the only other available source of power besides coal, which, it may be said, can be regarded as the accumulated energy of the sun, stored up through countless ages, is water power. This, unlike coal, is a source of energy which is always with us. The sun piles the waters of the ocean upon the mountain side, and following the force of gravity it flows down again in a never ending cycle, watering, fertilising and, under the careful direction of mankind, rendering the land fruitful and inhabitable and providing for the wants of the human race a source of power immeasurably greater than any power to be derived from the combustion of coal, and what is more, a source of power which will never cease, or be exhausted, while the world lasts. To form a computation of the total energy of the atmospheric depositions is very difficult. It has been calculated to reach the value of 100,000 million horse-power. The realisation of the one-thousandth part of this would be enough to replace the whole of the coal consumption for an incalculable time to come.

An example of how a water power can be used to its fullest extent is furnished by the Upper Hartz. There nearly every drop of water available is utilised, and, although boasting no streams of any size, the respectable total of 3300 horse-power is generated and used in the mining operations carried on there. It is, however, with the advent of electricity that the full realisation of water power has become possible. By means of the facilities offered us by this agent we arrive back at the original motive power of mankind, and will be enabled to tap energies incalculable in comparison with our present ones. This greatest and farthest-reaching application of electricity is but now in its infancy. In 1891, only ten years ago, the first long distance power transmission plant was erected at Lauffen on the Neckar. The power, amounting to 100 horse-power, was transmitted to the electro-technical exhibition at Frankfort on the Maine, a distance of 110 miles, at a voltage of 8000 volts, using a three-phase current. In the short space of time since then immense progress has been made. Now whole towns and large tracts of country are supplied with power and light from distant waterfalls, and new industries have sprung into existence which were formerly impossible. The future developments of this branch of science will be as great, comparatively, as the mighty forces of nature they are designed to employ, and in endeavouring to imagine them the scientific mind merges into the poetic, with which it is, after all, very closely related.

THE COLOUR AND POLARISATION OF BLUE SKY LIGHT.[1]

THE theory of the colour of the sky has been of slow growth. One of the first explanations that we find in scientific literature—almost barbarous in its crudity and unsupported by fact or theory—is the speculation of Leonardo da Vinci that the blue of the sky is due to the mixing of the white sunlight, reflected from the upper layers of the air, with the intense blackness of space. This corresponds to the speculative stage of science, the age of the philosophers. In the next step analogy comes into play; this is a most valuable and effective tool for the man of science endowed with a vivid scientific imagination and with a keen, clear insight into nature, but for others a most dangerous weapon. In this case it is wielded by no less an intellect than that of Sir Isaac Newton. In his optical investigations, about 1675, he had been led to a study of the colours produced when light is reflected from thin films of transparent substances; these he found to depend upon the thickness of the film. When it is very thin it appears black; as the thickness gradually increases it becomes blue, then white, yellow, red, &c. This blue which first appears, and which may be seen surrounding the black spot on soap bubbles, Newton termed the "blue of the first order," and he thought it was of the same tint as the blue of the sky. Analogy now steps in and suggests that the colour of the sky is due to the reflection of sunlight from transparent bodies of such a size that the reflected light is the blue of the first order. This was Newton's belief, and he thought that the reflecting particles were small drops of water.

This is the first theory worthy of serious consideration, and was for a time generally accepted as correct. But no theory based on pure analogy can be regarded as final; it must first be subjected to the most severe analytical and experimental criticism of which we are capable. If it stands the test, well and good; if not, it must be rejected. In 1847 Clausius subjected Newton's theory to a strict mathematical analysis, and proved that, if the blue of the sky is the blue of the first order, resulting from the reflection of light from transparent bodies, these bodies must be in the form of thin plates or thin-walled, hollow spheres. They cannot be solid drops or spheres, for then astronomical objects would never be sharply defined; a star would appear as large as the sun, and the sun immensely larger; all celestial objects would appear as large discs of light, brightest at the centre and fading out gradually toward the edges. For this reason Clausius, believing the blue to be that of the first order, held the opinion that the reflecting bodies were hollow spheres, or vesicles of water. The belief in the existence of so-called "vesicular vapour" did not originate with Clausius, but was a relic which had persisted from the speculative age to this time in spite of its *a priori* improbability, and the natural opposition so caused. As the theory of vesicular vapour has now been completely discarded we need say no more about it; the real value of the work of Clausius lies in the proof that the light from the sky cannot be due to the regular reflection of sunlight from small drops of water.

The experimental test was applied by Brücke, who pointed out that the blue of the sky is radically different from the blue of the first order. Thus, the era of analogy began to give way to that of experimentation and analysis, which must go hand in hand.

Brücke (1853) proved that the light scattered from a turbid medium is blue, and Tyndall (1869) performed his beautiful experiments on this subject, in which he showed that when the particles causing the turbidity are exceedingly fine (too small to be seen with a microscope) the scattered light is not only a magnificent blue but is polarised in the plane of scattering, the amount of polarisation is a maximum at an angle of 90° with the incident light, and the definition of objects seen through it is unimpaired by the turbidity. Here, for the first time, all the essential features of sky light were reproduced in the physical laboratory. This experiment of Tyndall's was at once recognised as giving the key to the problem. Lord Rayleigh (1871–1899) undertook the analytical treatment of the subject and proved that when white light is transmitted through a cloud of particles, small in comparison with the cube of the shortest wave-length present in the incident light, the light scattered laterally is polarised in the plane of scattering, the maximum of polarisation is at 90° to the incident light, and the intensities of the components of the scattered light vary inversely as the fourth powers of their wave-lengths; no account is taken of the light which has undergone more than a single scattering. All these facts have been shown to agree with the phenomena observed in the laboratory when light is passed through turbid media. Recently (1899) Lord Rayleigh has shown that in this way about one-third of the total intensity of the light from the sky may be accounted for by the scattering produced by the molecules of oxygen and nitrogen in the air, entirely independent of the presence of dust, aqueous vapour, or other foreign matter.

We cannot do better than to stop here for a few moments to consider Lord Rayleigh's physical explanation of the scattering produced by small particles. On this theory, light is propagated as transverse vibrations of the atoms or corpuscles of a medium that acts like an elastic solid; it is something like the waves that go along a rope when one end is shaken, only in the case of light we are dealing with no rope but with an infinite medium. When we speak of a beam of light being polarised we mean that all the vibrations in this beam take place in the same plane, and the plane of polarisation may be defined as the plane passing through the direction of propagation of the light but perpendicularly to the direction of the vibrations, and therefore perpendicular to the plane of vibration. Now, imagine a beam of parallel light advancing through a homogeneous medium, say the free ether, in a vertical direction; there will be no light propagated except in this direction; there will be no scattered light. If, however, there exist in it particles optically denser than the ether, but small as compared with the wave-length of light, then light will be scattered laterally by these. Indeed, the effect of these particles is to locally increase the effective inertia of the ether, whereas the rigidity remains unaltered; therefore, when a wave advancing through the medium reaches one of these particles, the displacement of the medium at this point is less than it would be were the particle absent. If we should apply to each

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[1] Abridged from an article by Dr. N. E. Dorsey, in the U.S. *Monthly Weather Review*, September 1900.

particle a suitable force (which of course must be in the direction of the displacement and proportional to the difference of the densities of the particle and of the ether) we could restore the amplitude to the value it would have were the particle absent; under these conditions everything would go on as though there were no particle in the ether, and consequently there would be no scattered light, *i.e.*, we should have neutralised the effect of the particle by the application of this force. Hence, on the other hand, we would have the same scattered light if the particle were absent, and we should apply to this portion of the ether this force reversed in direction, that is to say, each particle acts as a centre of a certain harmonic force acting upon the surrounding ether. Such a force will send out a plane polarised wave, whose intensity is symmetrical about the direction of the force as axis; it is zero in the direction of the force, and a maximum in the plane perpendicular to this direction.

The exact effect of such a force has been investigated analytically by Stokes and also by Lord Rayleigh. The displacement in the wave sent out by it is

$$\xi = \frac{\mathrm{F} \sin \alpha}{4\pi b^2 \mathrm{D} r} \cos \frac{2\pi}{\lambda}(bt - r)$$

if the force is F cos $\frac{2\pi bt}{\lambda}$; where r is the distance from the centre of force to the point where the displacement is measured; α is the angle between the direction of the force and the line joining the point considered to the centre of force or the mean position of the disturbing particle; b is the velocity of light; D the density of the ether; λ the wave-length of the light sent out by the force; and π is the ratio 3.1416.

If the displacement in the incident wave is A cos $\frac{2\pi bt}{\lambda}$, the force we must apply to the particle to restore the displacement to its natural value is

$$\mathrm{T}(\mathrm{D}' - \mathrm{D})\,\mathrm{A}\left(\frac{2\pi b}{\lambda}\right)^2 \cos \frac{2\pi bt}{\lambda},$$

where D′ is the optical density of the particle and T is its volume; therefore,

$$\xi = \mathrm{A}\,\frac{\mathrm{D}' - \mathrm{D}}{\mathrm{D}}\,\frac{\pi \mathrm{T}}{r\lambda^2} \sin \alpha \cos \frac{2\pi}{\lambda}(bt - r),$$

and the intensity of the scattered light is for each particle

$$\mathrm{A}^2\left(\frac{\mathrm{D}' - \mathrm{D}}{\mathrm{D}}\right)^2 \frac{\pi^2 \mathrm{T}^2}{r^2 \lambda^4} \sin^2 \alpha.$$

Since the particles are in motion the light scattered from different particles will have no definite phase relation; hence, to get the effect of a cloud of such particles we must add the intensities of the light sent out by each separate particle.

If the incident light is plane polarised, α will be a constant for any given direction from the incident beam, and the total intensity of the light scattered in this direction will be

$$\mathrm{A}^2\left(\frac{\mathrm{D}' - \mathrm{D}}{\mathrm{D}}\right)^2 \frac{\pi^2 \sin^2 \alpha}{\lambda^4} \Sigma \frac{\mathrm{T}^2}{r^2}.$$

If the incident light is unpolarised, the intensity of the light scattered at an angle β with the direction of the incident beam will be

$$\mathrm{A}^2\left(\frac{\mathrm{D}' - \mathrm{D}}{\mathrm{D}}\right)^2 \frac{\pi^2 (1 + \cos^2 \beta)}{\lambda^4} \Sigma \frac{\mathrm{T}^2}{r^2},$$

where $\Sigma \frac{\mathrm{T}^2}{r^2}$ denotes the sum of $\frac{\mathrm{T}^2}{r^2}$ for all the scattering particles in the line of vision. In none of this have we taken account of the light that has undergone more than a single scattering. If we denote the mean of the square of $\frac{\mathrm{T}}{r}$ by $\frac{\mathrm{T}_1^2}{r_1^2}$ and let N denote the number of particles in the line of vision, we can write the expression for the intensity of scattered light in the form

$$\mathrm{A}^2\left(\frac{\mathrm{D}' - \mathrm{D}}{\mathrm{D}}\right)^2 \frac{\pi^2 (1 + \cos^2 \beta)}{\lambda^4} \frac{\mathrm{N}\mathrm{T}_1^2}{r_1^2}.$$

What are the assumptions we have made in this treatment? They are:

(1) Every scattering particle is so small that when a wave of length λ passes through the medium containing it the force is the same at every point of the particle, *i.e.*, each particle is small as compared with the cube of the shortest wave-length of the incident light.

(2) The particles are so far apart that their effect upon the velocity of light through the medium is negligible; *i.e.* the particles are far apart as compared with the longest wave-length with which we are dealing.

In his discussion of Lord Rayleigh's equations, Crova claims there is a third assumption, viz., that the number of particles in unit of volume must be sensibly the same for all sizes of particles. He says: "La formule $\frac{1}{\lambda^4}$ est basée sur l'hypothese que le nombre N de corpuscules contenus dans l'unité de volume d'air est sensiblement le même pour toutes les dimensions de ceux-ci." Mascart is of the same opinion. This is evidently wrong. The expression

$$\mathrm{A}^2\left(\frac{\mathrm{D}' - \mathrm{D}}{\mathrm{D}}\right)^2 \frac{\pi^2 \mathrm{T}^2 \sin^2 \alpha}{r^2 \lambda^4}$$

applies to particles of *all* sizes, provided they are small in comparison with the cube of the shortest wave-length. The light from a cloud of such particles is merely the sum of the light from the individual particles; the relative number of particles of various sizes does not enter into the consideration at all; indeed, the composition of the light is entirely independent of all consideration of the number and size of the particles other than as specified in the two assumptions we have named. Particles of a size intermediate between these small ones and those larger ones that reflect light regularly produce effects as yet unknown, and are not amenable to this analysis.

From Lord Rayleigh's expression for the intensity of the scattered light we may conclude, if the manifold or multiply scattered light may be neglected:

(1) The scattered light is polarised in the plane of scattering and the amount of its polarisation is $\frac{1}{1 + \cos^2 \beta}$, being a maximum (completely polarised) when the direction of scattering is perpendicular to the direction of propagation of the incident light.

(2) The intensity of the scattered light varies $\frac{1}{\lambda^4}$ times the intensity of the incident light. Its colour or wave-length is independent of the direction of scattering.

(3) The maximum intensity of the scattered light is in a direction almost coincident with that of the incident light and in the opposite direction, and the minimum is in the plane perpendicular to this.

(4) The larger the particles (provided the assumptions above are fulfilled), the more intense is the scattered light.

As stated above, we know little, if anything, about the action of particles that are just too large for this treatment to apply, but in another of his papers Lord Rayleigh has solved to the next approximation (on the electro-magnetic theory) the special case of spherical particles, and finds that the light scattered should vary as the inverse eighth power of the wave-length. In the air there are surely some particles approximately fulfilling these conditions, and hence the sky should appear bluer than indicated by the simple theory we have just considered. But we have not yet bridged the gap between "very small" particles and those large enough to give regular reflection.

We have thus far neglected the multiply scattered light, but this increases in intensity as the square and higher powers of the number of particles per unit volume, while the once-scattered light increases as the first power only. Hence, for a cloud of particles the multiply scattered light may easily become appreciable. This again increases the proportion of the blue.

For all these reasons the colour of the light from the sky should be expressed by the sum of a series of terms of powers of the reciprocal of the wave-length; not by a single term, as is ordinarily attempted. Crova, endeavouring to express the intensity by a single term of the form $\frac{k}{\lambda^n}$, found values of n varying from 2 to 6 under different conditions, the average being about 4, as Lord Rayleigh and Captain Abney had found. But in no case could n be determined so as to give more than a fair agreement. As we have seen, values of n higher than 4 are to be expected; the lower ones are to be accounted for by the lateral scattering caused by the particles between the observer and the source of the scattered light which reaches him, by the absorption of the short waves by interposed water vapour and by the admixture of white light reflected from the larger particles.

The scattering to which we have been referring is evidently different from what we ordinarily mean by reflection; the latter assumes that the reflecting surfaces have an area large as compared with λ^2; whereas scattering assumes that the volume of the particle must be small as compared with λ^3.

Such is in outline the theory and the main facts in regard to the cause of blue sky light; but there are several secondary features which must be now considered. The sky is bluer in the zenith than elsewhere, evidently because the path traversed by the scattered light is here the shortest, so that it suffers less admixture with white light and less absorption of blue light. Conversely it should be less blue near the horizon, and when the sun is low may take on a red or orange tint, as we know is the case. The light from the zenith is most intense when the sun is nearest it, as at true noon, and its blue is least pure at the hottest part of the day, on account of the maximum amount of large particles of dust and vapour constituting the haze existing at this time.

Arago discovered that there is a point, about 15° above the point diametrically opposite the sun (the antisolar point), where the polarisation is zero; between this and the horizon the polarisation is horizontal. Babinet discovered a similar point above the sun, and Brewster found one below it. Between the neutral points discovered by Babinet and by Brewster the polarisation is horizontal; below Brewster's point and above Babinet's it is vertical. For a little way on each side of the neutral points the plane of polarisation is inclined at about 45° to the vertical. This seemed to indicate that superposed upon the polarisation resulting from the scattering of direct sunlight is a horizontal polarisation due to some secondary cause. It was soon suggested that the horizontal polarisation is due to a secondary scattering of the light coming from the lower layers of the atmosphere, and this has generally, but not universally, been accepted as the most probable explanation. Other neutral points have been observed under rare conditions.

The positions of the neutral points, the amount of polarisation, the position of the point of maximum polarisation, as well as the colour of the sky, are intimately connected with other meteorological phenomena, but as yet the observations have been so meagre, made under such dissimilar conditions and by such various forms of apparatus, that it is nearly impossible to tell what is the true connection.

Cornu says—in words of which the following is a translation—"In a general way, the amount of polarised sky light is connected in so direct a manner with the condition of the atmosphere that I have been led to think that it is characteristic of the state of the atmosphere. The greatest clearness of the sky corresponds to the greatest amount of polarisation; cirrus and fog decrease the amount, and even completely destroy the polarisation when the sky is overcast. . . . What is particularly interesting is that the least change in the state of the atmosphere is plainly shown by the polarimeter several hours before other precursory phenomena (barometric variation, halos and various other optical phenomena) have begun to indicate a change.

"Under these conditions it would be useful to carry out these observations in a methodical manner, and to compare the polarimetric variations with other elements characteristic of the atmospheric condition. . . . The amount of polarisation increases as the sun sinks below the horizon until it reaches a certain maximum, after which the polarisation rapidly disappears. The law of this increase of polarisation with the time is very important, for it appears to me to give the vertical distribution of fog in the atmosphere; indeed, if the increase is rapid the lower layers are foggy and the upper ones transparent; if the increase is slow, the atmosphere is more homogeneous."

In short, the more fog or cloud there is present the less the amount of polarisation and the less pure is the blue of the sky.

The most extensive series of observations are those of Rubenson and of Brewster on the polarisation, and of Crova and Abney on the colour of the light from the sky. The first limited himself to observations made in fairly clear weather, and the second directed his attention principally to the determination of the positions of the various neutral points. Rubenson and most other observers have laid special stress upon the intensity of the polarisation at its maximum point in the vertical circle through the sun. This is undoubtedly the point where observations can be most easily taken, and those so obtained must be of great meteorological value; but the interpretation of them is rendered difficult by the variation in the length of the path of the scattered light at different times of the day. At sunrise and sunset the point observed is the zenith, and the path is a minimum; while at noon, if the observer be in the tropics, the point observed may be on the horizon, and the length of the path a maximum. For other positions on the surface of the earth the variation in length of path is less than this.

On the other hand, unless we observe a point of maximum polarisation the observations will be vitiated by every error in determining the position, with respect to the sun, of the point observed. Though other objections may be urged, it has occurred to me that for meteorological prediction the most valuable data would be obtained from continuous observations of the amount of the polarisation of the light from points of the sky on the horizon and 90° distant from the sun. These are points of maximum polarisation; these observations will give a kind of integration of the atmospheric conditions over a large area, and the length of path being the same at all times the observations should all be comparable, except for the varying angle of illumination of the surface of the earth, which, unless the nature of the surface differs greatly in different directions, I think would hardly affect the results appreciably, except, perhaps, when the sun is near the horizon. No one, to my knowledge, has carried out such a series of observations, hence the suggestion is advanced with great hesitation.

Since the colour of the sky is independent of the angular distance of the point observed from the sun, being a function of only the state of the atmosphere and the thickness of the stratum observed, there is but little choice in the altitude of the point where we make the colour observations. But since the blue is a maximum in the zenith this is rather to be preferred, for a slight error in the position of the point observed will here produce the least effect.

Whatever point or points are observed, the fact remains that careful observations on the colour and the polarisation of the light from the sky will give us data determining the amount and size of the particles floating in the air, be they dust or water, and, as any change in the state of the atmosphere will affect these quantities, such observations should be of ever-increasing importance to meteorology. First, however, we must have a long series of observations taken at different places and under all conditions, with exact meteorological data obtained at the same time and place, together with a description of the nature of the surrounding country. When these have been obtained it should be not very difficult to find means of using future observations with great success.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

The Senate of the University of Dublin has decided to confer the honorary degree of D.Sc. upon Prof. W. Burnside, F.R.S., and Mr. W. E. Wilson, F.R.S.

On Tuesday, June 18, Lord Avebury will open an exhibition of students' practical work, executed in connection with the technological examinations of the City and Guilds of London Institute, at the hall of the University of London.

The Report of the Council of the City and Guilds of London Institute upon the work of the Institute during last year refers to a number of noteworthy matters. The Institute has been incorporated by Royal Charter, but the general constitution remains unchanged. The Central Technical College has become a School in the Faculty of Engineering of the University of London. The Departmental Committee appointed to consider "the best means for coordinating the technological work of the Board of Education with that at present carried on by other educational organisations" has had several meetings, and it is hoped that arrangements may be made for the more intimate association of the work of the Institute's Technological Examinations Department with that of the Board, by which the overlapping of examinations may be avoided and the instruction provided by county councils and technical schools may be brought into closer relationship with the Board of Education and the Institute. Referring to the extrance examination and the teaching of science in secondary schools, the Council remarks: "The Central Technical College is the only college of