separating in search of food, have left their carcases, wasted by famine, variously scattered at a distance from each other.

The following questions are thus suggested for inquiry :—

Are the bones of young and of old animals mixed indiscriminately throughout the whole of these bone-beds ?

Is it possible to distinguish the bones of females from those of males ?

Do the bones of the larger and stronger individuals occur in greater abundance near the top of the bone-beds, and those of the smaller and feebler animals nearer the bottom of those beds ?

If the sea followed these animals quickly, the young and the feeblest would perish before they reached the great deposits of bones.

Although not at all confident that either of these explanations is the true one, I look upon them as open to less objection than any other of which I have yet heard, and therefore give them a temporary assent.

The conclusion to which these remarks lead, is that whilst we ought to be quite prepared to examine any evidence which tends to prove the great antiquity of our race, yet that if the facts adduced can be explained and accounted for by the operation of a few simple and natural causes, it is unphilosophical to infer the coexistence of man with those races of extinct animals.

The interest and importance of the subject are such, that new and still more extensive researches cannot fail to be made ; and if these remarks shall in any way contribute to lighten the labour of future inquirers, or to promote the true explanation of the facts, they will have fully attained the object of their publication.

XI. "Remarks on Colour-Blindness." By Sir John F. W. Herschel, Bart., F.R.S.

[Extracted from a Report by Sir J. F. W. H. on Mr. Pole's paper on the same subject*, and communicated at the request of the President and Council.]

I consider this paper as in many respects an exceedingly valuable contribution to our knowledge of the curious subject of colour-blind-

* "Proceedings," vol. viii. p. 172 ; and vol. ix. p. 716.

ness—1st, because it is the only clear and consecutive account of that affection which has yet been given by a party affected, in possession of a knowledge of what has yet been said and written on it by others, and of the theories advanced to account for it, and who, from general education and habits of mind, is in a position to discuss his own case scientifically; and 2ndly, for the reasons the author himself alleges why such a person is really more favourably situated for describing the phenomena of colour-blindness, than any normal-eyed person can possibly be. It is obvious that on the very same principle that the latter considers himself entitled to refer all his perceptions of colour to three primary or elementary sensations—whether these three be red, blue, and yellow, as Mayer (followed in this respect by the generality of those who have written on colours) has done, or red, green, and violet, as suggested by Dr. Young, reasoning on Wollaston's account of the appearance of the spectrum to his eyes—on the very same principle is a person in Mr. Pole's condition, or one of any other description of abnormal colour-vision, quite equally entitled to be heard, when he declares that he refers his sensations of colour to two primary elements, whose combination in various proportions he recognizes, or thinks he recognizes, in all hues presented to him, and which, if he pleases to call yellow and blue, no one can gainsay him; though, whether these terms express to him the same sensations they suggest to us, or whether his sensation of light with absence of colour corresponds to our white, is a question which must for ever remain open (although I think it probable that such is really the case). All we are entitled to require on receiving such testimony is, that the party giving it should have undergone that sort of *education of the sight and judgment*, especially with reference to the prismatic *decomposition* of natural and artificial colours, for want of which the generality of persons whose vision is unimpeachably normal, appear to entertain very confused notions, and are quite incapable of discussing the subject of colour in a manner satisfactory to the photologist.

It is as necessary to distinguish between our sensations of colour, and the qualities of the light producing them, as it is to distinguish between bitterness, sweetness, sourness, saltness, &c., and the chemical constitution of the several bodies which we call bitter, sweet, &c. Whatever their views of prismatic analysis or composition

might suggest to Wollaston and Young, I cannot persuade myself that either of them recognized the *sensation* of greenness as a constituent of the sensations they received in viewing chrome yellow, or the petal of a Marigold on the one hand, and ultramarine, or the blue Salvia on the other; or that they could fail to recognize a certain redness in the colour of the violet, which Newton appears to have had in view when he regarded the spectrum as a sort of octave of colour, tracing in the repetition of redness in the extreme refrangible ray, the commencement of a higher octave too feeble to affect the sight in its superior tones. Speaking of my own sensations, I should say that in fresh grass, or the laurel-leaf, I do not recognize the sensation either of blue or of yellow, but something *sui generis*; while, on the other hand, I never fail to be sensible of the presence of the red element in either violet, or any of the hues to which the name of purple is indiscriminately given; and my impression in this respect is borne out by the similar testimony of persons, good judges of colour, whom I have questioned on the subject.

I would wish, then, to be understood as bearing in mind this distinction when speaking of the composition of colours by the superposition of coloured lights on the retina. It seems impossible to reason on the joint or compound sensation which ought to result from the supraposition in the sensorium of any two or more sensations which we may please to call primary; so that if, following common usage, I speak in what follows of red, yellow, and blue (or in reference to Young's theory of red, green, and violet) as *primary colours*, I refer only to the possibility of producing all coloured sensations by the union on the retina of different proportions of lights, competent separately to produce those colours, which is purely a matter of experience.

It is necessary to premise this, when I remark that I by no means regard as a logical sequence Mr. Pole's conclusion in § 15, that because he perceives as colours only yellow and blue, *therefore* the neutral impression resulting from their union must be that sensation which the normal-eyed call green. On the contrary, I am strongly disposed to believe that he sees white as we do, for reasons which I am about to adduce.

Mr. Maxwell has lately announced his inability to form green by the combination of blue and yellow. On the other hand, the pris-

matic analysis of the fullest and most vivid yellows (those which excite the sensation of yellowness in the greatest perfection), as the colours of bright yellow flowers, or that of the yellow chromate of mercury, clearly demonstrates the fullness, richness, and brilliancy of their colour to arise from their reflexion of the whole, or nearly the whole of the red, orange, yellow, and green rays, and the suppression of all, or nearly all the blue, indigo, and violet portion of the spectrum. On the hypothesis of an analysis of sensation corresponding to an analysis of coloured light, these facts would seem incompatible with the simplicity of the sensation yellow, and it would appear impossible (on that hypothesis) to express them otherwise than by declaring red and green to be primary sensations, and yellow a mixture of them—a proposition which needs only to be understood to be repudiated—quite as decidedly as that the *sensation* of greenness is a mixture of the *sensations* of blueness and yellowness, and for the same reason; the complete want of suggestion of the so-called simple sensations by the asserted complex ones.

Mr. Maxwell's assertion that blue and yellow do not make green, assuredly appears startling as contradictory to all common experience; but the common experience appealed to is that of artists, dyers, and others in the habit of mixing natural colours as they are presented to us in pigments, coloured tissues, &c., who have for the most part never seen a prismatic spectrum, or at least attended to its phænomena. The perceptions of colour afforded by such objects are those of white light from which certain rays have been abstracted by absorption, that is to say, they are *negative hues*, or hues of darkness rather than of light, inasmuch as all the colouring of the artist is based, not on the generation, but on the destruction of light. This circumstance, which is not generally recognized, even among educated artists, has vitiated all the language of chromatics as applied to art, and so placed a barrier between the painter and the photologist, which has to be surmounted before they can come to a right understanding of each other's meaning. It is evident, that, to make experiments on the subject free from this objection, absorptive colours must be discarded, at least in bodily mixture with each other. Thus it is true that a dingy green may be produced by rubbing together in powder prussian blue and the yellow chromate of mercury above mentioned; but both these agree in reflecting a con-

siderable, and the latter a very large proportion of green light, to the predominance of which in the joint reflected beam its tint is owing. So also, when blue and yellow liquids (not acting chemically on each other) are mixed, as in water-colour drawings, greens, sometimes very lively ones, are produced. In these cases the yellow absorbs almost all the whole of the incident blue, indigo, and violet light, and the blue a very large proportion of the red, orange, and yellow, both allowing much green to pass; and to *this*, rather than to a mixture of the other rays, the resulting tint is due.

In the light transmitted by cuprate of ammonia of a certain thickness, the red, orange, yellow, and green are wholly extinguished, while the blue, indigo, and violet are allowed to pass. The result is the fullest and *bluest* blue it is possible to obtain. From this result, compared with that derived from the analysis of natural yellows, it follows that the union on the retina of the yellowest yellow, and the bluest blue, in such proportions that neither shall be in excess, so as to tinge the resulting light either yellow or blue, is *not green, but white*. The same conclusion follows from dividing the spectrum into two, the one portion containing all the less refrangible rays up to the limit of the green and blue, the other all the remaining rays. If the blue portion be suppressed, and the remainder reunited by a refraction in the opposite direction, the resulting beam is *yellow*, if the other, *blue*, both vivid colours—but if neither, *white* of course, and not green, results from the exact recomposition of the original white beam.

It may be objected to this, that in the complementary colours exhibited by doubly-refracted pencils in polarized light, yellow is often found to be complementary to purple, and blue to orange. But in neither of these pairs of colours is the spectrum divided in the manner above indicated; and, moreover, in many instances yellow and blue *are* found as complementary colours in the oppositely polarized pencils; of which examples will be found in the scale of tints produced by sulphate of barytes in my paper "On the Action of Crystallized Bodies in Homogeneous Light" (Phil. Trans. 1820, Table I.). "Rich yellow" appears also as opposed to "full blue" in the scale of complementary tints exhibited by mica in my "Treatise on Light" (Encyc. Metrop., art. 507). It is not asserted that either a good yellow or a good blue cannot be produced otherwise

than in a particular manner, but that they *can* be produced *in* that particular manner, and that *when* so produced, their union affects the eye with no sensation of greenness.

Let two very narrow strips of white paper, A, B, be placed parallel to one another in sunshine, so as to be seen projected on a perfectly black ground (a hollow shadow), and viewed through a prism having the refracting edge parallel to them, the refraction being towards the eye, and let the nearer B be gradually removed towards A, so that the red portions of B's spectrum shall fall upon the green portion of A's. Their union will produce *yellow*, or, if too far advanced, *orange*. On the other hand, it will be seen that the yellow space in B's spectrum on which the blue of A's falls is replaced by a streak of white,—whiteness, and not greenness, being the resultant of the joint action of these rays on the retina. If the strips be made wedge-shaped, tapering to fine points, and A being still white, B be made of paper coloured with the yellow chromate of mercury before mentioned, the whiteness of the streak where the blue of A mixes with the yellow of B near the pointed extremities will be very striking.

There is a certain shade of cobalt-blue glass which insulates, or very nearly so, a definite yellow ray from the rest of the spectrum, suppressing the orange and a great deal of the green. If the spectrum of B, formed and coloured as last described, be viewed through this glass, a very well-defined image of it, clearly separated from its strong red and very faint blue images, will be seen. As the glass in question allows blue rays to pass, the white object, A, besides its definite yellow image, will form a broad blue, indigo, and violet train nearer to the eye. Now let B be gradually brought up towards A, so that the violet, indigo, and blue rays of this train shall coincide in succession with the yellow image of B,—*no sensation of greenness will arise at any part of its movement*. Again, if a white card be laid down on a black surface, the edge nearest the eye, when refracted towards the spectator by a prism, will of course be fringed with the more refrangible half of the spectrum. Let this be viewed through such a glass, and in the blue space so seen introduce one half of a narrow rectangular slip of paper thus coloured, having its upper edge in contact with the lower edge of the white card, the other half projecting laterally beyond the card. In this arrangement the definite

image of the yellow paper insulated by the glass will be seen divided into a *yellow* half, projecting beyond the blue fringe, and a purplish- or bluish-white one within it, hardly to be distinguished from the image of the white paper, of which it seems a continuation, and which through the glass in question appears a pale blue. This same purplish tint was observed to arise also under the following circumstances:—Laying down in a good diffused light a paper of an exceedingly beautiful ultramarine blue, and beside it, and somewhat overlapping it, another coloured with the same yellow chromate, I set upon the line of junction a sheet of glass inclined to the plane of the papers upwards towards the eye, so as to allow the blue to be seen by transmitted light, while the yellow reflected from the glass was at the same time received into the eye. By varying the inclination of the glass, the yellow reflexion could be made more or less vivid, so as either to be nearly imperceptible or quite to *kill* the blue of the paper. But at no stage of its intensity, gradually increased from one to the other extreme, was the slightest tendency to greenness produced. The colour passed from blue to yellow, not through green, but through a pale uncertain purplish tint, not easy to describe, but as remote from green as could be well imagined.

Of course in all such experiments one eye only must be used. Stereoscopic superposition of colour, which at first sight would appear readily available, does not satisfy the requisite conditions, and yields no definite results.

The conclusions from these facts may be summed up as follows:—1st. That in no case can the sensation of green be produced by the joint action on the eye of two lights, in neither of which, separately, prismatic green exists; 2ndly. That the joint action of two lights, separately producing the most lively sensations of blue and yellow, does not give rise to that of green, *even when one of them contains in its composition the totality of green light in the spectrum*; and, 3rdly. That all our liveliest sensations of yellow are produced by the joint action of rays, of which those separately exciting the ideas of red and green form a large majority; and that a decided yellow impression is produced by the union of these only.

From these premises it would seem the easiest possible step to conclude the non-existence of yellow as a primary colour. But this conclusion I am unable to admit in the face of the facts,—1st, that

a yellow ray, incapable of prismatic analysis into green and red, may be shown to exist, both in the spectrum and in flames in which soda is present; and 2ndly, that neither red nor green, as sensations, are in the remotest degree suggested by that yellow in its action on the eye. Whether under these circumstances the vision of normal-eyed persons should be termed trichromic or tetrachromic, seems an open question.

That Mr. Pole's vision is *di*chromic, however, there can be no doubt. If I could ever have entertained any as to the correctness of the views I have embodied of the subject in that epithet, after reading all I have been able to meet with respecting it, this paper would have dispelled it. That he sees blue as we do, there is no ground for doubting; and I think it extremely likely that his sensation of whiteness is the same as ours. Whether his sensation of yellow corresponds to ours of yellow, or of green, it is impossible to decide, though the former seems to me most likely.

One of the most remarkable of the features of this case, and indeed of all similar ones, is the feebleness of the efficacy of the red rays of the spectrum in point of illuminating power, which certainly very strongly suggests an explanation drawn from the theory of three primary coloured *species of light*, to one of which the colour-blind may be supposed absolutely insensible. Mr. Pole himself evidently leans to this opinion. I had satisfied myself, however, in the case of the late Mr. Troughton, that the *extreme* red—that pure and definite red which is seen in the solar spectrum only when the more luminous red is suppressed, and in which I cannot persuade myself that any yellow exists, was not invisible to him,—though of course not seen as *red*; and on supplying Mr. Pole with a specimen of a glass, so compounded of a cobalt-blue and a red glass as to transmit positively no vestige of any *other* ray, but *that* copiously, so that a candle seen through it appears considerably luminous, and the window-bars against a cloudy sky are well seen if other light be kept from falling on the eye,—I am informed by him that he saw through it "gas, *fire* and other strong lights with perfect distinctness," and that the colour so seen is a "very deep dark yellow." Now it seems to me impossible to attribute this to any minute per-centage of yellow light of the same refrangibility, which this can be supposed to contain. The purity of its tint is extraordinary; and its total intensity

so small, that supposing it reduced to one-tenth of its illuminating power by the suppression of the whole of its primary red constituent, I cannot imagine that any gas-flame or fire-light would be visible through it, or any other luminous body but the sun.

Still it remains a fact, however explained, that the red rays of the spectrum generally are to the colour-blind comparatively but feebly luminous. Mr. Pole speaks of red in more places than one as "*a darkening power*;" and in the letter I have received from him in reply to my query as to the visibility of light through the red glass above mentioned, he insists strongly on its action as *darkness*. This, however, can only be understood of the effects of red powders in mixture, and not of red *light*; and as, to our eyes, an intense blue powder, such as prussian blue, has, besides its colorific effect, a violent darkening one (owing to its feeble luminosity), so, to the colour-blind, red powders, when added to others, contribute but little light in proportion to the bulk they occupy in the mixture, and therefore exercise a darkening power by displacing others more luminous than themselves. I think it therefore very probable that red appears to the colour-blind as yellow-black does to the normal-eyed, or, in other words, that our higher reds are seen by them as we see that shade of brown which verges to yellow—that of the faded leaf of the tulip-tree for instance. Now it is worthy of remark, that it is very difficult for the normal-eyed to become satisfied that the browns are merely *shades* of orange and yellow. *Brownness* (such at least has always been my own impression) is almost as much a distinct sensation as greenness; so that I am not at all surprised at the expression in § 22, that the "sensation of red as a *dark yellow* is certainly very distinct from *full yellow*," or that a colour-blind person should, after long and careful investigation, arrive at the conclusion that red is not to him a distinct colour. I find all this completely applicable to my own perception of the colour brown.

Mr. Pole (§ 11) appears to lay great stress on the fact, that in a closed colour circle in which red, yellow, and blue are so arranged that each shall graduate into both the others, there occurs in the space where red and blue graduate into each other, "a hue of red which is to him absolutely insensible," and that this red corresponds *not* to that colour which, under the name of carmine, offers to the normal-eyed the *beau-ideal* of redness, but what they term "crim-

son." Invisibility, as an element of colour, must not here be confounded with invisibility as light. It is certain that he *sees* the crimson. It is not to him black, but (just what it ought to be on the supposition that his vision is dichromic, and the union of his colours produces white) a neutral, obscure grey; grey being only an abbreviated expression for feeble illumination by white light. In a circle coloured with three elements graduating into each other, there is no neutral point—none, that is, where whiteness or greyness can exist; but when coloured with only two elements, such as yellow and blue (*positive* yellow and blue, that is, whose union produces white, not green), there are of necessity two neutral points which would be both equally white, *i. e.* equally luminous, if the two extremities of each of the coloured arcs graduated off by similar degrees. But this not being the case with the yellow arc, one of its ends to the colour-blind corresponding to a continuation of the red, and so being deficient in illuminating power, the point of neutrality will be that where a feebler yellow is balanced by a feebler blue, and will therefore be less luminous, *i. e.* less white or more grey than the other neutral spot. It is evident, from the general tenor of Mr. Pole's expressions throughout this paper, that his ideas on the subject of colour are gathered mainly from the study of pigments and absorptive (i. e. *negative*) colours, and not from that of prismatic (or *positive*) ones. In other words, his language is that of the painter, as distinguished from the photologist; the distinction consisting in this—that in the former colour is considered in its contrast with whiteness, in the other with blackness; and thus it is that black is considered by many painters as an element of colour, as whiteness necessarily is by photologists.

I may perhaps be allowed to add a few words as to the statistics of this subject. Dr. Wilson gives it as the result of his inquiries, that one person in every eighteen is colour-blind in some marked degree, and that one in fifty-five confounds red with green. Were the average anything like this, it seems inconceivable that the existence of the phenomenon of colour-blindness, or dichromy, should not be one of vulgar notoriety, or that it should strike almost all uneducated persons, when told of it, as something approaching to absurdity. Nor can I think that in military operations (as, for instance, in the placing of men as sentinels at outposts), the existence,

on an average, of one soldier in every fifty-five unable to distinguish a scarlet coat from green grass would not issue in grave inconvenience, and ere this have forced itself into prominence by producing mischief. Among the circle of my own personal acquaintance I have only known two (though, of course, I have heard of and been placed in correspondence with several); and a neighbour of mine, who takes great delight in horticulture, and has a superb collection of exotic flowers, informs me that among the multitude of persons who have seen and admired it, he does not recollect having ever met with one who appeared incapable of appretiating the variety and richness of the tints, or insensible to the brilliancy of the numerous shades of red and scarlet. It may be, however, that the percentage is on the increase—certainly we *hear* of more cases than formerly; but this probably arises from the fact of this, like many other subjects, being made more generally matter of conversation.

In further reference to the question of the superposition of colours in the spectrum, or of the intrinsic compositeness of rays of definite refrangibilities, I may mention a phenomenon which I have been led to notice in the prosecution of some experiments on the photographic impressions of the spectrum on papers variously prepared, which appeared to me, *when first noticed,* quite incompatible with the simplicity of those rays at least which occupy the more luminous portion of the spectrum, extending between the lines marked D and E by Fraunhofer, and clearly to demonstrate the presence of green light over nearly the whole of that interval. In these experiments the spectrum formed by two Fraunhofer flint prisms, arranged so as to increase the dispersion, and adjusted to the position of least deviation for the yellow rays, was concentrated by an achromatic lens, and received on the paper placed in its focus, which could be viewed from behind. A series of white papers impregnated with washes of various colourless or very slightly coloured chemical preparations, and dried, were exposed; and the spectrum being received on them, and the centre of the extreme red image as viewed through a standard glass, adjusted to a fiducial pinhole; a sensitizing wash of nitrate of silver, or any other fitting preparation, was copiously applied to the exposed surface while under the action of the light. Now, under these circumstances, I uniformly found that whereas the spectrum viewed from behind through the paper exhibited all over the space

in question a dazzling very pale straw-yellow, hardly distinguishable from white, yet as the photographic action proceeded, and the translucency of the paper began to be somewhat diminished also by incipient drying, very nearly the whole of that space became occupied by a full and undeniable green colour, so as to give the idea of a distinctly four-coloured spectrum—red, green, blue, and violet; the yellow being in some instances almost undiscernible, and in others limited to a mere narrow transitional interval rather orange than yellow. It was at the same time evident that a great extinction of light (illumination independent of colour) had also been operated, the vivid glare of the part of the spectrum in question being reduced to a degree of illumination considerably inferior to the red part, or, at all events, not much superior. The change of colour was far greater than could be attributed to any effect of contrast, and was proved decisively not to be due to that cause by hiding the adjacent red and blue when the green remained unaffected in apparent tint.

When, for the photographic preparations wetted as described, ordinary, dry, coloured papers were substituted, the change of colour in question was always produced whenever the thickness of the paper and its absorptive power were not such as to destroy or very much enfeeble the more refrangible light. Taking, as a term of comparison, a purely white, wove, writing-paper, I found that the substitution of writing-paper, tinted with the ordinary cobalt blue commonly met with, sufficed to give a very great extension of the green, almost to the extinction of the yellow, while, when the papers used were pale-yellow or clay-coloured, answering to the tints called "buff" or "maize" (nearly approximating to Chevreul's *orangé* 4 and 3), and which might naturally have been expected to transmit yellow rays more abundantly at all events than the blue, the spectra (viewed at the back of the papers) were particularly full and abundant in green, occupying the whole of the debateable ground. In the case of the former, a narrow yellow space was seen, and the blue was very much enfeebled, and separated from the green by a very perceptible suddenness of transition. With the latter the green was finely exhibited, and the yellow confined to a narrow orange-yellow border: the blue and violet much enfeebled.

On further considering these facts, there seemed to be but three ways of accounting for them:—1st, by the effect of contrast. This

I consider to be disposed of by the suppression of the adjacent colours, as recorded above. 2ndly, by extinction of a *yellow element* of colour over the space DE, allowing a substratum of green to survive; or, which comes to the same, by the extinction of the red element over the same space, which, by its combination with (an assumed elementary) green, produced the original brilliant straw-yellow. And 3rdly, by admitting as a principle, that our judgment of colours absolutely, *in se*, and independent of contrast, is influenced by the *intensity* of the light by which they affect the eye, and that very vivid illumination enfeebles or even destroys the perception of colour. As the apparent change of colour from pale-yellow to green in the cases above related was always accompanied with a great diminution of general intensity, it occurred to me to produce such diminution by optical means, which should operate equally on all the coloured rays, and diminish all their intensities in the same ratio. This was accomplished by viewing the spectrum (as projected on purely white paper) by reflexion on black glass, or by two successive reflexions in different planes, and I found the very same effect to take place. That portion DE of the spectrum which in the unreflected state appeared dazzlingly bright and nearly colourless, was seen by one such reflexion, and still more so by two, green. The extension of the green region was greater, and the limitation of the yellow portion more complete, according to the amount of illumination destroyed by varying the angles of incidence on the glasses. When much enfeebled by two cross reflexions, the aspect of the spectrum was that represented in Chevreul's coloured picture of it from the line A to H. When enfeebled by other means, as by viewing the spectrum thrown on a blackened surface, the effect was exactly the same.

The last of our three alternatives, then, would appear to be established as the true explanation; and in respect of the second, it is eliminated by the consideration that neither the slight degree of coloration in the bluish papers, or the tint of the pale-yellow ones which effected the change, would give rise to so great a *preferential* extinction of yellow or red rays as an explanation founded on that alternative would require. The phenomenon is certainly a very striking one, and has created great surprise in those to whom I have shown it.