Crustacea. By Charles Howard Edmondson. Pp. 40. (Honolulu: Bernice P. Bishop Museum.)

Memoirs of the Bernice P. Bishop Museum. Vol. 11, No. 6: The Fishes of Oceania, Supplement 2. By Henry W. Fowler. Pp. 385–466. (Honolulu: Bernice P. Bishop Museum.)

Bernice P. Bishop Museum. Bulletin 113: Society Islands Insects. (Pacific Entomological Survey, Publication 6.) Pp. 156. Bulletin 114: Marquesan Insects, 2. (Pacific Entomological Survey, Publication 7.) Pp. ii+378. Bulletin 123: Archæology of the Pacific Equatorial Islands. By Kenneth P. Emory. (Whippoorwill Expedition, Publication No. 4.) Pp. 43+5 plates. Bulletin 125: Hawaiian Helicinidae. By Marie C. Neal. Pp. 102. Bulletin 126: Outline of Hawaiian Physical Therapeutics. By E. S. Craighill Handy, Mary Kawena Pukui and Katherine Livermore. Pp. 51. Bulletin 127: The Legends of Maui and Tahaki. Translated by J. F. Stimson. Pp. 100. Bulletin 128: Flowering Plants of Samoa. By Erling Christophersen. Pp. iii+221. Bulletin 129: Polychaeta from Hawaii. By Maximilian Holly. Pp. 33. (Honolulu: Bernice P. Bishop Museum).

CATALOGUES

Foyles Catalogue of Books on Folklore, Comparative Religion, Mythology (New and Secondhand). Pp. 12. (London: W. and G. Foyle, Ltd.)

Books, Periodicals and Pamphlets on Geology, including Palaeontology, Mineralogy and Mining. (New Series, No. 40.) Pp. 44. (London: Wheldon and Wesley, Ltd.)

Electrical Measuring Instruments. (Special List No. 5.) Pp. 32. Polarograph. Pp. 2. (Köln: E. Leybold's Nachfolger A.-G.; London: W. Edwards and Co.)

Editorial and Publishing Offices:
MACMILLAN & CO., LTD.
ST. MARTIN'S STREET, LONDON, W.C.2
Telephone Number: WHITEHALL 8831
Telegraphic Address: PHUSIS, LESQUARE, LONDON