THE BRITISH JOURNAL OF OPHTHALMOLOGY

FEBRUARY, 1934

COMMUNICATIONS

DATA CONCERNING RADIATION AND PROTECTIVE GLASSES WITH A NOTE ON RETINOSCOPES

BY

A. RUGG-GUNN

LONDON

THE publication in 1914 of a paper by Sir William Crookes proved the starting-point of a change in the attitude of the lay public towards protective glasses. Since that date, popular taste in regard to the proper enjoyment of leisure has developed along lines that call for, or appear to call for, some measure of protection for the eyes. The recreations of all classes and both sexes now include long walks, sun-bathing, winter sports, and Mediterranean cruises. Expeditions to the Sahara, exploration of the Arctic, and long-distance flying may almost be termed fashionable. The extended use of radiation in therapeutics, and, not least, constant and persuasive advertising are other factors which have stimulated an ever-increasing demand. Glass manufacturers, particularly abroad, have not been slow to respond. The industry at the present time has attained to considerable proportions. It provides the prescribing surgeon with an embarrassingly rich selection of types, and circulates an extensive trade literature. The position, however, is far from satisfactory. The available literature, being very largely derived from manufacturers and agents, is anything but disinterested. The claims preferred for a particular glass as a rule bear little relation to

its intrinsic merits. Nearly all the widely advertised glasses are of unknown composition, and the latter is not always uniform. There is no certainty, except in one or two instances, that, after the initial supply is exhausted, a new glass can be repeated, as successive melts, or even different parts of the same melt, may possess very different properties. Few of the glasses are made in the British Isles, so that contact between the actual maker and the lens manufacturer or dispensing optician is not very intimate. In almost every instance there is an entire absence of standardization; nor is there any general agreement as to the best standard to adopt. As the composition of each glass is almost invariably a trade secret, and analysis, both chemical and spectroscopic, is tedious, the prescriber is actually in a position similar to that of a physician who had to depend exclusively on a pharmacopoeia of patent remedies. The aim of the present paper, as its title implies, is to assemble the data relating to radiation on the one hand and to the more important types of protective glass on the other, and to attempt to analyse the factors against which protection is desirable and the means at our disposal for ensuring it.

I.—Radiation

Some acquaintance with modern theories concerning the ultimate constitution of matter is indispensable to the study of radiant energy and its effect on living and other substances. The basis of these conceptions is the Rutherford-Bohr theory of atomic structure, which defines the atom in its simplest form as a central, positively charged nucleus surrounded by a cluster of negative electrons which describe circles or Kepler ellipses with the nucleus as focus. In this atom-model a planetary electron rotates in its orbit without the emission or absorption of energy. When, however, an atom is subjected to a field of radiation from an outside source, the energy, not of the light but of its frequency or wave-length, may drive an electron from its orbit. That electron then passes suddenly into another orbit, either nearer the central nucleus or further from it. When this transition takes place from one orbit to another, energy is radiated or absorbed, according to the direction of the transition, in the form of an energy-quantum of homogeneous, monochromatic light. Absorption and radiation are completely reciprocal processes, of essentially the same nature but proceeding in opposite directions. The frequency is just the same for both and only this frequency can effect the transition. Transition from an orbit of low energy level to one of high means absorption; transition from one of high to low means radiation. In the latter case the surplus energy left over, after that expended on the jump, becomes available and is transmuted into a light quantum.

Electromagnetic Radiation

As a preliminary to the consideration of the more restricted field of solar radiation, the whole range of electromagnetic radiation, so far as at present known, is set forth in the following table, with approximate values for the wave-lengths of the several regions. This assignment is, of course, somewhat arbitrary. The energy represented by electromagnetic waves is termed radiant energy.

				Wave-length*
Cosmic (ultra-gamma) ray	...	...	...	0.001 Å
Gamma ray from radium	...	...	...	0.01 to 0.1 Å
X-ray	...	...	...	0.1 to 50 Å
Millikan—Osgood region	...	...	...	200 Å
Lyman region	...	...	...	600 Å
Schumann region	...	...	...	1,300 Å
Ultra-violet	...	...	...	1,850 to 3,900 Å
Violet	...	...	...	3,900 to 4,240 Å
Blue	...	...	...	4,240 to 4,920 Å
Green	...	...	...	4,920 to 5,350 Å
Yellow	...	...	...	5,350 to 5,860 Å
Orange	...	...	...	5,860 to 6,470 Å
Red	...	...	...	6,470 to 7,500 Å
Infra-red	}	...	...	7,500 to 3×10^6 Å
Rest-strahlen				
Electric waves	...	...	...	3×10^6 to 10^7 Å
Hertzian waves	...	...	...	10^7 to 10^{13} Å

Solar Radiation

The quality of solar radiation is about that of a black-body at a temperature of $6,000^\circ\text{C}$. or $10,000^\circ\text{F}$. This may be taken as the effective temperature of the sun, although that of its centre on account of enormously high pressure is estimated at 30 to 60 million degrees. The limits of the solar spectrum received on the earth's surface may be said to lie between 30,000 Å in the infra-red and 2,915 Å to 2,900 Å in the ultra-violet (Miethe and Lehmann; Dobson). Langley (1883) found that the solar spectrum could be followed in the infra-red to 180,000 Å though it became very faint after 50,000 Å. (Fig. 1.)

* Throughout this paper wave-lengths are expressed in Ångström Units (Å). Each Ångström unit is equal to one ten-millionth of a millimetre, i.e., 10^{-8} cms.

FIG. 1.

Curve showing distribution of energy in the solar spectrum, after Langley.

In estimating the transmission through the atmosphere of direct light from the sun it is commonly said that the noon-day sun passes through a depth of one atmosphere and a low sun through a depth of two atmospheres. As the air is not of uniform density throughout, the ratio of the two masses of air encountered is greater than the ratio of the lengths of the two paths. The ratio of the two

FIG. 2.

Ratio of value of masses of air for the sun in the zenith and on the horizon.

values of the mass of air for the sun in the zenith and on the horizon is 1 : 35.5. (Fig. 2.) The main constituents of the atmosphere responsible for absorption and diffusion of solar radiation are oxygen, ozone, carbon dioxide, water-vapour and dust particles, including smoke. Even a clear atmosphere takes up from 40 per cent. to 50 per cent. of the sunlight—30 per cent. at the zenith and 75 per cent. at the horizon.

Ultra-violet Rays.—From the stratosphere or region of the aurora borealis to the surface of the earth the limiting wave-length of the ultra-violet spectrum recedes from 1,350 Å to 2,900 Å or 2915 Å. The opacity of the atmosphere to short-waved ultra-violet is due, partly, to absorption by oxygen and ozone and, partly, to reflection and scattering. Probably quite three-fourths of the total radiation

received from sun and sky is diffused by reflection from surfaces and large particles and scattered by air molecules, liquid particles and fine dust. Surfaces, *e.g.* clouds, cause regular reflection and affect all waves; large particles give rise to diffuse reflection and also affect all waves; fine particles cause scattering and affect short waves only. The more minute the particle the more selective the scattering. Scattering of light is inversely proportional in degree to the fourth power of the wave-length (λ^{-4}), hence extreme violet

FIG. 3.

Relative spectral distribution of radiant power in D. black-body at 5000° abs. — approximately sunlight. E. Blue sky.

Relative visibility curve for the average human eye. L.V. Source with constant radiant power throughout the visible spectrum. L.E. Blue sky. Gibson and McNicholas.

and ultra-violet rays are diffused 16 times as much as extreme red. This accounts for the blue colour of the sky. When the sun is directly overhead the indirect ultra-violet radiation from the blue sky is 15 per cent. stronger than that direct from the sun. (Fig. 3.)

The total atmospheric content of short-waved radiation is increased by certain atmospheric conditions, *e.g.*, the fine haze of cirrus clouds, which consists of ice needles; by reflection from the earth; and by altitude. Snow and ice, sea and, to a less extent, sand are all good reflectors. As much as 70 per cent. of light may be reflected by snow; even more from snow with a slightly frozen surface. Dry sand and light-coloured rocks can reflect 30 per cent. and grass-land, crops, etc., 15 per cent. Water is almost as good a

reflector as snow for short-wave radiation, so that diffuse light is particularly intense at the sea-side.

Although there is no selective ultra-violet absorption with decrease of altitude, there is a very definite variation in ultra-violet intensity. The zones below 4,000 ft. and the zones above 6,000 ft. are very different. The former do not differ materially from sea-level with regard to intensity of insolation. At 8,000 ft., however, we have left below about a quarter of the mass of the atmosphere, usually about half of the atmospheric vapour, and more than half of the suspended dust.

Insolation intensity is one of the most prominent features of tropical climates. The glare experienced when travelling or flying over deserts or large tracts of dusty, rocky or sandy soil with little or no vegetation is not strictly analogous to that experienced from haze on an antarctic snow-field. Sand and dust have not the regular reflective properties of snow and ice. They reflect diffusely and the relatively gross particles exercise less selective scattering. Tropical glare is the resultant of long-wave radiation from heated rocks and sand, diffuse luminous reflection and diffuse ultra-violet reflection. That is to say, the relative intensity of ultra-violet radiation in the diffuse light spectrum under desert conditions is much less than that of blue sky or snow fields. True ultra-violet conjunctivitis in the tropics, apart from that experienced on snow-covered mountain ranges, is rather infrequent and not very severe. Chronic conjunctivitis of another type, however, is relatively common.

The following brief description of "snow-blindness" is based on notes of an attack experienced by the writer in the high Himalayas, amplified by information kindly placed at his disposal by Dr. G. Murray Levick, who was a member of Captain Scott's last Antarctic Expedition (1910-1913). Strong sunlight with clear skies is a feature of the Antarctic summer. Captain Scott's party at Cape Evans secured a continuous record of 66 hours 25 minutes of sunshine in December, 1911. There was an average of about 14 hours a day in the summer months and the total for the year was considerably more than is experienced in England, although the sun was above the horizon on only 246 days. The risk of conjunctivitis, however, was greater on days of light haze, when the horizon was undefined and sky and snow merged into one. The commonest form of cloud is a very thin stratus consisting of ice particles, which immensely increase the ultra-violet content by scattering. In addition there is reflection from the snow. The risk is less at sea under similar conditions. One attack of conjunctivitis predisposes to others—photosensitization. The magnitude of the risk will be appreciated from the fact that during a long day's sledging under appropriate conditions, a slight crack in the sides of the goggles permitted sufficient exposure to precipitate an attack.

Symptoms develop during the evening or at night. At first there is a sensation of grittiness; later agonizing, throbbing pain. Photophobia is acute; the conjunctiva becomes red and swollen, and there is lacrimation and slight discharge. Even in mild attacks the photophobia and throbbing pain are severe. The acute stage lasts for two or three days.

To sum up: at the poles, in the tropics, at sea-level and at altitudes up to 4,000 ft., the range of the ultra-violet spectrum remains constant, extending to a wave-length of about 2,900 Å. The intensity of radiation in the ultra-violet region, on the other hand, is increased through selective dispersion and scattering by ionized particles—indirect blue sky radiation; through non-selective reflection by light clouds and atmospheric haze; and by non-selective reflection from the surface of the earth, particularly from snow and ice-fields, water and desert. The relative absence of suspended dust at altitudes of 6,000 ft. and over permits a high ultra-violet intensity in winter as well as in summer. Tropical sunlight is also characterized by high ultra-violet intensity constant throughout the year.

Infra-Red Rays.—Infra-red radiation includes rays of increasing wave-length and diminishing frequency, ranging from 7,500 Å to several millions. As observed on the earth's surface this region of the solar spectrum extends approximately from 7,500 Å to 30,000 Å. Most of the radiant energy from the sun is in the form of infra-red radiation. Of the total radiation reaching sea-level the infra-red percentage is about 56 per cent. (Kimball).

In its passage through the atmosphere infra-red radiation suffers absorption, mainly by carbon-dioxide and water vapour. The absorbing power of the latter for radiant heat is 72 times greater than that of dry air (Tyndall). This property, however, does not begin to be very serious until a wave-length of 9,000 Å to 9,500 Å is reached. The near infra-red, on the contrary, is characterized by its ability to travel great distances through hazy or misty atmospheres.

The infra-red content of the atmosphere is not well known but it does not always run parallel with the visible daylight intensity. Infra-red rays are relatively immune from scattering.

The total amount of energy which reaches the earth by radiation through space, in the long run is radiated back into space by the earth and atmosphere as long-wave radiation. The amount of energy is the same but the wave-length is longer. All the radiation given out by the earth is in the form of infra-red radiation. The earth as a radiator is similar to a black-body, its effective temperature being equal to about 253° abs. The intensity of the re-radiated energy is much less than that of the absorbed energy, probably about a quarter. Radiating efficiency depends on effective absorption. A perfect absorber is also a perfect radiator. A perfect reflector, on the other hand, can neither transmit, nor absorb, nor radiate. Lack

of vegetation increases absorbing and radiating efficiency, so that the best absorbers of solar radiation are rocks, sand and bare-ground; grasslands and forests are medium absorbers; and water, snow and ice are the worst absorbers. Air is a poor radiator. The wavelength of maximum earth radiation is between 80,000 Å and 120,000 Å, roughly 100,000 Å.

The high radiating efficiency of rocks, sand and bare-ground achieves considerable infra-red intensity in the tropics, and during the day is reinforced by regular reflection. A surface that is sufficiently rough to scatter short waves may give regular reflection of the long heat waves (Lord Rayleigh).

The energy-density distribution of radiant energy at various positions along the optical path in the eye varies according to whether the source is a point object, such as the sun in eclipse, or an extended object, such as a tank of molten glass or metal. The optical path in both examples is shown in Fig. 4. If the intensity and spectral quality of the radiation from a luminous source of large extensity are equal to those from a point source, the amount of energy that passes through the pupil in the first case is much greater than in the second and the retinal image will be equally bright throughout. The relation between the pupillary area and the illuminating source is a logarithmic one. The visual field subtends approximately a solid angle of 120° . The ratio of energy-densities in the plane of the pupil will be approximately equal to the ratio of the solid angles subtended by the sources. Therefore, in the case of an extended object the energy is concentrated in the lens; in the case of a point object on the retina. Theoretically, cataract formation from habitual exposure to infra-red and visible radiation, whether directly from action on the lens protein or indirectly from the effect on iris and ciliary body, is no more improbable than the production of a thermal lesion in the retina through gazing at the sun.

Summary: the near infra-red region from 7,500 Å to 9,000 Å is characterized by the property of haze penetration. From 9,000 Å

FIG. 4.

Transmission curve of white crown glass. A. 1.68 mm. thick. B. 2.33 mm. thick. Also relative visibility curve of the human eye for an equal energy spectrum. Gibson and McNicholas.

onward strong water-vapour absorption takes place. High infra-red intensity is associated with the decreased humidity of mountain summits and low intensity with areas near the sea even in the tropics. Earth re-radiation combined with a certain amount of regular infra-red reflection reaches a high intensity in dry tropical climates. This is at a maximum where the soil is barren of vegetation but occurs also from grassland, crops and forests. Infra-red intensity is insignificant over snow or ice-fields or surfaces of water.

Visible Rays.—The extent of the visible spectrum is a subjective phenomenon. It varies somewhat for different observers and is shortened for light of very low intensity. It may be said to extend from 8,100 Å to 7,500 Å at the red end to 3,900 Å at the violet. Within this range the distribution of intensity, which coincides with the distribution of visibility for the average eye, is by no means uniform. The greatest value* is in the region of wave-length 5,550 Å, from which it decreases rapidly to low minimum values at either end of the visible spectrum. The variation of visibility of radiation with the wave-length is a considerable one. That between wave-lengths 5,550 Å and 4,000 Å, for example, represents a very large factor, perhaps 40,000 to 60,000. Figs. 3 and 5 show, plotted in the form of a curve, the relative sensibility of the average human eye to light of different wave-lengths for an equal energy spectrum,† *i.e.*, a source emitting equal amounts of energy at all wave-lengths in the visible spectrum. Such a curve, although similar to, is not identical with the visibility curve of the human eye for the spectrum of sunlight, which may be very luminous as a whole but very weak if only a small interval of wave-length, *e.g.*, in the deep blue, be taken. The total transmission factors for sunlight, however, do not in general differ much from those for a source emitting equal amounts of energy at all wave-lengths (Gibson and McNicholas).

The sole difference between infra-red, visible and ultra-violet radiant energy is that of frequency or wave-length. All visible rays, particularly the red, orange and yellow regions possess the property of radiant heat and all visible rays, but particularly green, blue and violet possess an actinic action. Although it must be assumed that the eyes of living organisms on the surface of the earth are adapted to exposure to radiation of all wave-lengths at least not shorter than

* It is an interesting and significant fact that the wave-length of greatest energy in the solar spectrum—stellar spectra are different—*i.e.*, the wave-length with the greatest number of ergs, is also that for which the human eye has the greatest sensitivity. The absorption of visual purple (rhodopsin) in aqueous solution is at a maximum of 5,030 Å and the absorption spectrum of the photo-sensitive substance, presumably rhodopsin, in the retinal rods shows a maximum at 5,100 Å (Hecht).

† Energy curves of a light source can be determined by comparison with a black-body. The energy units can be computed from Wien's displacement equation and the colour-temperature of the source.

2,900 Å, yet there remains the possibility of depression of visual function and discomfort or even injury from excess. Intrinsic brilliancy of a high order may cause absorption of excessive energy by the media of the eye or may produce excessively bright images upon the retina. There is also the problem of glare.

It is difficult to define glare satisfactorily. Certain varieties have been described under such names as veiling glare, contrast glare, dazzling glare, brightness glare, reflection glare, etc. It may be said, however, that the sensation of glare depends on the relative distribution of brightness within the field of vision. A certain, usually limited, part of the field is excessively bright, causing interference with vision, such as a blinding effect or dazzling, or causing annoyance and discomfort, probably as a result of undue strain on the delicate mechanism which regulates the admission of light. It is evident that a light source emitting brightness of a high order of magnitude may over-stimulate the physiological mechanism of vision and upset normal retinal adaptation. An angular position of the source of light relative to the direction of vision, by tending to capture the attention or by directing light into the eye at unaccustomed angles, may cause a sensation of glare even without the factor of high intrinsic brilliancy. Too little contrast in the field of vision may be as bad as too much. With completely diffuse illumination, shadows are lacking; all specular surfaces glitter; and the general effect is unpleasant. The eye functions to the best advantage when contrasts in the field are not less than about 2 per cent. and not more than 10 per cent. The best ratio of diffuse to total light appears to be between 30 per cent. and 60 per cent. Finally, visual depression may be due to haze resulting from scattered light within the eye, as experiments have shown that this is greatest when the light falls upon the optic papilla and is reflected from it (Borschke, 1904; Cobb, 1911). As a general rule, however, glare resolves itself into specular reflection. Further, glare is a property of the visible spectrum, perhaps mainly of the region of wave-length 5,550 Å, which has been shown to be the region of maximum energy. It has nothing to do with either ultra-violet or infra-red rays.

The phenomenon of specular reflection is pertinent to the present discussion. It is characterized by the fact that the incident beam, the reflected beam and the normal to the surface at the point of impact all lie in the same plane. Any surface can be made specularly reflecting to a beam of light if the height of the inequalities of the surface projected on the beam direction is less than one wave-length. Even a dead black surface reflects well at grazing incidence. Thus, a piece of smoked glass, which at perpendicular incidence will not reflect light, *e.g.*, from a lamp, gives a clear reflected image at near grazing incidence. The colour of the image

is at first red but becomes white as the glancing angle, *i.e.*, the angle between the impinging beam and the plane of the surface, is decreased. If θ_0 is the glancing angle, the condition for specular reflection is $h \sin \theta_0 \sim \lambda$, where h is the average height of the inequalities on the surface. The inequalities on the most perfect possible mechanically polished surface are of the order 10^{-5} cm.

In 1808 Malus discovered that when light is reflected at a particular angle from the surface of water, glass or almost any other except metallic substances, it is nearly completely polarized in the plane of incidence. This particular angle of incidence is called the polarizing angle and at this angle the reflected and refracted rays are at right angles to one another. The degree of polarization of the reflected rays varies with the angle of incidence and is at a maximum at the polarizing angle. This angle is not the same for all substances. It varies with their refractive index according to Brewster's law,* and, in general, the most effective angle of reflection is greater, the greater the refractive index. Not only is the reflected ray partly polarized but the refracted ray also, though in a lesser degree.

Polarized light behaves at reflection in an essentially different manner from ordinary light. As has already been seen the reflected intensity of ordinary light increases with increasing angle of incidence up to grazing incidence. That of polarized light reaches a minimum at the polarizing angle and increases as the angle is increased.

The surface reflection from a sheet of rough water, *e.g.*, a river, illuminated by both sun and sky, prevents the eye from seeing into its depths. If, however, we view the water through a plate of tourmaline cut parallel to the optic axis of the crystal, under certain conditions surface reflection is eliminated, the water becomes transparent; and its contents become visible to the eye. Thus, when the crystal is rotated in its own plane in front of the eye, it will be found that in one position the intensity of the reflection is unaffected. On continuing to rotate the reflected light is observed to fade and, finally, when the plate has been turned through a right angle to become extinguished. This experiment shows the surface reflection from water to be partly polarized. Actually, specularly reflected light is almost completely plane polarized; diffusely reflected light, however, is unpolarized. Blue light from the sky is also polarized. This can readily be verified by using tourmaline or a Nicol prism. Glare, in short, is largely the effect of polarized light and is present whenever the eye is so placed as to receive reflected rays at the polarizing angle. More accurately, glare, as represented by specular reflection, is a resultant of two components: (1) polarized light

*Brewster's law: $\tan i = n$, where i is the required angle of incidence and n is the index of refraction.

which is present whenever the eye is so placed as to receive reflected rays at the polarizing angle; and (2) ordinary regular reflection combined with a certain amount of diffuse reflection in all other relations of the eye to the reflected light. The intensity of the former, which is by far the more important, can be diminished only by some such instrument as a plate of tourmaline acting as an analyser; the latter perhaps only by selectively absorbing or reflecting the rays in the region of maximum energy; *i.e.*, in the yellow-green round about wave-length 5,550 Å.

II.—Protective Glasses

Glass is the result of fusing silica, generally in the form of sand, with active mineral solvents or fluxes, *e.g.*, the alkalies, such as Na or K; earthy bases such as lime or barium; or metallic oxides, such as oxide of lead. It is not a homogeneous or definite chemical compound. In a physical sense glass is a super-cooled or solid solution of a very high viscosity. It apparently consists of one or more solid phases in fine suspension in a liquid phase or in colloidal solution. The essential element is silica, SiO_2 . The acids are silicic acid, and, in optical glass, boric acid; the alkalies, Na and K, are used in the form of carbonates, sulphates or nitrates; and the other bases as barium or calcium carbonates. Sodium and potassium silicate are soluble in water, consequently, other bases, such as lead oxide, barium or lime, are added to form more insoluble combinations, such as the double silicates of soda and lime. Potassium nitrate during fusion releases oxygen and thus keeps up an oxidising action. The reactions which occur during fusion are complex and imperfectly understood. Possibly there is some formation of chemical compounds, probably of considerable molecular complexity. On the whole the absorption spectrum is that of SiO_2 .

Optical glass does not differ in composition from any other glass. It often contains lead or zinc oxide, especially in association with boric acid. The raw material must be the finest and purest obtainable. The sand must be washed free of salt, chalk and other impurities and heated to redness to destroy organic matter. It must be rendered homogeneous and fit for use in optical instruments by prolonged mechanical agitation of the molten metal. It must be free from striae, irregularities of density, bubbles and other defects, and conform to a fixed standard in respect of refractive index, density, mean dispersion and other optical constants. Probably over 90 per cent. of all the glass manufactured is composed of a combination of silica with a mixture of two bases, soda and lime.

The glass used in spectacles is ordinary white crown glass, *i.e.*, a glass of rather low refractive index, density and mean dispersion. Strictly speaking, spectacle glass is not optical glass because

mechanical agitation is not employed in its manufacture. Such a glass transmits with slight falling off all rays down to $3,500 \text{ \AA}$. After this transparency falls off rapidly to zero at about $3,000 \text{ \AA}$. Some very light crowns are a little more transparent, but any glass that transmits beyond $3,000 \text{ \AA}$ at 1 mm. thickness should be rejected. The higher the refractive index the greater the absorption of the shorter wave-lengths, therefore flint glass transmits a narrower

FIG. 5.

Energy-density distribution of radiant energy along the optical path in the eye. (1) From point object A. (2) From extended object B B.

range than crown glass, the limit being about $3,150 \text{ \AA}$. Glasses that contain metals of large atomic weight are the most absorbent of the short wave-lengths. The absence of standardization is most unsatisfactory. Spectacle glass should be standardized so as not to transmit through a thickness of 1 mm. rays shorter than at least $3150 \text{ \AA}$. White crown glass of this thickness transmits infra-red, though feebly, to about $25,000 \text{ \AA}$ — $30,000 \text{ \AA}$ (Fig. 5).

The transmission of light through glass, as through other transparent media, accords with Bouguer's law. As the rays pass through successive layers of equal thickness each layer absorbs the same fraction of the energy of the radiation that impinges upon its first surface. That is, if the first millimetre absorbs $1/10$ th of the incident radiation the next will absorb $1/10$ th of the remainder and the third $1/10$ th of what has passed through the second and so on. Hence, the first layer will have transmitted $9/10$ th; the second $(9/10)^2$; the third $(9/10)^3$; and the n^{th} $(9/10)^n$. The amount

absorbed will be the difference between I_0 and $(9/10)^n I_0$. The amount which survives to pass the n^{th} layer is $I_0 (9/10)^n$.

The relation may be expressed in the form $I = I_0 a^n$ where a represents the fraction of the incident radiation transmitted through unit thickness of the absorbing substance, glass, air, etc., and is therefore defined as the coefficient of transmission. This is a logarithmic or exponential law which may be expressed as

$$\text{Log } I - \text{log } I_0 = n \log a, \text{ or } I = I_0 e^{-kn}, \text{ where } e^{-k} = a.$$

The dependence of absorption on wave-length may modify the colour of glass in different thicknesses and will be discussed later.

Coloured Glasses.—The term "coloured" appears to be preferable to "tinted." A tinted glass is a feebly saturated coloured glass and is applicable only to a few varieties of protective glasses.

It has already been pointed out that a dead-black, rough surface absorbs infra-red rays. It also absorbs nearly every other ray that falls upon it and emits over a similarly large range of wave-lengths.* When a pigment or coloured fabric is illuminated by white light, however, some of the light is absorbed and the remainder reflected. The latter portion of the original light is the colour of the pigment. A white surface appears white only when illuminated with white light and a coloured surface shows its true colour only in white light or in light of its own colour. Thus, a red surface appears red in white or red light but almost black in green or blue, because green and blue rays are absorbed by the pigment and very little light reaches the eye. The colour of a surface is due to the non-absorbed light; the absorbed light is complementary and may initiate chemical change. The colour of a glass, on the other hand, is that of the transmitted light, and, sometimes, partly of scattered light. All glasses have some power of selective absorption, *i.e.*, all glasses are coloured, as can be seen when a sheet of glass that appears to be crystal clear is viewed edgewise. Transmission through glass is therefore always selective. The rays absorbed are roughly complementary in colour to the rays transmitted, *i.e.*, to the colour of the glass.

* Such a body when heated at first emits only dark rays. Later, at 525°C , it begins to glow visibly, first with a reddish colour, then yellowish, and finally it becomes white hot. The following digression may perhaps be pardoned because of its ophthalmological interest. In 1895 Eugen Dubois published a theory of the origin of colour blindness, regarding it as a reversion to the conditions obtaining in previous geological epochs when radiation of certain wave lengths was absent from the solar spectrum. Dubois assumed that our sun has passed through a series of stages represented now by various fixed stars. At first, there was a stage represented by blue-white stars, when radiation was more intense and the terrestrial climate warm. Next, the sun changed to yellow, radiation diminished and the earth cooled. This was during the Tertiary period and at intervals the sun passed into a third stage, intermediate between yellow and red stars, when radiation was still more feeble—the various glacial epochs of the Quaternary.

The dependence of absorption on wave-length has already been noticed. This may modify the colour of a glass according to its thickness. Thus, cobalt blue glass is moderately transparent for blue light over a broad band and very transparent for a narrow band in the deep red. If the coefficient of transmission is 0.1 for blue and 0.9 for red for a layer of 1 mm., then for 2 mm. the transmitted blue will be 0.01 and the transmitted red 0.81. For a third layer the values will be 0.001 for the blue and 0.729 for the red. Hence a layer a few millimetres in thickness is practically no longer blue but very definitely red.

In coloured glasses the pigment generally used consists of metallic oxides. These are in chemical combination; in true solution; or in fine suspension. Apparently some chemical action occurs. Some colours are obtained by the combination of two or more coloured salts, giving a great variety of shades. The colour produced varies largely with variations in the composition of the glass, and is also influenced by the conditions during melting. The more acid in character the batch, *i.e.*, the greater the proportion of silica, the more readily is oxygen evolved. Reducing furnace gases or reducing agents may destroy the colour. Some agents act in a two-fold manner by oxidising and by colouring.

The presence of metallic salts in a state of true solution is inferred because the absorption spectrum is similar for salts dissolved in fluid and in glass. The intensity of the bands varies by altering the composition of a melt in exactly the same way as by concentrating liquid solutions. The depth of the colour and, to some extent, its quality is dependent upon the concentration of the coloured silicate in the glass or, if this be constant, upon the thickness of the glass. The element may be present as the silicate or as some other compound, *e.g.*, borate, phosphate, etc., which is soluble in the glass.

The colour may also be present in colloidal suspension. Siedentopf and Szigmondy were able by oblique illumination to demonstrate the presence of non-atomic or molecular particles of gold in ruby glass.

Transparent coloured glasses may be classified according to their composition or according to their colour. The latter method is more convenient. Practically any colour of glass can be produced by manufacturers. The following notes are confined to a few selected colours but include practically all varieties of protective value.

Amber glass exists in many shades and can be produced by a variety of ingredients. One example contains black manganese dioxide (1 per cent.) and iron oxide. The manganese oxidises the iron, producing the ferric colour, so that the greenish yellow iron colour is superimposed on the violet or purple of the manganese. If the oxides are present in large amount the result is amber.

Amber may also be produced by carbon and by sulphur in colloidal

solution in the glass. The colour depends on the size and shape of the particles; the finer the division the more intense the colouring. Carbon is used as a reducing agent in the form of charcoal, coke, sawdust, even potatoes to produce other colours. In its finely divided form carbon produces a very stable amber. The sulphur colour is destroyed by oxidising agents and the best results are obtained from carbon combined with sulphates in a high alkali glass. The amber bottle of commerce is a carbon amber. Its dark colour is due to part transmission in the green.

Selenium red is the purest red known. It is a common ingredient in amber glass, because thin sections, such as are used for spectacle

FIG 6

Transmission curves of amber glass. C. Light amber. D. Dark Amber. Gibson and McNicholas.

lenses, transmit some green, resulting in a pink or orange-amber colour.

Amber glass absorbs ultra-violet completely and has high transmission in the visible; up to 85 per cent. It does not affect infra-red. Transmission curves of two specimens of amber, light and dark, are given in Fig. 6. It is also claimed that amber reduces painful glare and gives increased defining power for distant vision under conditions of blue haze, by eliminating the blue and violet rays. Normally, blue rays are out of focus at the retina. Amber causes a certain amount of distortion of colour, but, although it is asserted that interference with the colour sense has a depressing effect, amber, for most people, is rather a cheerful colour.

Yellow and greenish-yellow glasses form a distinct group. The typical yellow glass is canary glass, which has a characteristic yellow colour with a greenish fluorescence due to the presence of uranium. Uranium trioxide, UO_3 , is an acid oxide and is generally used in the form of one of its alkali salts, *e.g.*, sodium uranate, $\text{Na}_2\text{U}_2\text{O}_7 \cdot 3\text{H}_2\text{O}$ (0.5 per cent.), which gives excellent colour and fluorescence. Selenium in glass gives a peculiar yellowish rose or pink shade; cadmium sulphide, CdS , a rich yellow; vanadium confers yellow as well as green tints; and the sulphur compounds of barium produce yellow and deep green. Other yellows, *e.g.*, orange yellow, result from iron, antimony and lead oxide, although antimony is apt to be unstable; greenish yellow from praseodymium; and a clear brilliant yellow from titanium, cerium and vanadium.

Many of the glasses of this group are known under mysterious trade-names, *e.g.*, euphos, akopos (a rather dark shade of euphos); fieuzal; hallauer; saniweld; noviol; and noviweld. The last is a brownish-yellow glass, the brown probably due to nickel sulphate, which protects from ultra-violet and at the same time transmits only 1 per cent. of the infra-red from a furnace at $1,050^\circ\text{C}$. The green of fieuzal, a dark yellowish-green, is probably due to chromium, and hallauer is a combination of greenish-yellow with a smoke tint. No glass transmits spectral yellow only. Canary glass transmits red, yellow, green, and, in thin sections, one or two bands in the blue. It distorts colour less than medium amber and converts ultra-violet, violet and blue rays, by fluorescence, into yellow-green light. This

FIG. 7.

Transmission curve of typical yellowish-green glass.

group as a whole may be said to afford efficient protection against ultra-violet (Fig. 7), although the light, yellowish-green euphos, while absorbing at $4,000 \text{ \AA}$, begins to re-transmit at $3,200 \text{ \AA}$. Generally speaking, glasses of this group obstruct about 60 per cent. of the infra-red radiation from a furnace heated to $1,000^\circ$ to $1,100^\circ \text{ C}$.

The yellowish-green group of glasses has received an undue amount of attention, especially in America, on account of a statement by Luckiesh that these glasses permit very accurate observations on colour-temperature in industrial processes. The subject of protective glasses for industrial purposes has not been examined in this paper, partly because it is under consideration by the British Scientific Instrument Research Association under its Director, Dr. H. Moore. It is pertinent to state, however, that the views of Luckiesh are not supported by the experience of workers in this country.

Green glasses constitute the next important group. Chromium is one of the oldest and best known green colouring materials. The chromic salts corresponding to basic oxide Cr_2O_3 (2 per cent.) produce a bright grass-green colour; peroxide of copper (0.5 to 3 per cent.) dark bluish-green; and the protoxides of iron (0.5 to 1 per cent.) a somewhat similar colour. Iron is in the ferric state and the colour yellow in the presence of oxidising agents. When the latter are absent in the batch the iron is ferrous and the colour green. Sir William Crookes' famous sage-green glass, No. 246, contains iron in the ferrous state:—raw soda flux 90 parts; ferrous oxalate, $\text{Fe C}_2\text{O}_4, 2 \text{ H}_2\text{O}$, 10 parts; with a small quantity of red tartar and wood charcoal to prevent oxidation. Crookes' glass, No. 217, has the following composition:—fused soda flux 96.8 per cent.; ferroso-ferric oxide or iron scales Fe_3O_4 (2.85 per cent.); carbon 0.35 per cent. Its colour is pale blue. Uro and etex are pale greenish-blue glasses containing iron oxide. Other blue iron glasses are made by neutralizing the orange yellow ferric colour by a little cobalt. Ferric oxide, Fe_2O_3 is the rouge of commerce.

Green glass is opaque to ultra-violet. (Fig. 8). Less than 1 per cent. chromium in the glass cuts transmission down to $4,550 \text{ \AA}$ (blue) and in larger proportion as far as $5,600 \text{ \AA}$ (mid-green). Clear green signal glass shows absorption in the violet, red and orange, and complete absorption in the further ultra-violet; even wavelength $3,650 \text{ \AA}$ is weakened.

The ferrous state of iron obstructs heat rays. Crookes' sage-green glass cuts off 98 per cent. of heat and transmits 27.6 per cent. of incident visible light. It has no action on the ultra-violet. The darker shade of uro absorbs 70 per cent. of the infra-red radiation between about $7,000 \text{ \AA}$ and $13,000 \text{ \AA}$. Ferric glasses obstruct some ultra-violet; 2 per cent. cuts off ultra-violet to near $4,000 \text{ \AA}$. Crookes' No. 217 cuts off all ultra-violet shorter than $3,550 \text{ \AA}$;

transmits 40 per cent. of visible light ; and only 4 per cent. of heat rays. Ferrous iron is easily the most important agent known for absorbing infra-red radiation. Glasses that absorb highly in the infra-red, however, have either a low transmission throughout the visible spectrum or have the transmission band shifted into the green or blue.

Neutral tints are achieved in a variety of ways. No single colouring agent known confers a neutral colour. The effect can be

FIG. 8.

Transmission curve of typical green glass.

produced by combining two complementary absorption tints, such as green and purple ; brown and blue ; yellow and blue ; or red and blue-green. In practice, a mixture of colours is used that cuts out almost all tints in the spectrum. Thus, manganese gives a neutral colour to green glass (oxides of copper and iron). Cobalt alone gives a rich blue ; nickel alone gives brown ; cobalt and nickel combined give neutral grey. Praseodymium gives a greenish-yellow glass ; neodymium gives violet ; together they produce neutral grey. Cerium, nickel and copper glass is almost neutral. Platinum (0.3 per cent.) with sand, potassium carbonate and red-lead is a translucent grey ; the addition of 3 per cent. oxide of iridium makes

it a dense black. Another black glass has a high manganese content, with some cobalt and copper or ferric silicates.

A peculiarity of dark glasses, which is probably physiological rather than physical, is the difficulty of suppressing red. The percentage of transmission of this colour should be cut down considerably relative to the rest of the visible spectrum.

Light amethyst or violet tints are sometimes used as substitutes for neutral grey. The principal agent used is manganese in potash-lime glass. An example is soft-lite. The greatest absorption of light is in the green or blue-green. Manganese has no effect on either ultra-violet or heat radiation. Didymium glass belongs to this group and has the unique merit of cutting out the wave-lengths of greatest radiant energy in the solar spectrum. (Fig. 9). Didymium exhibits a discontinuous emission spectrum. In thick sections two dark bands of medium breadth can be seen through an ordinary hand spectroscope. In thin sections it gives rise to a fine line-like absorption spectrum in the yellow-green. Unfortunately, didymium glass, as a rule, is muddy in appearance and unsuitable for use as a spectacle lens. Chance's didymium glass, however, is perfectly transparent and is probably the best protective glass available for glare in temperate climates. Didymium is a mixture of praseodymium and neodymium and Chance's glass probably owes its

FIG. 9.

Transmission curve of didymium (2.25 per cent.) crown glass.
Chance Bros. and Co., Ltd.

superior transparency to the elimination of praseodymium and its freedom from contamination with other rare earth oxides.

Crookes' glass.—The last group comprises the pale, almost colourless glasses, such as the Crookes' A series, which are extremely opaque to ultra-violet. Chance's Crookes' series consists of four types:—A.1, A.2, B.1, B.2. Crookes' A.1 is very nearly colourless, but has a vaseline-like tint when viewed edgewise. A.2 is slightly bluish, due to the presence of cobalt. B.1 is a light neutral shade, darker than A.2; and B.2 is a dark neutral. The last three members

FIG. 10.

Transmission curves of Chance's Crookes' glass A1, A2, B1, B2. Thickness, 3 mm. Chance Bros. and Co., Ltd.

of the series, strictly speaking, belong to the neutral group just discussed. They differ essentially from the members of that group in possessing the specific properties of Crookes' A.1 glass and are more properly described in this section. All Chance's Crookes' glasses contain cerium and didymium. Their spectral transmission curves are shown in Fig. 10, and the glasses are very carefully standardized. The ingredients of Crookes' No. 221 are as follows:—fused soda flux 80 per cent.; cerium nitrate (crystallized) 13.4 per cent.; uranoso-uramic oxide 6.6 per cent. This glass is a faint yellow colour. Its transparency to visible light is 60 per cent.; it cuts off ultra-violet at 3,685 and obstructs 39 per cent. of heat rays. Most rare earth oxides cut off ultra-violet beyond wave-length 3,650 Å and transmit nearly all the visible. The laboratory of the U.S. Bureau of Standards has prepared a soda-lime glass containing

7 per cent cerium oxalate. In thicknesses of 2 mm. this glass has a faint yellowish tinge and transmits 85 per cent. to 88 per cent. of the visible spectrum and only 3 per cent. to 4 per cent. of the 3,650 Å line of the mercury arc. Cerium oxide in a soda flux base is a very pale salmon tint or, in a potash lime flux with 0.2 per cent. manganese dioxide, flesh coloured.

The effect of titanium oxide on ultra-violet absorption is about half that of cerium oxide. A typical glass contains lime, barium, lead or zinc and 6 per cent. titanium dioxide and nitre. Vanadium (1 per cent.) may be substituted in the form of one of the higher oxides, as V_2O_3 does not cut off ultra-violet. The addition of borax increases the refractive index and, therefore, the ability to absorb ultra-violet, of glasses containing titanium and vanadium. Incidentally all boro-silicate glasses are hard to surface.

Chance's Crookes' A. 1, 3 mm. thick, practically ceases to transmit beyond wave-length 3,650 Å, but transmits 77 per cent. of incident daylight, and 40 per cent. of radiant heat from a source at 1,400° C.

Reflecting Glasses.—A common property of nearly all metals is a very high reflecting power (90–98 per cent.) in the infra-red, especially beyond 20,000 Å. Almost all metals have low reflectivity in the ultra-violet and violet-blue. An exception is the new German alloy, hochheim, which is apparently a combination of aluminium and silicon, and is the best metallic reflector known for the visible and ultra-violet. The next best reflector in the visible is silver, 92.5 per cent. at 5,550 Å (Hagen and Rubens). Magnalium, an aluminium-magnesium alloy, is said to reflect 67 per cent. at wave-length 2,500 Å. Gold in thin films has great transparency in the region of 5,000 Å, while it reflects 60–80 per cent. compared with 4 per cent. from glass. Beyond 20,000 Å the transmission is less than 1 per cent. and ceases entirely beyond 25,000 Å. Gold obstructs 99 per cent. infra-red radiation from a furnace heated to 1,050° C.

About twenty-five years ago Pfund in America patented a gold-plated glass for protection against infra-red radiation in welding and this has been manufactured in that country ever since, and in England for something like ten years. Seven or eight years ago Imre in Hungary re-introduced the gold-plated glass and two additional varieties, platinum and silver. All these glasses are of the type termed "laminated" by the trade, *i.e.*, the metallic film is deposited on the surface of one glass and protected by another superimposed upon it. In the Pfund glass the gold film is usually deposited on Crookes' glass.

Three methods are available for depositing the metal. These are—

- (1) Cathode sputtering.
- (2) The evaporation process of Ritschl.
- (3) The "burning in" process.

Cathode sputtering has numerous industrial applications. When a high voltage discharge takes place *in vacuo* most metallic cathodes slowly disintegrate, and a film of the metal of which the cathode is composed is deposited on objects in its vicinity. The nature of the action is somewhat obscure, but, at least in some cases, it would appear that the particles are torn off from the cathode as a result of positive-ion bombardment.

In the evaporation process, which has been developed mainly by Ritschl of Berlin, a fragment of the metal of which the mirror is to be formed is placed in a high vacuum (10^{-4} mm.) and the object, *e.g.*, the glass to be coated, is set some 10 or 15 cm. distant. On heating the metal it evaporates and part condenses on the glass, forming a mirror.

The "burning in" process is applicable mainly to platinum salts but it has also been successfully used for other rare metals, such as iridium, palladium, vanadium, etc. It has been practised in a rough form and jealously guarded as a trade secret for many years, but during the war was developed to a high state of perfection by Mr. Julius Rheinberg in this country. Essentially, the Rheinberg process consists of coating the glass with a film of collodion in which the platinum salt and a small quantity of bismuth are dissolved, and subjecting it in a furnace to a temperature of 600° or 700° C. This temperature, while stopping short of the point at which the glass tends to become viscous, is sufficient to expand the ultra-microscopic texture of its surface so that the particles of platinum sink into and become incorporated within it. The depth of penetration is somewhere about one or two wave-lengths. In another process the platinum is first deposited on the surface as a film and subsequently burnt in.

Each method has advantages and disadvantages. The "burning in" process has the great merit of not requiring a cover-glass. The metal is actually embedded in the substance of the surface layer of the glass and the latter can be polished and cleansed with impunity. Surfacing and grinding must, of course, be done beforehand. A cover-glass is a great disadvantage in that it absorbs some heat-rays before reflection can occur at the metallic surface and transmits the heat by conduction to the rest of the lens. The "burning in" process, however, has a slight tendency to deform curvature and to render the glass rather brittle. When carried out under factory, as distinct from laboratory conditions, deposition is apt to vary in density and regularity of surface. Cathode sputtering requires a cover-glass to preserve the film. The elements which sputter best are those of high atomic weight. Aluminium, for example, cannot be sputtered. The evaporation process is available for metals of low melting point. Aluminium, tin, silver, gold, can be readily evaporated but platinum cannot. Very fine mirrors are formed in this way, and it is a method applicable to a large number of metals.

The primary use of reflecting glasses is the elimination of infra-red radiation. For this purpose they are extremely suitable, but obstruction of infra-red radiation can be equally well achieved by other methods. For example, Crookes' sage-green ferrous glass absorbs 98 per cent. of heat rays. It has already been stated that a good absorber is also a good radiator and that all absorbers of radiation at a temperature below 500°C . re-radiate the absorbed energy in the form of long-waved infra-red radiation. Thus, any glass that absorbs not only infra-red but also visible and ultra-violet light will in time re-radiate all the energy as infra-red rays in every direction including that of the eye. The supreme merit of reflecting glass is its relative poverty as a radiator and for certain purposes, particularly its use by aviators in hot desert countries, a reflecting glass is unrivalled.

A rough comparison of the efficiency of various types of protective glass for obstructing heat rays can readily be made by means of a radiometer or small light-mill such as is often seen in instrument makers' windows rotating under the influence of sunlight. The movement of the vanes of the radiometer is explained by the action of the air molecules which remain in the glass container. The

Fig. 11.

Test of heat-obstructing properties of glass by means of a radiometer.

blackened surface gets warmer than the polished one. Any molecule which happens to hit the black surface will rebound with a greater velocity than one which hits the cooler, polished surface. There is, consequently, a greater pressure on the black faces than on the polished one and rotation of the arms is inevitable. A black surface absorbs all the rays of the solar spectrum from the ultra-violet to the far infra-red, the maximum intensity being a little below the Fraunhofer line A in the extreme red. Owing to the predominance of the heat rays, however, the result may be regarded as due to their influence. The source of light, *e.g.*, a 100-watt lamp, is enclosed in a stout wooden box, which is light-proof except for one aperture about the size and shape of a trial-case lens. The radiator stands opposite the aperture and about $3\frac{1}{2}$ inches from it. When the light is switched on, the radiometer (Fig. 11) begins to spin. Various glasses can be placed in succession in front of the opening and their influence on the rate of spinning compared. The following are a few typical results, but the time intervals vary with the temperature of the room:—

1. *Amber*: no effect.
2. *Fieuzal*: no effect.
3. *London smoke*: slows down but does not stop after 35 minutes.
4. *Uro*: slows down but does not stop after 35 minutes.
5. *Gold reflecting glass (flat)*: stops in one minute.
6. *Silver reflecting glass (flat)*: stops in three minutes.
7. *Platinum reflecting glass (domed)*: slows down but does not stop after 35 minutes.
8. *Infrex O*: slows down but does not stop after 35 minutes.
9. *Infrex I*: stops after 30 seconds.

Theoretically, the absorbing glasses, such as infrex *I* ought to restart the radiometer after an interval. When the glass becomes hot and itself acts as a radiator, the secondary radiation is of very long wave-length and to these the glass container of the radiometer is completely opaque.

At my request Mr. L. A. Walters of Messrs. George Spiller, Ltd., to whose interest in this investigation I am much indebted, obtained a report from the National Physical Laboratory, Teddington, on the behaviour with regard to light and heat transmission of Imre's gold glass compared with Crookes' B. The latter was chosen for comparison as it seemed to be the only available glass that was definitely standardized. In each case the glasses were domed, *i.e.*, concave towards the eye, but of zero power.

“The following quantities were measured for one of the glasses of each pair:—

- (1) The fraction of visible light transmitted.
- (2) The fraction of total heat from a carbon-arc lamp transmitted.
- (3) The relative amounts of heat re-radiated from the back surface of each glass when exposed to the same intensity of incident light for the same time.

The results were as follows:—

		Transmitted light.	Transmitted heat.	Relative amount of re-radiated heat.
Crookes' B	-	48 per cent.	74 per cent.	1.
Imre	- -	36.5 per cent.	28.5 per cent.	1.40

It will be observed that the actual amount of re-radiated heat is greater for the Imre glass than for the Crookes' B. On the other hand, the amount of heat which is not transmitted is 4.47 times as great for the Imre glass as for the Crookes' B. The relative amounts of re-radiated heat per unit of heat not transmitted is only about one-third as much for the Imre glass as for the Crookes' B.”

Reflecting glasses have little or no effect on the ultra-violet. Silver transmits ultra-violet freely, having a transmission band at 3160 Å. They also have selective transmission in the visible spectrum. Silver is transparent for blue and violet, and gold for green. Imre claims that platinum holds back the whole visible spectrum evenly and that its colour is a perfect neutral grey. This is not quite accurate, however, as platinum has a definite though slight selective transparency for red.

A Simple Method of Colour Analysis

The only precise method of ascertaining the transmission spectra of glasses is by means of the absorption spectro-photometer. This apparatus, however, is costly, and its use requires special training and experience. The following method was designed by the writer in order to give a rough and rapid estimate of monochromatic transmission through glasses in the visible portion of the spectrum. The results are sufficiently accurate to recommend its use to the dispensing optician. The writer has had the opportunity of examining a large number of coloured glasses of the groups described above and of many not included in these groups. His observations

support the statement that much of the glass manufactured, or at least, sold for protective purposes does not conform to the typical transmission curves selected to illustrate this paper.

The principle of the method is the light sensitivity of a photo-electric cell. The apparatus consists of a source of light, a series of filters, a photo-electric cell and a galvanometer. The best photo-electric cell for the purpose is the Photronic cell. The source of light is an ordinary 20 watt opal electric bulb. Two holders are fixed in series in front of the cell, one to take a filter and the other the glass under examination. To provide a numerical relation between the incident light and the indicator of a measuring instrument, the cell is connected with a resistance adjustment and voltmeter (Fig. 12). Valve amplification is unnecessary. Both the light source and the photo-electric cell are enclosed in a stout box to

Fig. 12.

Circuit diagram of colour analyser. *F*. Filter. *Ga*. Galvanometer. *Gl.* Glass. *P*. Photo-electric cell. *R*. Resistance.

exclude stray daylight. The filters are standard Wratten light filters transmitting only one spectral colour. The complete set consists of seven monochromatic filters, but as few as three will suffice for most purposes, *i.e.*, Nos. 70 (deep red), 72 (orange yellow), and 74 (pure green).

The procedure is as follows: the light is trained on the photo-electric cell and the deflection of the galvanometer indicator noted. After the pointer has come to rest, the first filter is interposed in the path of the beam, causing the pointer to move back a certain distance towards the zero position. The light reaching the photo-electric cell is now monochromatic and the same colour as that of the filter. As the filters have rather narrow transmission bands the amount of light that they absorb is rather high. Usually, however, a sufficiently large margin is left between the zero position and that accounted for by the addition of the filter to enable the necessary calculations to be made. The glass under examination is now inserted in the path of the monochromatic light. If the colour transmitted by the filter is not transmitted by the glass, the pointer moves back to the zero position. If a certain percentage is transmitted, measurement of the deflection will give an approximate value to this percentage. In interpreting the readings obtained,

allowance must be made for the loss of light in transmission through the glass. No serious error will be introduced if this loss is regarded as similar to that of a standard white glass. By interposing in turn the different filters the colours of the spectrum can be examined in succession and the values corresponding to the several filters plotted as a colour curve. The main source of fallacy is infra-red radiation, but the Photronic cell used in this apparatus* is not particularly sensitive to infra-red. Wratten filters do not stand heat and should not be placed too close to the light source.

Applications and Standardization

From the seeming complexity of circumstances in which glasses for protective purposes are really required, three illustrative examples may be chosen, as these three and their variants may be said to cover practically the whole field. The three selected problems are (1) the reduction of glare; (2) the elimination of discomfort for aviators in dry, tropical areas; and (3) protection against ultra-violet conjunctivitis on snowfields. It may be said at once that, with one exception, *viz.*, fluorescent glass, all coloured glasses should now be regarded as obsolete.

The reduction of glare.—Intolerance of glare may be regarded as a form of photophobia which sometimes is physiological and sometimes pathological. In health, considerable tolerance, after a period of adjustment, is normal up to a certain intensity of stimulus, the degree of intensity varying with the individual and with the demands made on his visual activities. The greater the effort exerted by the eyes the lower is the minimum threshold and the more pronounced the disturbance experienced from glare. All departures from health in the eyes, however slight, *e.g.*, minor errors of refraction and muscle balance, mild inflammations of the conjunctiva or lids and *a fortiori*, more serious diseases, tend to decrease tolerance. There is often a nervous element. In some persons intolerance of light amounts to a neurosis which over-protection may accentuate. Unless natural tourmaline lenses can be obtained—and this is practically impossible—or until such time as an artificial analyser of polarized light can be devised, protection against glare in temperate climates at least can be achieved sufficiently well for all practical purposes by wearing lenses of Chance's didymium glass. This glass contains 2.25 per cent. didymium and in sections of 2.25 mm. transmits 70 per cent. of the total visible spectrum. It transmits, however, only 20 per cent. of wave-lengths 5,550 Å up to 6250 Å, *i.e.*, the wave-lengths of maximum radiant energy in the solar spectrum

* The colour analyser described may be obtained from Messrs. Adam Hilger, Ltd., 98, King's Road, N.W.1. I am indebted to Mr. D. R. Follett of that firm for much help in its design.

which are also the wave-lengths for which the human eye possesses maximum sensitivity. A somewhat similar glass is the German neophan. The faint lilac colour of didymium glass in thin sections is inconspicuous in daylight, although occasionally, fastidious blondes have been known to object to the reflection thrown down when rather high-powered convex lenses are worn. The Crookes' A.1 glass also contains didymium and is still less conspicuous but not quite so effective. For more serious cases of intolerance there are available the other members of the Crookes' series, *viz.*: A.2, B.1 and B.2. The rule should be that the lightest tint compatible with comfort should be prescribed. Neutral greys and London smoke tints have no advantage, either of appearance or of cost, over the Crookes' glasses, and, in the writer's opinion, need never be prescribed. The present artificially high cost of Chance's Crookes' glass is the fault, not of the makers, but of opticians.

Aviation in the tropics.—The nature of the radiation to which the aviator is exposed in areas such as the N.W. Frontier of India and Iraq has already been discussed. The chief source of discomfort probably is absorption by and re-radiation from his goggles of long-waved infra-red rays. Whether radiation of this kind is definitely injurious or otherwise is open to question. It may be objected, quite legitimately, that at its worst this radiation is scarcely more harmful to the aviator than that which he would experience if he were sitting quietly on a winter's night in front of a glowing gas-fire. The probable explanation of the discomfort in the former case lies in the associated, sustained, visual concentration and effort to which the eyes of the pilot or observer are subjected and which is rendered tolerable by adequate protection. Theoretically, the ideal glass is Crookes' B.1 or B.2, with a thin metallic film adherent to its outer surface. It has already been explained that most deposition films are unsuitable as they readily become worn off or detached unless protected by a cover-glass. The latter, on the other hand, would itself absorb and conduct the heat which it is desired to reflect. Nor, for other reasons, is it possible to utilise any of the "burning in" methods. There is now being perfected, however, a process which promises to solve all these difficulties. By means of the evaporation method a film of aluminium is deposited on the surface of the lens, providing a very fine mirror of high reflecting power.* It is also very tenacious, resisting scrubbing with paper and other materials most satisfactorily. The resulting glass transmits a pleasant neutral grey which is less depressing than the majority of dark tints and gives a sensation of coolness and shade which should prove of definite psychological value. The combination, Crookes' B and an aluminium film, is not laminated. At present it is still in the

* The writer is much indebted to Dr. A. Harvey, Assistant Lecturer on Physics, Manchester University, for his valuable and helpful work in perfecting this process.

laboratory stage of development, but there seems no reason why, with continued experience, its production on a commercial scale should not be practicable. If it fulfils its present promise this glass should prove ideal for the aviator in the tropics. It reflects long-waved infra-red such as is derived from terrestrial re-radiation and from regular and diffuse reflection from the ground. Its absorption of these rays is slight, so that the lens does not become hot and act as a re-radiator. Further, it not only provides special protection against infra-red, but, partly by absorption and partly by reflection, against excessive visible and ultra-violet light also.

On snow-fields.—For the conditions that obtain on arctic and antarctic snow-fields a laminated glass is advisable. The suggested basis for this combination is again Crookes' B.2 glass, upon which a metallic film, *e.g.*, gold, is sputtered. The cover-glass is a uranium glass, somewhat more amber in colour than ordinary canary glass, and definitely fluorescent. This combination gives adequate protection against excessive visible and infra-red radiation, while the protection afforded against ultra-violet rays is three-fold, *i.e.*, three different principles are involved in obstructing short-waved, ultra-violet radiation. Firstly, fluorescence, converting ultra-violet into longer-waved rays by means of the uranium cover-glass; secondly, reflection by the gold film; and thirdly, absorption by the Crookes' B element. Further, the psychological factor is not ignored, as the outlook through such a glass is distinctly cheerful. During polar exploration parties or even single individuals are often isolated for long periods in extremely monotonous, fatiguing and depressing conditions. Very dark glasses make the surroundings appear even more gloomy and dreary than they actually are and intensify the tendency to depression. In the glass in question this effect is largely neutralised by considerably reducing transmission of the darker shades, green, blue and violet, relatively to that of the brighter shades, red, orange and yellow.

The uranium cover-glass recommended in the preceding paragraph is the only coloured glass that need be retained for the prescribing of protective lenses, and the manufacture in this country of a standardized form is very desirable. So far as can be ascertained no glass of this description is now being manufactured in the British Isles for optical purposes, although both canary and amber shades made for other purposes are used in so-called sun-spectacles. Such an optical uranium glass must be standardized in two respects:—(1) its transmission curve from the ultra-violet region right through the visible spectrum; (2) its density with regard to visible light. The transmission curve must be constant and should approximate to that of the light amber glass illustrated in Fig. 6, c. Density can be estimated by means of the Hilger-Nutting polarization photometer and expressed as fractions of I , *i.e.*, $\log_{10} \frac{I_0}{I_t} = D$.

Metallic films, such as gold and aluminium, should likewise conform to a fixed standard of density. Thickness of film can be measured approximately by the time taken for deposition. Possibly it can be ascertained more directly and more accurately by some application of interferometry. Chance's series of glasses, didymium and Crookes', are already satisfactorily standardized.

With regard to frames all that need be said in this place is that metal should not come into contact with the skin in the case of goggles worn in polar latitudes, and that certain materials which act as poor conductors of heat are sometimes surprisingly transparent to infra-red radiation. Thus, the majority of woods, *e.g.*, beech, sycamore, pine, deal, etc., transmit infra-red freely in thicknesses of $\frac{1}{8}$ th inch. Celluloid and bakelite of the same thickness are equally transparent. Leather, which is or was used a great deal in the Services, is also transparent in the near infra-red.

A Note on Retinoscopes

Reflecting glasses make excellent retinoscopes. Owing to its high reflectivity in the visible spectrum, silver is better than gold or platinum, though, possibly, liable to become tarnished under the atmospheric conditions of a manufacturing city. A silver retinoscope, however, that has been in constant use in London for about 18 months is still perfectly clear. The absence of an aperture gives a retinoscope of this nature a mechanical advantage, although **probably** it does not confer any optical advantage, as the amount of **light permitted** to enter the observer's eye is conditioned by the size of the pupil. A disk rather larger than that of the ordinary plane mirror retinoscope, *i.e.*, about 5 cms. diameter, appears to give the **best results**. A concave glass, *i.e.*, concave towards the patient, of **one dioptré** does not appear to have any advantage over a plane glass. Reflecting glass retinoscopes are particularly suitable for minor errors, bordering on emmetropia, and for hypermetropia. They are not so useful for myopia, especially high myopia, nor for eyes in which opacities are present in the lens or cornea. In the writer's experience the old type of concave mirror is the best non-luminous retinoscope for these conditions.

The most difficult eye from the point of view of refraction, and perhaps the one most urgently in need of help, is the eye in which the basic error is masked by a superadded, irregular corneal astigmatism due to corneal nebulae, not necessarily in the pupillary area. Retinoscopy is rendered difficult by irregular reflection from inequalities on the corneal surface. It has been shown above that when the reflected and refracted rays in the plane of incidence are at right angles to one another, the former are plane polarized. In the case of irregular reflection from surface irregularities a large

proportion of the reflected rays may be polarized. If, now, an appropriate plate of transparent tourmaline is placed behind the aperture of a retinoscope and rotated to a position that extinguishes the maximum quantity of polarized rays, the tourmaline acts as an analyser of the polarized light. The scattered rays are largely eliminated and it is sometimes possible to do a satisfactory retinoscopy and discover unsuspected refractive defects. It need hardly

FIG. 13.

Reflecting glass retinoscope. (a) Pocket model. (b) Consulting room model.

be pointed out that often the result does not materially assist vision, because the best correcting lens does not make corneal haze in the pupillary area any less opaque. In some cases, however, probably owing to the presence of minute points of transparency in this region, a surprising improvement in vision can be obtained. The necessary alteration to a retinoscope is comparatively simple, although good tourmaline is not easy to obtain. Ten years ago Messrs. Hamblin fixed a small plate of tourmaline—part of a lens-tester—on the back of a retinoscope for the writer. A hinge enables the plate to be folded back out of the way when not in use. This device has been used with satisfaction in cases of irregular astigmatism ever since.

The reflecting glass retinoscopes (Fig. 13) are made by Messrs. George Spiller, Ltd., 32, Wigmore Street, W.1, from whom they can be obtained.

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A TRANSPARENT PROTRACTOR FOR SCOTOMETERS

BY

JOHN FOSTER

LEEDS

ANY simplification of the means employed to measure the position of any point upon a "Bjerrum-Screen" represents the saving of a considerable amount of time, and wider use of this most sensitive test. The actual test itself demands an unusual amount of concentration from both patient and examiner, and is often very tiring.

Since in addition, the transfer of the map outlined by the pins on the screen to the chart may take almost as long as the original mapping, many ophthalmologists appreciating this difficulty have employed a variety of methods to overcome it.

White lines on the back of the screen are helpful but the points of the pins are less easy to see than the heads, and the positions of scotomata are reversed. Stitched marks on the face of the screen are satisfactory but there is an absence of numbering which makes frequent reference to the centre, and the vertical, or horizontal, meridians desirable; often the radial lines are as far apart as 30°, calling for approximate estimations of considerable magnitude.