will be published before the great interest which has been aroused by the present foretaste has evaporated.

The most interesting points brought out in the present book are those which serve to throw partial light on the great stone statues which are so abundant in the island, and, in connection with these, on the origin of the Easter Island folk. It has hitherto generally been assumed that these folk were of Polynesian race. But recent research, by Prof. Keith and others, seems to show that, in Easter Island, as in so many of the South Sea Islands, several races with other than Polynesian culture have from time to time invaded this remote and isolated islet. Mr. Henry Balfour (in *Folklore* for December, 1917) has suggested (modestly he disclaims to have done more) some of the main results to which Mr. and Mrs. Routledge's experiences seem to point, and chiefly to the probability that at some long-distant time a strong wave of Melanesian influence reached Easter Island. Certain points of curiously strong resemblance between Easter Island arts and customs and those found in certain of the Solomon Islands serve to illustrate this.

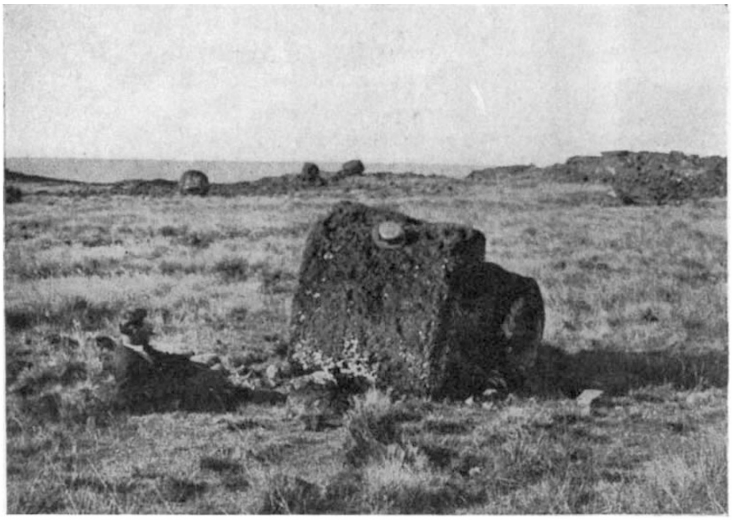

FIG. 2.—A finished Hat at Ahu Hanga O Ornu; others in the distance. From "The Mystery of Easter Island."

Without throwing any doubt on this suggestion, tentatively put forward by Mr. and Mrs. Routledge, with the strong support of Mr. Balfour and others, I again venture to put forward the view that, while Easter Island culture is doubtless of very mixed origin, Polynesian and Melanesian elements being most strongly represented, there were probably also other elements—*e.g.* some influence, possibly slight, and only very occasional, from the not far distant American shore lying to the eastward. For instance, the script (on wooden plaques), the rock-carvings, the featherwork, and the very peculiar form of tapa (bark cloth) which was used in Easter Island, all seem to me to suggest an Eastern, rather than a Western, origin.

One other suggestion may here be put forward as a contribution to the consideration of the Easter Island mystery. Mrs. Routledge writes of the well-known "top-pieces" which are, or were, superimposed on the statues as "hats"; and Mr. Balfour suggests that these were very probably meant to represent not hats, but hair, and in the number of *Folklore* above quoted he works this out in very ingenious detail. I venture to suggest a slight amendment to Mr. Balfour's proposition—*i.e.* that the stone cap-pieces in question were meant to represent not actual growing human hair, but wigs, such as those which were, and still to some extent are, commonly used by Fijians—though whether by those of Polynesian or Melanesian origin I cannot now say. It would be interesting to know how far such wigs were used in other parts of the Pacific.

It is satisfactory to know that a second edition of Mrs. Routledge's book is already in course of preparation, and all ethnologists must hope that the full scientific data will also soon be published.

The Blue Sky and the Optical Properties of Air.[1]

By the RIGHT HON. LORD RAYLEIGH, F.R.S.

Scattering by Small Particles. Polarisation.

THE subject chosen for this evening is one which specially interested my father throughout his career. I shall try to put before you some of his conclusions, and then pass on to more recent developments, in which I have myself had a share.

Let us begin with one of his experiments which illustrates the accepted theory of the blue sky. We have here a glass tank containing a dilute solution of sodium thiosulphate. A condensed beam from the electric arc traverses it and then falls on a white screen, where it shows the usual white colour. I now add a small quantity of acid, which decomposes the solution with slow precipitation of very finely divided particles of sulphur. As soon as this precipitation begins you see that light is scattered—that is to say, it is diverted to every side out of the original direction of propagation. Moreover, you will observe that the

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[1] Discourse delivered at the Royal Institution on Friday, May 7, 1920.

scattered light is blue. The transmitted beam is robbed of its bluer constituents, and tends to become yellower, as you may see on the screen.

The light scattered laterally is to be compared to the blue sky; the yellow transmitted light to the direct light of the setting sun when it has traversed a great thickness of air.

As the precipitation goes on, the transmitted light becomes orange, and even red. But the particles of sulphur eventually get bigger, and then give a less pure blue in the lateral direction. We shall have more than enough to occupy us if we confine our attention to the earlier stages, when the particles are small compared with the waves of light.

A very important property of the scattered light is its polarisation. The vibrations of the scattered light as you have seen it, viewed laterally in the horizontal plane, are almost wholly up and down. No light is emitted which vibrates in the horizontal plane. It is easy for individual observers to verify this with a Nicol's prism held to the eye, but this direct method unfortunately does not lend itself to public demonstration.

We may, however, use polarised light to begin with, and you can then observe that if the polarising Nicol is set so as to transmit up and down vibrations, these are abundantly scattered towards you by the small particles. As I turn the polarising Nicol through a right angle, you will see that the light scattered towards you is extinguished.

The polarisation of light scattered by the sulphur particles is one of the most conclusive reasons for considering it to be an analogue of the blue light of the sky, for the latter shows a polarisation of exactly the same kind when examined at right angles to the sun.

A cloud of small particles of any kind is capable of producing these effects, the essential condition being that the individual particles should be of small dimensions compared with the wave-length of light, so that at a given moment the vibration at a given particle may be regarded as having a definite phase. In this case it was shown by my father that the shorter (blue) waves are of necessity more scattered than the longer ones (red); thus the scattered light is bluer than the original. This conclusion can be justified in detail whether we adopt the elastic solid theory, or the electromagnetic theory of the nature of light, but it is also deducible from the general theory of dimensions, without entering upon any details of the nature of light beyond its characterisation by the wave-length.

An alternative theory which still sometimes shows its head attributes the colour of the sky to a blueness of the air, regarded as an absorptive medium. Such blueness is referred to the presence of ozone, and appeal is made to the undoubted fact that a sufficiently thick layer of ozone shows a blue colour by absorption. This theory gives no account of why the sky light is polarised, or indeed of why there is any light in the clear sky at all. Further, its fundamental postulate that the air is blue by transmission is contrary to observation. The setting sun is seen through a greater thickness of air than the midday sun. According to the theory under discussion, the setting sun ought to be the bluer of the two, which everyone knows it is not. No doubt the presence of ozone tends to make the air blue by transmission. But this effect is more than compensated by the lateral leakage (scattering) of blue light from the beam, which makes the transmitted light yellow.

Dusty Air and Pure Air.

If it be conceded that the blue sky is due to scattering by small particles, we are confronted with the question: Of what nature are these particles? At the time of my father's early investigations (1871) this was left open, though they were regarded as extraneous to the air itself. In 1899 he returned to the subject, and considered the matter from the point of view of what was lost by the original beam by lateral leakage (scattering), which simulates the effect of absorption. He then found that the air itself, regarded as an assemblage of small particles (molecules of oxygen and nitrogen), would have an apparent absorbing power not much less than that actually deduced by observations of the sun at different altitudes. The inference was that the air itself was capable of accounting for much, if not all, of the scattering which is observed in the blue sky; in fact, that the molecules of air are the small particles in question.

When a beam of sunlight enters a room through a small aperture in the shutter, its course is readily traced by the brightly illuminated motes in the air. Prof. Tyndall, working in this institution, devoted much attention to the nature of these motes, and the methods by which they may be got rid of. His results may be consulted in his fascinating essay on "Floating Matter." One way of getting rid of the motes is to filter the air through cotton-wool. We have here one of Tyndall's own experimental tubes. The electric beam passes axially along it, and is concentrated to a focus about the middle of its length. Its track is conspicuous. If now we displace the air originally in the tube by filtered air, you see that the cone of light fades into invisibility.

Another of Tyndall's experiments was merely to place a spirit lamp or Bunsen burner under the beam. Since most of the dust particles are combustible, the gases rising from the flame are free from them. As you now see, dark rifts appear in the beam where the uprising stream of dust-free gases traverses it.

Tyndall, on the strength of these experiments, stated without qualification that dust-free air does not scatter light, but my father's views and theory lead clearly to the conclusion that it does. But when I asked him what he thought about the feasibility of detecting it by a laboratory experiment, he was not very sanguine of success. It seemed worth while, however, to make the attempt, and I came to the conclusion that the difficulty was not so much in the faintness of the effect to be looked for as in the avoidance of stray light which came into competition with it. The essential thing is to get a perfectly black background against which the beam (viewed transversely) can be observed. We cannot get this with a vessel like Tyndall's tube just used. It is necessary to have what may be called a black cave, and to view the beam as it crosses in front of the mouth of the cave, the latter forming the background. If the cave is deep enough, there is no limit to the blackness attainable. The great sensitiveness of the well-rested eye, or the photographic plate, can then be brought to bear, and the track of the beam can be well seen, however carefully the dust is removed.

Some persons have been inclined to question whether the dust is removed completely in these experiments. As a matter of fact, this is not where the difficulty lies at all. Dust so fine as to be very difficult of filtration is an arm-chair conception, not encountered in practical experimenting. An enormous multiplication of the length and tightness of the cotton-wool filter makes no difference at all, a filter of modest dimensions doing all there is to do.

The dust particles which are originally present in the air, near the ground or in a room, are large, being in some cases individually visible to the naked eye; thus they do not fulfil the condition for scattering a preponderance of blue light. The molecules of air are, of course, amply small enough, and the band of light seen stretching across the mouth of the dark cave is, to my eyes at least, of a full blue colour. In exhibiting the effect to individual friends (and unfortunately it is not bright enough to be shown to an audience), I have been surprised and somewhat disconcerted to find that they do not all see it blue as I do, but some, for example, describe it as lavender. This is undoubtedly due to a peculiarity of colour-vision where faint lights are concerned. The ultimate test is the spectroscope. Photographs of the scattered light taken with this instrument clearly show that the maximum of intensity is shifted towards the blue, as compared with the original exciting light.

Polarisation of Light Scattered by Pure Air.

A very important point to examine in connection with the scattered light is its state of polarisation. Visual examination with a Nicol's prism soon showed that the polarisation was very nearly complete. For closer examination I had recourse to photography. It may perhaps be thought an easier and more effective plan to look at a phenomenon than to photograph it, and no doubt it is so in many cases: not, however, where the light is very faint, but admits of long exposure. It has long been recognised that photographs of the nebulæ will show much more than can be detected visually by the keenest and most discriminating eye. In this work on the scattering of light, I have found it positively less trouble to take a photograph than to make a visual observation, even when the latter was feasible. The time required to rest the eye in darkness and the effort of attention required in observing a faint effect cost the experimenter more than the exposure and development of a plate.

When the scattered beam in pure air is photographed, with a double image prism of Iceland spar mounted over the photographic lens, it is found that the polarisation is nearly complete, but not absolutely so. However carefully the instrumental adjustments are made and the air filtered, I have found that there is a slight residual polarisation indicating vibrations parallel to the direction of the original beam. The intensity of this residual polarisation, in what may be called for convenience the wrong direction, is about 4 per cent. of the whole. Now, as the theory shows, there are two causes to which failure of complete polarisation may be attributed. One, which we may dismiss in this case, is that the particles are not small enough. Another is that they are not spherical—that is to say, it is not a matter of indifference which way they are presented to the primary beam. The latter alternative may be illustrated by considering an extreme case—namely, what we may call a needle-like molecule, capable of vibrating only in one direction fixed within it. Evidently such a molecule when obliquely situated will have a component vibration parallel to the direction of the incident light.

From the experimental fact that there is such a component we may infer that the molecules of air are not in the optical sense spherical. Experiments on various gases have shown a characteristic departure from complete polarisation, different for each gas. Much effort has been spent on determining the exact amount for each, and it is hoped that the numbers obtained will form valuable material in the future for investigating the structure of atoms and molecules.

Polarisation of the Night Sky.

We have seen that the polarisation of the daylight sky is one of the most conclusive proofs that its light is due to scattering by small particles. What of the sky at night? Some of you will perhaps be inclined to reply that the sky at night is dark, and that the question whether its light is polarised does not arise. It is, however, by no means the case that the sky on a clear night is absolutely dark, as anyone may readily prove by holding his hand with outstretched fingers against the sky. The fingers will appear dark against the sky as a luminous background.

The light is no doubt very faint, but I thought it would be practicable to test whether it was appreciably polarised or not. For this purpose what is called a Savart polariscope was used. Time will not allow us to consider the rather complex theory of this apparatus; it must suffice to say that if the light which falls upon it contains even a small part which is polarised, bands alternately bright and dark are produced, which further show colour due to the composite nature of white light. These bands are clearest when the incident light is completely polarised, as you now see them projected on the screen. But they can still be seen when the polarisation is but slight. I will illustrate this by removing the polarising Nicol which I have been using, and substituting a single glass plate, through which the incident light passes. If I incline this plate so as to polarise a small fraction of the light, you see the bands, faint but sufficiently distinct. In examining the light of the night sky, a photographic plate is substituted for the paper screen I have been using to-night, and the apparatus is designed for the utmost economy of light. With two hours' exposure a definite image of the sky was obtained, with the stars superposed upon it. The Savart bands could be seen, but they were very faint compared with what would have been observed with an equally good image of the daylight sky. The part of the sky examined was near the pole, and therefore nearly at right angles to the sun. If, as seemed possible, the night sky derived its light from an attenuated atmosphere so high as to be outside the earth's shadow, we should expect it to show the same polarisation as the day sky. Since it does not do so, we must attribute the light at night to some different origin.

I was fortunate in being able to interest Prof. Hale in this matter while he was on a visit to England, and as a result Mr. Babcock repeated the observations in a modified form at the Mount Wilson Observatory in California. The traces of polarisation which he obtained in that clear atmosphere were even less than what I got in England.

Ozone, and the Limit of the Solar Spectrum.

Although, as we have seen, the idea that the blue colour of the sky is due to any action of ozone cannot be admitted, yet there are points of great optical interest connected with the presence of this gas in the atmosphere. We may now turn to the consideration of some of these.

It is of course well known that when the solar spectrum is formed by a prism of quartz or by a grating, the spectrum can be observed to extend beyond its visible limit in the violet into the region called ultra-violet. When, however, we examine the spectrum of an electric arc (and for this purpose an iron arc is particularly suitable), the extension is observed to be very much greater than in the solar spectrum. This is not because the sun does not emit any rays of the kind in question, but because the earth's atmosphere will not allow them to pass through so as to reach us at the earth's surface. There are many reasons for feeling sure that this is the true explanation, but one of the simplest will here suffice. When the sun is near the horizon, so that the rays pass obliquely through the earth's atmosphere, and consequently have to traverse a thicker absorbing layer, the extent of the ultra-violet spectrum is found to be even less than when the sun is high and less air is traversed by the rays. This sufficiently proves the point.

It has long been suspected that ozone in the atmosphere is the effective cause of this absorption of the ultra-violet rays. The most important constituents of air, oxygen, and nitrogen do not appreciably absorb at the point where the solar spectrum ends, nor do the constituents of secondary importance, carbonic acid, water-vapour, and argon. We must therefore look to some rare constituent of air which is very opaque to this region of the spectrum. Ozone possesses this opacity, as I shall now show you. So far as I know it has not been attempted to show this before to an audience, but I think you will be able to see it without difficulty. As a source of light an iron arc is used, and the lenses and prism employed in forming the spectrum are of quartz. I allow the spectrum to fall on a piece of paper, and you see the usual succession of colours, red, yellow, green, blue, and violet, forming a comparatively narrow rainbow-like band. Beyond the violet all appears dark, the eye being insensitive to the ultra-violet rays. If now I substitute for the paper a screen of barium platinocyanide[2] (of the kind used in X-ray work), we see an immense extension of the spectrum beyond the violet. The screen has the property of transforming the ultra-violet rays, which the eye cannot detect, into green rays which are readily visible. Thus beyond the violet region we see green, which is, of course, in no way to be confused with the original green which was present in the source. and appears in its normal position in the spectrum, on the other side of the blue-violet. I interpose a thin sheet of ordinary glass, and the greater part of this extension of the spectrum which we get on the fluorescent screen disappears. What I want specially to show you, however, is that a thin layer of ozone, much too thin to have any perceptible colour, will have the same effect. There is a glass tube, about 6 in. long and $\frac{3}{4}$ in. in diameter, situated between the quartz lantern condenser and the slit, when the beam is parallel, and the walls of the tube are projected as two thin transverse lines on the slit, dividing the spectrum into thin horizontal strips, one over the other. The light constituting the middle strip has traversed the tube, but the light constituting the upper and lower strip has traversed the open air above and below the tube. A stream of oxygen passes through a Siemens ozone generator and enters the middle of the observation tube, streaming out at the two ends. While the ozone generator is not excited, the middle strip of the spectrum is similar to the comparison strips above and below. If the induction coil is turned on so that ozone passes into the tube, you see that in a few seconds the greater part of the ultra-violet spectrum fades out from the middle strip, which contrasts sharply with the upper and lower ones. When the coil is turned off, the ozone is rapidly blown out by unozonised oxygen, and the original state of things restored.

It must be remembered that the ozone used in this experiment is extremely dilute, probably only a fraction of 1 per cent. of the oxygen in the tube.

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[2] Kindly lent by Messrs. Watson.

Yet it interposes an impassable obstacle to the ultra-violet rays, at least to those of shorter wave-length than about 2900 angstroms. It cuts off the iron spectrum at about the same point where the solar spectrum ends. Speaking roughly and generally, it may be said that glass is somewhat more opaque than ozone—*i.e.* that with diminishing wave-length the limit of transmission is reached somewhat sooner. To make a statement of this kind quite definite the thickness must of course be specified.

Sir William Huggins devoted a great deal of attention to the spectra of the sun and stars in the extreme ultra-violet region, using for the purpose a reflecting telescope, and prisms and lenses made of quartz or Iceland spar. In this way the absorption of a glass objective was avoided. He noticed in 1890 that the spectrum of Sirius showed a number of bands near the extreme limit of atmospheric transmission, the bands tailing off into complete absorption.

These bands were observed and discussed by other authors, but no definite conclusion was reached as to their origin until 1917, when the matter was taken up by my colleague, Prof. Fowler, and myself. Our interest was stimulated by an excellent photograph of the bands, taken at Edinburgh Observatory under Prof. Sampson's direction, which I show on the screen. We found that the same bands were present in the solar spectrum. It may seem strange that this had not been observed long ago, considering how closely the solar spectrum has been scrutinised for more than a generation. As a matter of fact this is one of the cases where a powerful instrument is a positive disadvantage. The bands are diffuse, and under high dispersion they are unrecognisable. In any case, they are less conspicuous than in the spectrum of Sirius, because in the sun numerous metallic lines are superposed upon them and distract the eye.

Now the position and general aspect of these bands suggested that they were connected with the absorption which terminates the spectrum. This led us to suspect that they were due to ozone, and the suspicion was readily confirmed by experiment. Burning magnesium ribbon gives a convenient source of continuous spectrum in the ultra-violet region. Interposing a long tube containing ozone between the burning magnesium and the slit, a series of bands was photographed which exactly corresponded to those photographed in the solar spectrum with the same instrument, as you will see in the slide shown.

Absence of Ozone near the Ground.

We are then driven to the conclusion that the absence of short waves from the spectra of the sun and stars is due to absorption by terrestrial ozone. But it was not thought desirable to let the matter rest there. It is true that many attempts had been made to determine the (no doubt very small) quantity of ozone in air by chemical means, but with very conflicting results, because other constituents of air, such as oxides of nitrogen, are liable to produce reactions not unlike those of ozone. It seemed more satisfactory to test the absorbing power of air near the ground for ultra-violet rays, to which ozone is so opaque. I used for this purpose a mercury vapour lamp in a quartz vessel, which is a powerful source of ultra-violet rays, and observed its spectrum four miles away, so that the mass of air intervening was as great as that between the midday summer sun and the top of the Peak of Teneriffe, from which observations of the extent of the solar spectrum have been made. The result was to show that the mercury lamp spectrum was by no means stopped when the solar spectrum stops, but that it extended to the region where ozone is most opaque. There is a strong mercury line (wave-length 2536) at about this point which was distinctly photographed. Its intensity was of course a good deal reduced relative to the visible spectrum by atmospheric scattering. But there was no evidence whatever of ozone absorption.

What conclusion can we draw? Evidently that the absorbent layer of ozone in the air is high up, and that there is little or none near the ground. It may seem at first sight that this thin and inaccessible layer of ozone, which we have learned of by a chain of reasoning not less conclusive than direct observation, is a matter of little importance to man and his welfare. There could be no greater mistake. It acts as a screen to protect us from the ultra-violet rays of the sun, which without such a protection would probably be fatal to our eyesight: at least if one may judge from the painful results of even a short exposure to such rays, which those who have experienced it are not likely to forget.

The Future of the Iron and Steel Industry in Lorraine.

By PROF. H. C. H. CARPENTER, F.R.S.

DURING the spring of last year two Commissions were appointed by the Minister of Munitions to visit and report upon certain steel-producing areas in Western Europe. One of them visited the steel works in Lorraine and certain parts of the Saar Valley, the other journeying to the occupied areas of Germany, Luxemburg, and certain parts of France and Belgium. The former was under the charge of Sir William Jones, and included Messrs. Percy Cooper, Rowland Harding, and Cosmo Johns, while the latter was entrusted to Dr. F. H. Hatch, who had with him Messrs. L. Ennis, James Henderson, and Richard Mather. The Commissions were absent about three weeks. The terms of reference to them were the same and were to ascertain:—