though they realize equally that Darwin's argument in "Animals and Plants" is not essential to the theory and may be removed without weakening the general structure in any way.

Finally we come to Lyssenko's condemnation and rejection of what he calls "Morganism-Mendelism". We can see that it arises from a failure to realize the relations of genetical development and the breeder's requirements. He says, in effect, that genetics is useless to the breeder and therefore should be abolished. But astronomy is of no great use to the breeder and yet we do not consider abolishing that science. The real situation is that the particulate and the chromosome theories of heredity are founded on a vast body of fact. They have been tested and re-tested, but never found wanting. Nor has Lyssenko himself any evidence of their alleged unsoundness, though he may have plenty of their faulty interpretation by geneticists themselves and by others. As a case to point, we may take his rejection of pure-line theory on the basis of his observation that intra-varietal variation exists in self-fertilizing cereals. The existence of such variation cannot in fact vitiate pure-line theory. Indeed Johannsen himself envisaged this very type of variability²². It does, however, show that the application of the theory was faulty because, as Lyssenko discusses it, both mutation and the small amount of out-crossing, known to occur in wheat, oats, etc., are overlooked. It is to the investigation of these agents that attention should be turned, rather than to the alleged unsoundness of misapplied genetical theory.

To call for the rejection of genetical theory is useless; for this theory is sound, no matter how disappointed we may feel that, while developing its internal structure, genetics has neglected those aspects which appeal to the breeder. What is required is experimental research on polygenic behaviour, so that genetical theory may be enlarged until the full potential value of genetics to evolutionist and breeder is realized. The task will doubtless be laborious, but the need is obvious and the opportunity great.

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ROLE OF PHOTOGRAPHY IN THE DETECTION AND MEASUREMENT OF RADIATION

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LIGHT which falls on a photographic plate causes the crystals of silver halide, which form the essential constituent of the sensitive layer, to be converted by subsequent development to silver grains, and gives rise to a blackening of the exposed areas. The silver grains can be counted under the microscope, but they provide no direct measure of the incident energy. Although much painstaking work, culminating in the recent theory of Gurney and Mott, has led to a fairly complete understanding of the mechanism of the photographic process, many factors enter in to prevent the establishment of a one-to-one, or other simple, relationship between silver grains and absorbed quanta. Thus the photographic plate cannot be used as a method of absolute measurement of radiation: like the part played by the eye in visual photometry, its role is that of a null instrument for the measurement of an unknown source of radiation by comparison with a known. In addition, and unlike the eye, it provides a permanent record of brightness variations, often over an extended field.

How the photographic plate compares in sensitivity with the eye is a question often asked, and one to which no simple answer can be given. Objects of sufficient brightness to be seen at a glance require an exposure of several minutes to be recorded when a photograph is taken using lenses at present available; yet the existence of distant nebulae is known only through the use of photography. The photographic plate can integrate radiation falling on it over long periods of time, and it is this ability which constitutes one of its greatest advantages, notably in stellar photography and astrophysics. Moreover, it can be used over a far greater wave-length range than the eye; the recording of ultra-violet lines of spectra provided one of its earliest triumphs; its sensitivity extends into the infra-red; and the great convenience of obtaining a record of the many lines of a source, which may be varying rapidly in intensity, has caused the almost universal use of photography in spectroscopy. X-rays were discovered by their action on the photographic plate, which is sensitive also to γ -rays, cosmic rays, electrons and nuclear particles. Over this wide range, comparative intensity measurements can be made. The accuracy attainable depends on the physicist's knowledge of the characteristics and behaviour of the photographic material and on his ingenuity in devising methods which reduce to a minimum the effect of the many possible sources of error. Under favourable conditions, accuracy of the same order as that possible in visual photometry can be obtained.

The light-sensitive unit is the silver halide crystal. The crystals are usually silver bromide, or mixed crystals of silver bromide with a small percentage of silver iodide, and are of the order of a micron in size. After exposure to light they suffer no visible change, but the affected crystals are completely converted to metallic silver by immersion in certain

* Substance of a lecture delivered to a joint meeting of the London and Home Counties Branch, Institute of Physics, and the Royal Photographic Society on Feb. 24.

reducing solutions known as developers, and are said, therefore, to contain a latent image. Since the conversion of any crystal to silver is complete, it is not surprising that the fastest photographic materials are those with the largest crystals; but departures are found, and size is not the only determining factor in sensitivity. The silver halides are conductors of electricity. In the dark the conductivity is ionic: it is temperature-sensitive, and at low temperatures falls to zero. On exposure to light there is conductivity at all temperatures, caused by the liberation of electrons; these tend to congregate at any point of low potential energy and to set up a field. Interstitial silver ions, which, ejected by thermal agitation from their lattice position, are responsible for the ionic conductivity, are attracted to the point and form there a speck of silver. This is the latent image which catalyses the process of development.

Thus, sensitivity depends upon the presence of nucleating centres in the crystals before exposure. Without these centres, which are produced in the course of manufacture and are believed to consist of minute traces of silver sulphide, the halide crystals are comparatively insensitive. It is this two-stage process in the formation of the latent image—the release of electrons and the subsequent attraction of silver ions—which is responsible for many of the complex phenomena that are observed. Any radiation that is absorbed will cause the formation of a latent image. The natural absorption of silver bromide is restricted to the blue and ultra-violet, where it is finally limited by the absorption of the gelatin in which the crystals are suspended. The addition of traces of sensitizing dyes results in the formation of a monomolecular coating of the crystals, and the energy absorbed by the dyes is passed on and utilized; in this way the sensitivity has been extended to a wave-length of 1.3μ ; theoretical considerations indicate that an upper limit will be set at about 2μ by thermal energy. The number of quanta required to produce a latent image is not known with any certainty; it probably varies from a few to many hundreds; and the crystals are found to vary widely in sensitivity even when their size is constant, an effect attributable to the need of a suitable nucleating centre. By comparison, high-energy quanta, X-rays, electrons, etc., appear to cause developability upon a single impact.

The photographic effect is conveniently measured by the density of the layer after development and drying. This is defined as the common logarithm of the reciprocal of the transmission, and bears no simple relationship to the number of grains, depending as it does upon size of the grains and upon the method of measurement. Although the silver grains are black, they scatter light appreciably; and the measured density depends to a considerable extent upon the proportion of the scattered light which is collected by the measuring instrument. The effects of exposure and development are usually represented by plotting the density as a function of the logarithm of the exposure; this results in the well-known S-shaped characteristic curve. The position of this curve with respect to the logarithm of exposure axis represents the 'speed' of the photographic material.

Since different materials differ also in the shape of their characteristic curves, the measurement of speed depends to a great extent upon the convention adopted; the choice will be governed by the purpose for which the measurement is required; in spectrography, for example, the reciprocal of the exposure to produce a density of 0.6 is often taken as a con-

venient measure. The slope of the curve determines the ability of the plate to reveal small object brightness differences; and, by the use of recording materials of high 'contrast', differences of brightness which are invisible can be readily recorded. The shape and position of the curve depend both upon the conditions of exposure and of development, so that it is characteristic of the photographic material in only a limited sense. With increase in the time or temperature of development, the curve increases in slope and tends to shift laterally towards lower exposure values as more and more grains become developed: in general, both contrast and speed increase.

Change of absorption with wave-length can cause the slope of the characteristic curve to change; exposure to ultra-violet light, which is strongly absorbed, leads to curves of much lower slope. The time of exposure is a factor of great importance. The photographic plate is not a perfect integrator of radiation: an x -times reduction in intensity cannot be made up for by an x -times increase in exposure time. Thus intensity and time are not reciprocal quantities, and the photographic plate is said to show failure of the 'reciprocity law'. If, therefore, the logarithm of the exposure (intensity $\times$ time) necessary to produce a given density is plotted as a function of exposure time, instead of a horizontal straight line being obtained, the curve passes through a minimum, which, with many materials, occurs at times of the order of 1 second. At both shorter times (higher intensities) and longer times (lower intensities), more exposure is necessary to produce the given result.

These departures, which are of great importance in many problems of photographic photometry, are the direct result of the two-stage formation of the latent image. At high intensities, the second stage—the moving up of the silver ions—does not take place quickly enough; the capacity of the nucleating centres for electrons is limited; some are repelled before they are neutralized by the silver ions, and the size of the silver speck is therefore reduced. At low intensities, the nucleating centres build up slowly: in the early stages of their growth they are not stable and tend to lose electrons by thermal agitation; considering the same total number of quanta incident on a crystal, the greater the rate at which they are received the greater their effect. In the extreme case, unless the rate of reception of quanta is more than sufficient to counterbalance the loss by thermal agitation, no duration of exposure will give a photographic effect. Thus, in astronomy, success depends upon the size of the telescope used, since this governs the brightness of the stellar image; prolonged exposure with small telescopes fails to reveal the fainter stars detectable by larger instruments. The shape of the so-called reciprocity curve can be modified in several ways. If the temperature is lowered during exposure, the mobility of the silver ions is decreased and the sensitivity at high intensities is thereby decreased, but at low intensities the sensitivity is increased, since the latent image becomes more stable. Use has been made of this effect in astronomy, and plates have been cooled to a temperature of solid carbon dioxide during exposure in order to increase their sensitivity.

The addition of a uniform exposure has interesting and useful results. The sensitivity of the plate may be increased either by a uniform exposure before the camera exposure or after it, depending upon the

actual time of the camera exposure; when this is long, as in the photography of faint celestial objects, the sensitizing exposure must take place beforehand and must consist in a short flashing of the plate; when the camera exposure is relatively short, the uniform exposure must follow and must be to a low intensity for a long time. In either case, the added exposure is adjusted in amount to produce only a small general fogging which does not greatly affect the interpretation of the record. Uniform after-exposure or pre-exposure can thus be useful, if applied deliberately; but equally they may lead to serious errors if they occur accidentally and pass unrecognized.

A manifestation of reciprocity failure that has long been recognized as a source of error in photographic photometry is the intermittency effect: an exposure given intermittently may produce a greater, or lesser, density than when the same total exposure is received continuously. Quite recently it has been shown that, if the interruptions are sufficiently rapid, the effect is the same as that produced by a continuous exposure of an intensity equal to the *average* intensity of the intermittent exposure. The frequency of interruptions must be so high that on the average each grain receives only one quantum during each separate exposure. Owing to the small size of the grains, the critical frequency is not as high as might be imagined: an exposure of one second duration need be interrupted at a rate of only a hundred per second. From being a source of error, valuable use can now be made of the effect: by rotating sectors at high speed, variations in time can be converted effectively into variations in intensity. Apart from the occasional advantages that can be made of these effects of reciprocity failure, the fact of importance in photographic photometry is that the calibrating exposure should always be of the same duration as the exposure to the unknown source. There are only two exceptions to this rule: X-rays, and other high energy quanta, because they make a grain developable by a single impact, show no reciprocity failure; the $\log I t / \log t$ curves for different wave-lengths are always parallel. If, then, during the process of calibration, one spectrum line is reduced in intensity until it matches in density another line of the same spectrum, the relative energy of which is known, the result will be independent of the exposure time; so that, in certain cases, the calibrating exposure need not be of the same duration as the unknown.

The general rules of photographic photometry follow readily from what has been said. The calibrating exposure should always be impressed on the plate used for recording the unknown radiation, so that errors of development may be reduced. Whenever possible, the two exposures should be made on contiguous areas, since the plate may show small local variations in sensitivity. The spectral composition of the calibrating radiation should be identical to that of the unknown radiation, although in spectrophotometry within narrow spectral regions it is permissible to use a mean wave-length for the calibrating radiation, for example, by the use of sharp cutting filters. The time of exposure must be the same for both exposures, apart from the two exceptions mentioned.

It has been assumed that the exposed areas are large and that edge effects can therefore be neglected: the sensitive layer has been imagined to be a two-dimensional continuum, and any effects caused by its finite thickness have been ignored. During the course of manufacture, the photographic 'emulsion',

which is a suspension of silver halide in a solution of gelatin, is coated evenly on to its support, and dries down to form a layer about one thousandth of an inch in thickness. During development, the layer swells to some five times this thickness. The images to be recorded are often of comparable dimensions, for example, the image of a star or of a spectral line; and second-order effects arise, owing both to the penetration of the light and the penetration of the developer. The light is strongly scattered on entering the layer, and a sideways spreading of the image results: the developer solution reaches the grains by diffusion, and the products of the chemical reaction diffuse outwards; they inhibit the reaction and produce local variations which may sometimes cause the density distribution of an image to depart seriously from its true form. Full development and vigorous agitation of the developing solution over the surface of the plate will generally reduce these effects to negligible proportions; but the effect of light scatter is not so easily overcome. Use can sometimes be made of this, as in astrophysics, where the growth of the image with exposure is used as a measure of stellar magnitude. More often the scatter tends to destroy the fine detail of the image, and can be limited only by the best choice of materials. The effect depends both on the grain size and the number of grains per unit volume of the layer, as well as on the wave-length of the light; and the finest grain emulsions are not necessarily those which scatter least. The discrete nature of the developed image also plays a part in the detection of fine detail. A microdensitometer record of a uniformly exposed and developed area shows irregularities caused by this granularity of the image; variations due to this cause will be superimposed on those which are the subject of investigation, and will tend to mask them. The graininess increases both with the density of the image and with the size of the grains; its effect on visibility tends to outweigh that of light scatter, so that slower emulsions almost invariably have greater resolving power than faster ones. An additional reason is that slower emulsions generally have higher contrast, and this naturally increases the ability to differentiate small brightness differences.

It is not surprising that an almost bewildering array of photographic materials is available. The choice must depend upon the problem in hand. Sometimes the need is for high resolving power and for low graininess; at other times, these desirable features must be sacrificed for extreme speed for some part of the spectrum; and consequently a compromise must usually be made.

OBITUARIES

Prof. A. W. Nash

ALFRED WILLIAM NASH, professor of oil engineering and refining at the University of Birmingham, died in his fifty-sixth year at his home in Solihull on March 14. After training as a mechanical engineer at King's College, London, he had some experience in dock construction in Hong-Kong, and shortly afterwards joined the (then) Anglo-Persian Oil Company and took part in the building of the great refinery in Abadan, South Persia. In 1913 he proceeded to the Caucasian oil territory and remained in Russia for more than five years, chiefly engaged in field production problems.