Quart. Jour. Exp. Physiol., vol. 15, p. 103; 1925). Conversely, Parkes and Bellerby have found it possible to produce œstrus during lactation in mice by injection of œstrin, the amount required depending on the number of young suckling above two (when spontaneous œstrus may occur). The inhibition to the action of œstrin is abolished in a lactating mouse unilaterally sterilised by exposure of one ovary to the X-ray, by removal of the opposite ovary, containing the corpora lutea, indicating that the inhibition is certainly due to a secretion from these bodies.

A functioning corpus luteum is associated with a sensitiveness of the uterine mucosa to stimuli, either the fertilised ovum or an artificial stimulus, resulting in the production of decidual tissue, in which the ovum, if present, can be embedded. Artificial stimulation of the mucosa is without effect in animals such as the rat or mouse with a short œstrous cycle, in which the corpora of ovulation are probably functionless; but the uterus can be made sensitive by inducing pseudo-pregnancy and is also sensitive during lactation; in both of these states the life of these organs is considerably prolonged. Their influence is probably hormonal in nature, since a grafted uterus can be sensitised.

The presence of a functioning corpus luteum is essential for the maintenance of pregnancy, or at any rate its greater part. In unilaterally sterilised mice, removal of the ovary containing the corpora

invariably resulted in abortion, whilst removal of the sterile ovary was without effect: hence the presence of ovarian tissue *per se* is without influence on pregnancy, the corpus luteum being the essential organ (Parkes). In the cow the corpus can be expressed manually: its removal results in abortion within a few days (O. Zallmann, *Publ. biol. Haute École Vét.*, Brno, vol. 1, p. 255; 1922). Towards the end of pregnancy the corpora lutea atrophy; evidence has been brought forward which suggests that during pregnancy the sensitivity of the uterus towards the oxytocic principle of the posterior lobe of the pituitary gland is diminished and returns to normal when the corpora atrophy: also injection of extracts, obtained from ovaries at the end of pregnancy, stimulate the secretion of this hormone, suggesting a mechanism whereby the corpus luteum both maintains pregnancy and allows parturition at the proper time.

The presence of functioning corpora lutea is associated with a degree of mammary gland development which is not observed in their absence, but it is not yet certain whether this stimulus alone suffices to bring these glands to complete lactation: it is possible that some product of conception is necessary for the final development. E. Homann has suggested that the uterus plays a part in the development of the mammary glands (*Berich. Naturforsch. Gesellsch. Freiburg*, vol. 26, p. 289; 1926).

(To be continued.)

Infra-red Spectra.¹

By Sir ROBERT ROBERTSON, K.B.E., F.R.S.

HISTORICAL.

IN the year 1800 the elder Herschel, by placing a thermometer in the region lying beyond the visible red of the solar spectrum, gave the first experimental proof of the existence of radiation there by observing a rise in temperature of the instrument, and his son in 1840 described the existence of emission bands in the same region as shown by a discontinuous evaporation of alcohol from blackened paper placed in the same region.

To illustrate action beyond the visible red of the spectrum the following experiment was made. As it was impracticable to use the sun's spectrum, the beam from an arc lamp was dispersed by means of a large rock-salt prism, giving the usual spectrum visible to the eye. A card on which a phosphorescent powder (calcium sulphide with nickel as impurity) was first caused to glow brightly by subjection outside the theatre to ultra-violet light from a mercury lamp and then placed in the spectrum, when the existence of radiation beyond the visible was shown by the quenching of the phosphorescence for some distance past the red.

This region of the spectrum attracted much interest from the middle of last century and onwards when instruments of increasingly refined character were evolved to detect and measure effects of emission and absorption of radiation

there. Thus photography was tried, and Abney succeeded in penetrating the region for a short distance, which has not been exceeded by more recent workers employing special sensitizers for their plates. Langley with the bolometer, Boys with the radiomicrometer, and Coblentz with the thermopile, succeeded in measuring quantitatively radiation in the infra-red; the last two instruments are the principal ones employed to-day in that region which lies nearest to the visible. Still farther out, measurement of the energy in the beam dispersed by means of reflection from the polished surface of crystals gave important results in the hands of Rubens and his colleagues, while within the last year Raman by an entirely different technique, to be mentioned later, has indicated how infra-red radiations can be deduced from spectroscopic measurements in the visible spectrum.

ELECTROMAGNETIC WAVES.

The relationship of the infra-red region to other parts of the spectrum was illustrated by a diagram simplified from that prepared by Dr. F. E. Smith (see "Phases of Modern Science," 1925), in which the whole range of electromagnetic waves from γ rays to the longest radio waves, and only completed in recent years, is set forth. On this diagram (Fig. 1) were indicated the respective lengths of the waves from crest to crest in each region: the cosmic rays of Millikan, supposed by him to proceed from

¹ Synopsis of the Friday evening discourse delivered on Mar. 1 at the Royal Institution.

the birth of atoms such as helium, oxygen, silicon, and iron, in the profound depths of space at the lowest extremes of temperature and pressure, of a wave-length of about $2 \times 10^{-8} \mu$ ($\mu = 0.001 \text{ mm.}$); the highly penetrative γ -rays about $4 \times 10^{-6} \mu$, which accompany radioactive change; the X-rays about $1.5 \times 10^{-5} \mu$, also penetrative of matter on account of their short wave-lengths; the ultra-violet rays, to about 0.4μ , which promote many chemical reactions; the visible spectrum, from about 0.4μ to 0.8μ ; infra-red rays, from 0.8μ to about 23μ (the near infra-red) or to 300μ (the far infra-red); heat rays and short Hertzian rays to $1 \times 10^8 \mu$; and then the rays used for wireless, the length of which may be measured in miles, 5XX, for example, being 1560 metres or about a mile long. It is a characteristic of all these waves, from the shortest to the longest, that they are propagated at the same speed, the speed of visible light, or 186,000 miles a second.

The clue to the properties of these waves was found by Faraday when he discovered rotation of

tion with a galvanometer for measuring the energy passing through the instrument. Its sensitiveness was illustrated by allowing a little compressed air to enter a sealed bell-jar containing the instrument, when by adiabatic compression of the air, the heat generated was registered by movement of a spot of light from a Moll galvanometer.

An experiment was then performed to illustrate the method of mapping an absorption band, ammonia being the gas employed. Two tubes were so arranged that they could alternately be thrown into the optical path between the source of radiation and the spectrometer, one tube being empty while the other contained ammonia gas. The energy passing through the respective tubes was measured by a galvanometer which threw a spot of light on a large scale on the wall of the theatre. At 1.8μ the difference between the throw of empty and gas tubes was small, but this difference increased up to 2.2μ and then decreased. These differences were noted and then plotted against wave-length on co-ordinates marked out on the

FIG. 1.—Electromagnetic waves. Velocity = 30,000,000,000 cm. per sec. = 186,000 miles per sec.

the plane of polarisation of light in the magnetic field, a discovery of which Tyndall said: "I would liken it to the Weisshorn among mountains, high, beautiful, and alone". This in turn was translated by Clerk-Maxwell into the succinct notation of mathematics, and it formed the basis of his electromagnetic theory, the foundation of modern electromechanics. Since then, the likeness in character of these electromagnetic waves has been shown by their being capable of dispersion, interference, resonance, and by many other physical properties.

As to the effects of the radiations in different parts of the spectrum, it may be said that whereas in the shorter wave-length regions comprising the γ , X-rays, and visible spectrum, these are mostly electronic, in the infra-red region the transitions are caused by changes in the oscillatory states of the atoms in the molecule or of the rotational states of the molecule itself.

QUANTITATIVE MEASUREMENT OF INFRA-RED BANDS.

Dispersion by means of a grating having been referred to, a modern infra-red spectrometer of Hilger was then described as to its respective parts, the source of radiation (a Nernst filament), the slits, the reflecting mirrors, the dispersing prism (of quartz up to 3μ , fluorite up to 8μ , of rock-salt up to 17μ , or of sylvan up to 23μ), and the thermopile. Special reference was made to the thermopile, composed of bismuth-silver couples used in conjunc-

tion with a galvanometer for measuring the energy passing through the instrument. Its sensitiveness was illustrated by allowing a little compressed air to enter a sealed bell-jar containing the instrument, when by adiabatic compression of the air, the heat generated was registered by movement of a spot of light from a Moll galvanometer.

OSCILLATION AND ROTATION BANDS.

Bands due both to oscillation of the atoms in the molecule and rotation of the molecule itself are found in the infra-red spectrum. Oscillation bands were shown by Drude, from the phenomenon of dispersion in crystals, to be necessarily present, having wave-lengths such as occur in this region of the spectrum, if certain smaller charged particles (electrons) are concerned in the ultra-violet region. As the effect is one of resonance, the atoms in a molecule respond in their vibration to radiation possessing some particular frequency, and this was illustrated by a model in which a ball suspended on a spring from the end of a light rod supported on two nodes, was made to perform vertical oscillations, whereupon a ball similarly suspended at the other end of the rod picked them up and vibrated vertically in phase with the former ball. The electronic linking between the atoms prevents their oscillation being truly sinusoidal; harmonics may therefore be expected and are in fact found.

Molecules also undergo rotation, and this effect is reflected in their infra-red spectra. The main bands are due to oscillation, but in addition the rotation of the molecule also produces bands, of a simple character in the far infra-red, but in the near infra-red as fringes superimposed on the oscillation bands. Rayleigh, assuming on the basis

of classical mechanics a Maxwellian distribution of velocities, in 1892 showed that an oscillator emitting and absorbing at a frequency ν_0 due to its oscillations alone, would, when rotating about an axis perpendicular to its line of vibration with a frequency ν_r , emit and absorb at the new frequencies $\nu_0 + \nu_r$ and $\nu_0 - \nu_r$. This seemed at first to meet the case, as in some of the early bands, such as those of Burmeister, two broad areas occurred which the Maxwellian distribution of rotational velocities would require. In 1911, however, Nernst concluded that rotation must also be quantised, and in 1912 Bjerrum and E. v. Bahr resolved a band of hydrogen chloride into a series of small bands, which they ascribed to the effects of rotation of the molecule. This band has been better resolved by Ines and others, and from the spacing of the fringes the diameter of the molecule of hydrogen chloride has been calculated. Sommerfeld, applying the principle of Bohr, showed that the equal spacing of the fringes is best explained by quantising the moment of momentum, so that each quantum jump represents a change in the moment of momentum. If the moment of momentum $J\omega$ is taken as a whole multiple of $h/2\pi$, $J = mh/2\pi$ and

$E_{\text{kin}} = \frac{h^2}{8\pi^2 J} m^2$, by the Bohr-Einstein conception

$$h\nu = E - E_1 = \frac{h^2}{8\pi^2 J} [m^2 - (m+1)^2] = \frac{h^2}{8\pi^2 J} (2m-1),$$

whence the space difference is $h/4\pi^2 J$, a result in accordance with facts. It will be seen that by putting the spacing difference $\Delta\nu = \frac{h}{4\pi^2 J}$, the moment of inertia of the molecule can be calculated, and, from the moment of inertia, given the masses of the vibrating atoms, the length of the molecule.

INFORMATION GIVEN BY INFRA-RED SPECTRA.

In the first place, we get the frequency of oscillation of the atoms within the molecule, and the frequency of rotation of the molecule itself. These have been shown for a simple molecule such as that of hydrogen chloride. In addition, with more complicated molecules, it is possible to construct models by taking into consideration the presence of absorption bands and assuming a law of force between the atoms in the molecule. Thus Hund considers that ammonia has a tetrahedral structure, and this is probably also the case with the analogous phosphine and arsine. With these gases at least three sequences of bands have been found in each, corresponding with three degrees of freedom of oscillation, one of the sequences in each gas having five or six harmonics. In this sequence the frequency of vibration gets slower as the weight of the atoms nitrogen $\rightarrow$ phosphorus $\rightarrow$ arsenic increases in the three gases.

It is interesting from the chemical point of view to see if any of these degrees of freedom correspond to the chemical bonds of the chemists, and some hint of this is obtained in one case at least. Thus by progressively substituting the H in NH_3 by CH_3 , a certain band—the first harmonic of the

main sequence mentioned above—disappears from the spectrum after the last H has been substituted, so this degree of freedom of oscillation has been identified as connected with the chemical bond N-H.

Again, as regards rotation, we have found two moments of inertia in ammonia, of which one can be attributed to rotation round the median line and the other round the centre of mass at right angles to the median line. Calculation of the length of the molecule, as above described, gives a value similar to, although somewhat smaller than that obtained by Rankine from measurements of viscosity of this gas. By the comparison of spectra of related compounds, as for example in the case of hydrocarbons, definite bands have been attributed to certain groups or radicles. In the case of solids, certain groupings such as NH_4^+ or CO_3^{--} have similarly been identified in the spectrum of salts.

In the hands of Coblentz, infra-red data and technique have been used to determine the quantity of radiation from the sun, stars, and planets, and he has also deduced the temperatures which prevail in these bodies, and even the differences in radiation from the hemispheres of Mars.

The knowledge of the infra-red spectrum of water vapour and of carbon dioxide is of importance in considering the nature and quality of energy reaching us from the sun, and only recently Dr. G. C. Simpson, by making use of the absorption coefficients of water and carbon dioxide in the infra-red, has deduced that an increase in solar radiation would result in increased cloud and precipitation, and even in the apparent paradox of an ice age. Further, Paschen's determination of the emission and absorption bands of these gases is fundamental in questions relating to combustion.

FUTURE WORK IN THE INFRA-RED.

Such are some of the results that spring from the consideration of infra-red spectra. On the more theoretical side it has thrown light on and given support to the quantum theory. It has passed into the hands of the still more modern exponents of the wave mechanics and found to be in accord with their predictions, as for example in connexion with the assumption of half-quantum numbers. This is a field in which its usefulness is only beginning.

Only last year, Prof. Raman of Calcutta, by imposing monochromatic radiation from a mercury lamp on gases and liquids, observed spectroscopically in the scattered light not only the original line but also others at frequency differences which he finds are equal to frequencies in the infra-red at which bands characteristic of the gas or liquid were known. This brilliant experimental confirmation of the quantum theory may prove of the highest importance from a theoretical point of view when it comes to be explained why in the Raman effect not all the bands found in the infra-red by the usual means appear, and why others appear to be disclosed only by the Raman effect.

Like the X-rays, the infra-red deals with the

structure of the molecule, but while X-rays reveal the molecule in its static condition and are especially applicable to solids, infra-red spectra reveal the dynamic characteristics of the molecule in gases, liquids, and to a restricted degree in solids. In the future it will undoubtedly be used to a greater extent in the determination of the nature of chemical linkages and generally for a solution of problems of chemical constitution.

As Garner and his school have shown, important deductions can be made as to the rôle of infra-red radiation in combustion, as for example in the effect of water, when it is present, in carrying off the energy of radiation produced when carbon monoxide combines with oxygen, and as the bulk of the radiation from flames is in the invisible part of the spectrum and mainly in the infra-red, there is here a wide field of work in clearing up the mystery of flame, and the same is true as regards the phenomena of explosion of both gaseous and solid explosives.

It is to be regretted, however, that more work is not being done in Great Britain in the exploration of this region. It is true that the technique is difficult, and there have been several investigations reported of an accuracy that leaves a good deal to be desired. Most of the work until now has been done in Germany and in the United States,

little having so far come from British universities with the exception of Cambridge, where there is an embryonic school. The subject is perhaps scarcely one suitable for a young graduate to acquire the technique and embody a year's work in a thesis for some degree, but one for a more permanent staff, and I should like to make a plea for its greater consideration in Great Britain, as a field of experiment and study likely to assist in the solution of many physical and chemical problems, which in due course will have its reflection in the domain of technical application.

Sir J. J. Thomson has given us the electron, Rutherford the proton with its planetary electrons and the structure of the proton, the Braggs have elucidated the structure of many molecular fabrics, but the molecule as a dynamical entity has been comparatively neglected. For it is in the infra-red region of the spectrum that this behaviour can best be studied. In this aspect the problem is a physical one for the most part; the technique is difficult, but likely to be productive of much that is important in our conception of the structure of matter. It is for this reason that one would like to see in Britain a strong school arise which would have as its object the study of the dynamical behaviour of the atoms in the molecule and of the molecule itself.

Obituary.

PROF. WILLIAM KÜSTER.

DR. WILLIAM KÜSTER, professor of organic chemistry and technology at the Technische Hochschule in Stuttgart died suddenly on Mar. 5 of heart failure. From the pages of a recent issue of the *Chemiker-Zeitung* we glean the following details of his career.

Born at Leipzig in 1863, Küster received his early education in Berlin and studied later at the Universities of Tübingen, Berlin, and Leipzig. At Leipzig he worked under the direction of Wislicenus, with whom he remained for a while after graduation until he was appointed assistant to Hüfner at Tübingen, where he was given charge of the practical chemistry classes for medical students. In 1894 he published his first paper on salts of hæmatin. This was followed by an intensive study of the pigments of blood and bile, subjects which he made peculiarly his own and remained his chief interest throughout life.

In 1903, Küster was appointed professor of chemistry and pharmacology at the veterinary college at Stuttgart and lecturer on pharmaceutical chemistry at the Technische Hochschule. The duties attached to these offices were so burdensome that but little time was available for research. Moreover, at the veterinary college he found that no provision had been made by his predecessor for experimental work. In spite of these difficulties he succeeded during the next eleven years in publishing numerous papers on hæmatin, porphyrin, pyrrole, and bile-pigments.

On the retirement of Prof. C. von Hell, the de-

partment of chemistry at the Technische Hochschule at Stuttgart was completely reorganised and Küster was appointed to the chair of organic chemistry and technology. Under his direction the department was greatly enlarged, and in spite of the difficult nature of the work in which he was engaged, he attracted a great number of research students to assist him in his investigations. In this way Küster and his collaborators were able to make a large number of important contributions in the field of biochemistry. Later his interest extended to other branches of natural products such as sugar, albumen, lignin, etc. He also contributed to the well-known handbooks of Abderhalden and Thoms.

WE regret to announce the following deaths:

Prof. Jules Cornet, the distinguished geologist and professor in the University of Ghent and at the School of Mines at Mons, *correspondant* of the Paris Academy of Sciences, who was well known for his geological explorations in the Congo in 1892 and 1895, on May 17.

Mr. Stewart Culin, curator of ethnology in the Museum of the Brooklyn Institute, Brooklyn, N.Y., known especially for his comparative studies of the games of North American Indians and other races, on April 8, aged seventy years.

Prof. Charles Deperét, professor of geology in the University of Lyons and a foreign correspondent of the Geological Society of London, on May 17, aged seventy-four years.

M. Ulysse Gayon, a distinguished biologist and chemist, and honorary doyen of the Faculty of Sciences at Bordeaux, aged eighty-three years.