

III. "On the Fossil Mammals of Australia.—Part III. *Diprotodon australis*, Owen." By Prof. OWEN, F.R.S. &c. Received December 10, 1869.

(Abstract.)

In this paper the author communicates descriptions, with figures of the fossil remains at his command, of *Diprotodon australis*, which have been received from various localities in Australia, since the first announcement of the genus, founded on a fragment of the lower jaw and tusk, described and figured in the 'Appendix' to Sir Thos. Mitchell's 'Three Expeditions into the Interior of Eastern Australia,' 8vo, 1838.

The fossils in question include the entire cranium and lower jaw with most of the teeth, showing the dental formula of:— $i. \frac{3-3}{1-1}$ ,  $c. \frac{0-0}{0-0}$ ,  $m. \frac{5-5}{5-5} = 28$ ; portions of jaws and teeth exemplifying characteristics of age and sex; many bones of the trunk and extremities.

After some introductory remarks, the author proceeds to the description of the skull and teeth, which are illustrated by many figures, those of the teeth being of the natural size. The result of the comparisons detailed establishes the marsupial character of *Diprotodon*, and the combination of characters of *Macropus* and *Phascolomys* with special modifications of its own. These latter are more fully and strongly manifested in the bones of the trunk and limbs, subsequently described. The pelvis and femora present resemblances to those in *Proboscidea*, not hitherto observed in any other remains of large extinct quadrupeds of Australia. But in all the bones described essentially marsupial characteristics are more or less determinable. The paper concludes with a summary of the characters of *Diprotodon*, throwing light upon the conditions of its extinction, its analogies with the *Megatherium*, its affinities to existing forms of *Marsupialia*, and the more generalized condition which it manifests of that mammalian type.

A table of the localities in Australia from which remains of *Diprotodon* have been obtained, and a table of the principal admeasurements of the skeleton, are appended to the text.

February 10, 1870.

Lieut.-General Sir EDWARD SABINE, K.C.B., President, in the Chair.

The Right Hon. Lord Napier of Magdala, and M. Charles Eugène Delaunay (Foreign Member) were admitted into the Society.

The following communications were read:—

I. "On some remarkable Spectra of Compounds of Zirconia and the Oxides of Uranium." By H. C. SORBY, F.R.S. Received December 27, 1869.

When a scientific man has been led into an error and afterwards discovers his mistake, I think it a matter of duty that he should take an early opportunity to correct it. I therefore now write the following notice of certain remarkable peculiarities in the spectra of some compounds of the oxides of uranium with zirconia which led both myself and others\* to conclude that they were due to a new elementary substance.

Though the spectra of the different salts of those bases which show well-marked absorption-bands often differ in detail, yet they usually resemble each other so much that there is no difficulty in recognizing each particular element. This is so constantly the case in the various compounds of erbium, didymium, and cobalt, and in the ordinary salts of uranium, that for a long time the more I studied this question, the more did it appear to be a general rule, and there seemed to be no reason to suspect that a few special compounds of uranium would give spectra with absorption-bands as unlike as possible those of all others. Such, however, turns out to be the fact, when its oxides are combined with zirconia.

As an excellent illustration of important differences in mere detail, but general correspondence, I would refer to the spectra of didymium in different states of combination†, and would especially refer to the most distinct of the numerous absorption-bands which occurs in the yellow. The various compounds agree in showing this band in the same general position; but by careful management, and by the use of sufficient dispersive power, it may be resolved into a very variable number of narrow bands or black lines. For example, in the case of the crystallized sulphate containing comparatively little lanthanum, it can be resolved into seven narrow lines, two of those near the centre being the darkest, whereas when much lanthanum is present, one line on the side next the green is so much darker than the rest that the others are comparatively absent. On fusing the mixed oxides with borax, the same spectrum is seen as with oxide of didymium alone, and I can resolve the above-named band into only two narrower bands; whereas when the saturated bead is made to deposit crystals by being kept some time at a very dull red heat, this band can easily be resolved into eight equal and very distinct black lines. Although these and similar differences in detail are of much interest, yet in no case are they so considerable as to prevent our recognizing at once that the spectra are all due to didymium. It is also important to notice that the amount requisite to give a most splendid spectrum when the bead is crystalline will scarcely show any trace of bands when it is in a vitreous condition, dissolved in the borax. This is

\* Professor Church, 'Chemical News,' vol. xix. p. 121, and Professor Loew, *ib.* vol. xx. p. 9.

† See also Bunsen's paper, *Pogg. Ann.* vol. cxxviii. p. 100.

analogous to what occurs in the case of solid and powdered crystals of sulphate of didymium; for the absorption-bands in the spectrum of the light transmitted by a thin layer of the fine powder, strongly illuminated from the other side, are as distinct as in that transmitted by a many times greater thickness of solid and transparent crystal. We may very conveniently take advantage of this fact in studying the spectra of such substances, when the amount of material at command is otherwise too small. This seems to be because the transmitted light does not simply pass through the crystals, but is in great measure reflected from them backwards and forwards, and thus, as it were, passes through a greater thickness. It is also to a considerable extent similar to that reflected from the powder when illuminated from above, as may be clearly proved by what occurs in the case of uranic salts. These when in a state of moderately fine powder transmit light, giving a spectrum showing not only the absorption-bands in the blue, which alone are met with in that transmitted by a clear crystal, but also the bands in the green, which depend on fluorescence, characteristic of that reflected from the powder\*. These two kinds of bands can be easily distinguished by means of a plate of deep blue cobalt glass, which has an entirely different action, according as it is placed below or above the object when the bands are due to fluorescence, but has no such effect when they are due to ordinary absorption. It would perhaps be well to mention here that I have in this manner proved that the abnormal bands seen in the spectra of the compounds of zirconia with the oxides of uranium described in this paper are due to genuine absorption, and not to fluorescence.

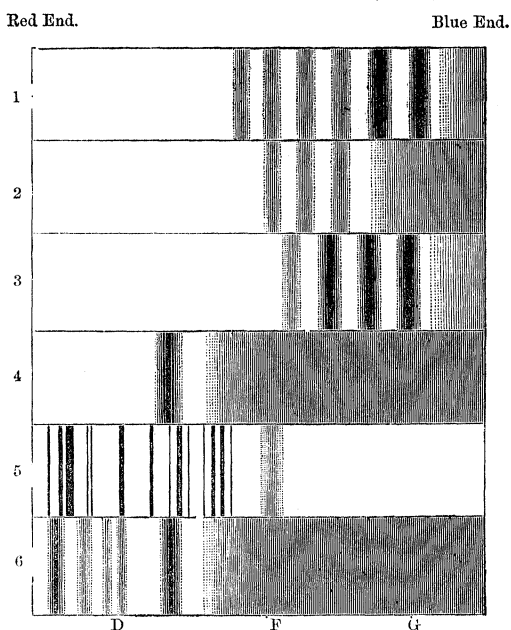
The remarkable spectrum of some jargons has been already described by me in the 'Chemical News'†, and in the Proceedings of the Royal Society‡. One of its most striking peculiarities is that when light passes in a direction perpendicular to the principal axis of the crystal, and the spectrum is divided by means of a double-image prism into two spectra, having the light polarized in opposite planes, though some of the absorption-bands are of equal intensity in both images, yet others are comparatively absent, some in one and some in the other; whereas in the case of other dichroic crystals which give spectra with absorption-bands, they are usually all more distinct in one image than when the light is not polarized, and all fainter, or even comparatively absent, in the other. No sooner had I observed this spectrum (No. 5, given below), than I made various experiments in order to ascertain whether uranium was present or not; and the then known tests that could be applied to the amount of material at my command seemed to show that it was absent. This was quite in accord with the results of the various analyses published by other chemists, none of whom mention the existence of any trace of that substance. Moreover the general character of the spectrum was entirely unlike that of all the known compounds of uranic oxide. The various artificial salts all agree in giving a variable but small

\* See Stokes's papers, Phil. Trans. 1852, p. 463, and 1853, p. 392.

† Vol. xix. p. 122.

‡ Vol. xvii. p. 511.

number of moderately broad absorption-bands in the blue end (Nos. 1, 2, and 3); and the same is also seen in the case of several natural minerals; whereas the jargon gave a most unusually large number of narrow black lines (fourteen quite distinct, besides others more faint, and a single broader band which I cannot separate into lines), extending from the red end, so that nearly all occur in that part of the spectrum which is entirely free from bands in all previously known compounds of uranic oxide. This same general fact was also seen in the spectrum (No. 6) of the opaque blow-pipe-beads gently flamed, as described in my former paper. These differences will be better understood by means of the following drawing, which shows three of the most striking spectra of uranic salts, that of uranate of soda, and the two which are rendered so abnormal by the presence of zirconia.



Spectra of Uranic Compounds.

Nos. 1, 2, and 3. Uranic salts of the common type, viz.:—

1. Native phosphate.
2. Nitrate in crystals.
3. Acetate in crystals.

No. 4. Uranate of soda in the carbonate-of-soda bead.

Nos. 5 and 6. Uranic compounds with zirconia, viz.:—

5. Jargon after ignition.
6. Crystalline borax blowpipe-bead.

I will not now enter into a description of the various chemical and physical facts which seemed to warrant the conclusion that zircons sometimes contain a new earth; but taking these into consideration, there seemed

to be every reason to believe that spectra which thus differed so much from those of any previously known substance were characteristic of this new earth. Judging from the facts then known, it was more probable that spectra of such a new type were due to a new element, than that they were due merely to a combination of two such elements as zirconium and uranium. Some of these chemical and physical facts can now be explained by the presence of uranium; but besides this and several of the more common earths and oxides, I have detected in some zircons erbium, didymium, yttria, and another substance which exists in such small quantity that I have not yet been able to ascertain whether or no it is the suspected new earth. These accidental constituents do not indeed occur in sufficient quantity to be of importance, except as modifying the physical and optical properties, the didymium giving its usual characteristic absorption-bands (zircons from Svalbard, Norway), and the manganese the same spectrum as that of garnets (zircons from an unknown locality in Siberia\*). This method, however, fails to give evidence of a new earth; for since the publication of my former paper, I have proved that the very abnormal spectra, which seemed sufficient to establish its existence, are really due to compounds of zirconia with the oxides of uranium, which have such a powerful action on light, that an almost inappreciable amount is sufficient to produce the spectra to great perfection—in fact so small an amount, that the total quantity which misled me was only a few thousandths of a grain; and its presence might easily have remained unsuspected, if I had not made a number of experiments, which at first did not seem to have much connexion with the subject.

In studying the spectra of crystalline blowpipe-beads, it seemed desirable to examine those made with carbonate of soda, with or without a little borax. This when melted dissolves certain oxides; and though it crystallizes on cooling, so as to be only partially translucent, yet with strong direct sunlight well-marked spectra may be seen. For example, in the oxidizing flame uranic oxide is easily dissolved by carbonate of soda alone; and when quickly cooled, an orange-coloured bead is obtained, probably containing uranate of soda in a vitreous condition, which gives a single well-marked absorption-band in the green (see spectrum No. 4) with so small a quantity of the oxide; that in a bead  $\frac{1}{8}$  inch in diameter shows the spectrum to the best advantage, and even  $\frac{1}{10000}$  grain can be easily detected. We need not be surprised that this spectrum differs so much from the usual type of uranic salts (Nos. 1, 2, and 3), since in this case the oxide plays the part of an acid. It may be only an accidental coincidence, but this difference is analogous to the change which commonly occurs on adding an alkali to neutral solutions of vegetable colours†. When gently reheated it seems as if the uranate passed into a crystalline state, for the spectrum then shows four absorption-bands, and is more like the

\* For both of these I am indebted to my kind friend Mr. David Forbes.

† See my paper in *Proc. Roy. Soc.* 1867, vol. xv. p. 433.

ordinary type; but this change does not occur if a little borax has been added. The addition of more and more borax causes the absorption-band to become more and more faint, and to advance towards the blue end, until we obtain a spectrum with very faint bands but of the usual character.

In examining the various products into which I separated jargons in order to study the supposed new earth in a state of purity, I obtained a small quantity of a dark-coloured substance, apparently zirconia containing some oxide which communicated a green tint to a glassy, borax blowpipe-bead, but yet not sufficiently distinct to show that it was due to uranous oxide. I therefore thought that the carbonate-of-soda method might throw light on the question; and though the presence of zirconia prevented solution by pure carbonate of soda, the addition of a little borax enabled me to prove that uranic oxide is really present in some jargons. Such, then, being the case, it seemed desirable to ascertain whether the oxides of uranium would give rise to any special spectra when present along with zirconia in crystalline blowpipe-beads. To my astonishment I found that the spectra were precisely the same as those obtained in the case of what I had thought to be an approximately pure new earth\*. When, however, I had ascertained the quantity of oxide requisite to give this result, I was no longer surprised that I had not suspected its presence. In the case of transparent blowpipe-beads of borax with microcosmic salt, it is requisite to have as much as about  $\frac{1}{80}$  grain of uranous oxide to show faintly the characteristic absorption-bands, whereas, when present along with zirconia in the crystalline beads,  $\frac{1}{500}$  grain gives an equally well-marked spectrum; and  $\frac{1}{2000}$  grain shows it far better than a larger quantity, which makes the beads too opaque. These very minute quantities were obtained by the repeated division of a small known weight, either before or after fusion with borax. This spectrum also differs very considerably from the spectra of the usual salts or blowpipe-beads of uranous oxide. On comparing them side by side, the only common peculiarity is the fact of there being numerous absorption-bands distributed over a large part of the spectrum, but they do not correspond in either number or position. On the contrary, they differ almost as much as possible, and the darker bands in the spectrum of this zirconia compound occur where the transmitted light is the brightest in other cases.

The oxide of uranium is so easily reduced at a high temperature to the state of protoxide in a borax-bead, with excess of boric acid, and is so readily peroxidized at a dull-red heat, when crystallized along with borate of zirconia, that there seemed good reason to refer the change in the spectra to temperature rather than to the state of oxidization, until after it was found that they were due to uranium. By gently flaming the crystalline bead, the spectrum is entirely altered, and becomes like No. 6, which seems to be characteristic of a compound of borate of zirconia with uranic oxide. This gives a spectrum with five well-marked absorption-bands,

\* Figs. 1 and 2 of my former paper.

all of which occur at the red end, where no trace of bands exists in the case of ordinary salts, as will be seen on comparing it with Nos. 1, 2, and 3. I have tried many experiments in order to ascertain whether any other element besides zirconia will cause uranium to give similar abnormal spectra, but none show anything of the kind, at all events in similar conditions. A few have special characters, as described below, but the majority exert little or no influence; and even when the blowpipe-beads are crystalline, they show only the usual spectra of the oxides of uranium. Moreover no such great change in the character of the spectra of any other elements which give absorption-bands is to be seen when they are combined with zirconia; and, as far as my present experience goes, it seems as if such very abnormal spectra were met with only in the case of these remarkable compounds of zirconia with the oxides of uranium.

Such, then, being the facts, it appears to me that we are now in a position to explain why certain zircons give three different spectra, as described in my former paper. Some jargons (usually those of a green tint) contain a little uranium so combined that the characteristic spectrum is only faintly visible, whereas, after ignition, the intensity of the absorption-bands is permanently increased to a variable extent, occasionally only a little, but in some cases as much as twenty-five times. This more powerful action on light is accompanied by an increase in hardness and in specific gravity (sometimes as much as from 4.20 to 4.60), as described in my former paper; and I have since found that these changes are approximately proportional to the amount of uranic oxide in the various specimens, as shown by comparing the spectra of the blowpipe-beads. This change may partly depend on the oxidization of the uranous oxide, since some specimens slightly increase in weight when ignited; but I think it cannot be mainly due to that; for sometimes there is no such increase, and uranous oxide combined with zirconia gives rise, not to a spectrum without bands, but to one with several of very marked character, as described below. On the whole, since this abnormal type of spectrum is so characteristic of combination with zirconia, it appears to me more probable that the effect of a high temperature is to cause the uranic oxide to combine more specially with the zirconia, as though the greater part existed naturally as a silicate, but after ignition as a zirconiate. We may also apply the same explanation in the case of zircons more or less strongly coloured by other oxides, which become almost colourless when heated, and thus this unexplained peculiarity of zircons may depend on the fact of zirconia being able to play the part of both a base and an acid, which, as compared with silica, has an affinity for bases varying according to the temperature.

The brown-red zircon from Ceylon, named at page 514 of my former paper, kindly presented to me by Mr. E. L. Mitford, of Rusthall, gives a spectrum precisely like that of the borax blowpipe-beads crystallized after treatment in the deoxidizing flame, and therefore no doubt contains uranous oxide. This spectrum being given by only one part of the crystal, probably

depended upon the presence of some substance which either reduced the uranic oxide or prevented the oxidization of the uranous.

These facts thus clearly show that the various spectra which seemed to indicate the presence of a new element existing in three different physical conditions, are in reality only characteristic of the two oxides of uranium combined with zirconia, or not in combination. Perhaps some may think that my having been thus led astray shows that little or no reliance can be placed on the method of investigation employed; but I contend that the mistake was due to its being such an unexpectedly delicate test for uranium; and, as explained above, the error was ultimately corrected by a further development of the same method. As far as the interests of science are concerned, there is no need to regret the general result. We have lost what appeared to be good evidence of a new earth, but have gained an almost entirely new system of blowpipe testing, which enables us to detect such a minute quantity of some substances as could not be recognized by the ordinary means. I shall not now attempt to give anything like a full account of this subject, since it would be much better to let it form part of a paper on various improvements in blowpipe chemistry, but will merely mention a few facts which have a special bearing on the question before us.

In the first place, I would say that zirconia and the oxides of uranium are most useful reagents in detecting the presence of certain substances with which they unite to form compounds having very special characters. The most striking of these are the compounds already described, which are distinguished by the spectra, and not by any well-marked colour,—the compound of ceric oxide with uranic oxide, which is of a splendid deep blue colour, but shows no absorption-bands; and that of yttria with uranic oxide, which is characterized by a deep orange-colour and extreme fusibility. Thorina and oxide of lanthanum form with uranous oxide compounds which give spectra with absorption-bands in special positions, but of the usual type, and not of such a marked character as to be useful in detecting minute quantities of those substances in mixtures.

In order to see the spectra of the zirconium-uranium compounds, it is requisite that both elements should be combined in a crystalline condition. When both constituents are melted in borax and are held in solution, or if when crystals are deposited any other substance replaces either the zirconia or the oxides of uranium, the characteristic spectra cannot be seen. The most simple application of this test for uranium is in the case of various zircons. As much of the powdered mineral as will dissolve should be melted with borax in a circular loop of platinum wire about  $\frac{1}{8}$  inch in diameter, so as to give a bead of moderate thickness. A little boric acid should then be added, which not only tends to keep the uranium in the state of protoxide, but also facilitates the crystallization of the borate of zirconia, which is far less soluble when there is excess of boric acid. The bead should then be kept at a bright red heat, just within the deoxidizing flame, until so much borax has been volatilized that small needle-shaped crystals begin to be



deposited, when it must be allowed to cool rapidly. It should then be transparent with scattered crystals, and the uranium all in the state of protoxide. On gently reheating it, the bead ought to suddenly turn white and almost opaque; and care must be taken not to heat it any more than is just requisite to cause the borate to crystallize out, or else the uranium will rapidly pass into the state of peroxide. Such beads must be examined by strong direct light from the sun, or from a lamp of very great brilliancy, condensed on them by means of an almost hemispherical lens of about  $\frac{1}{2}$  inch focal length; and in addition to the means described in my former paper, I have since found it very convenient to place them over a hole in a black card, so as to entirely prevent the passage of any light which has not penetrated through them, even when so arranged in the focus of the microscope that the spectrum of their thin edges may be examined, if the centre be too thick and opaque. If thus properly prepared, the presence of more or less uranium will be shown by the greater or less intensity of the absorption-bands of the spectrum described and shown in fig. 1 of my former paper. This test is so delicate that there is no difficulty in seeing the darker band in the green in the case of zircons which contain no more than  $\frac{1}{10}$  per cent. of uranic oxide; and I find that very few localities yield this mineral so free from it that it cannot be easily detected. Those from Miask, Siberia, are the only specimens in which I have not been able to recognize it. The jargons from Ceylon contain an amount varying up to about 1 per cent., although in no published analysis that I have seen is there any allusion to the presence of even a trace. It has also been overlooked in several other cases; and it now becomes important, because it gives rise to various well-defined spectra, which are so characteristic of the different minerals, that they can be very conveniently identified, even when cut and mounted as jewels, by means of the number and position of the absorption-bands, as I intend to explain in a paper on the spectra of minerals.

On flaming the bead at a moderate red heat, the protoxide passes into the peroxide, and the spectrum No. 6, given above, may be seen, if sufficient oxide be present, but considerably more is required than in the case of the protoxide. I may here say that the examination of better preparations has enabled me to detect another distinct band in the extreme red, not shown in fig. 2 of my former paper, and also an additional faint band in the blue, not shown in fig. 1.

In applying this test to detect minute quantities of uranium in other minerals, it is requisite to bear in mind that zirconia may play the part of both an acid and a base, and that various oxides and acids so combine with the zirconia or with the oxides of uranium as to prevent the formation of the compounds which give rise to the characteristic spectra. The zirconia appears to combine with some rather than with the uranous oxide, and with others rather than with the uranic, so that, if one spectrum cannot be obtained, the other may; and there are few, if any, cases when

neither can be seen, especially if care be taken to use excess of zirconia. If, however, the amount of uranium be very small, and so much of other oxides be present as to make the bead very dark, or too opaque from deposited crystals, before it is sufficiently concentrated for the compounds with the oxides of uranium to crystallize out, it may be impossible to detect it. In order to apply the test in the case of complex minerals, a bead of borax, boric acid, and pure zirconia should be prepared, then a small quantity of the mineral added, and, after fusion and sufficient concentration, the bead made to crystallize in the manner already described. If needle-shaped crystals be not deposited in the bead when very hot, and if it do not suddenly turn opaque when reheated, the result may not be satisfactory. In this manner it is easy to detect uranium in  $\frac{1}{200}$  grain of such minerals as Fergusonite, tyrite, and yttrantalite, even when they contain no more than 1 or 2 per cent. If in such cases the spectrum of the uranous compound cannot be obtained, the bead should always be flamed and reexamined, to see if that of the uranic compound is thereby developed.

In a similar manner we may make use of a little oxide of uranium to detect zirconia; but the test is far less delicate than the converse, because it is almost impossible to obtain the compound in a crystalline state, unless there be an excess of zirconia. Not more than  $\frac{1}{1000}$  grain of uranic oxide should be employed, or the bead may be too opaque. There is no difficulty in thus detecting zirconia in zircons, or in katapleit; but the presence of so much of other bases in minerals like eudialyte prevents our obtaining a satisfactory result. There certainly could not be a more characteristic test to confirm the results of other methods, or to identify such a small quantity of approximately pure zirconia as could not easily be distinguished in any other way.

The only other compound of uranic oxide of very abnormal character which I have so far discovered is that with ceric oxide. So much of both oxides should be fused with borax in the oxidizing flame as will yield a bead which is perfectly clear, and of pale yellow colour when rapidly cooled, but crystallizes when gently reheated. If the constituents be present in a certain proportion, it then turns from pale yellow to a deep blue, as though coloured by oxide of cobalt. In most cases the bead is rendered nearly opaque by the number of crystals; but sometimes, though it turns deep blue, it remains transparent, owing to the compound being set free in a state similar to that of the red oxide of copper in a borax blowpipe-bead, with carbonate of soda and oxide of tin, treated in the reducing flame. The spectrum of these blue beads shows no absorption-bands, but merely a general absorption at the red end; and it is curious to find that the combination of two yellow substances gives rise to a deep blue, in much the same manner as when the yellow ferrocyanide of potassium is added to a yellow ferric salt. The production of this blue colour on the addition of a little uranic oxide might be employed with advantage to identify moderately small quantities of cerium, even when mixed with a number of other

substances; but unfortunately the presence of much oxide of lanthanum, which is so commonly associated with it, interferes, as though the ceric oxide had a stronger affinity for the oxide of lanthanum than for uranic oxide.

The most characteristic peculiarity of the compound of yttria and uranic oxide is that it will not crystallize out from a borax blowpipe-bead, and that the affinity of the uranic oxide for yttria is stronger than for zirconia. Perhaps erbia may prove to act in the same way, but I have not been able to examine that earth quite free from yttria. On adding yttria to a bead with zirconia and a little uranic oxide, and gently flaming it in the oxidizing flame, the uranic oxide combines with the yttria and rises to the surface as an orange-coloured scum, which has a great tendency to collect on the platinum wire; and if sufficient yttria be added, the crystallized borate of zirconia is left in the interior almost colourless, and so free from uranic oxide that no absorption-bands can be seen in the spectrum. We may take advantage of this circumstance to detect yttria in small quantities of compound minerals like Gadolinite and Fergusonite; and I may here say that by combining such means with the observation of the spectra of the transparent or crystalline beads, and of the form of the crystals when slowly deposited, with or without the addition of suitable reagents\*, we may often detect twice as many constituents in minerals as could be accomplished by the ordinary methods of blowpipe chemistry—an advantage which I am sure will be appreciated by those engaged in the study of rocks, when it is often so important to obtain satisfactory results with small quantities of material. I have also found these methods of great practical use in examining small residues in the qualitative analysis of minerals, and have thus unexpectedly discovered small quantities of comparatively rare elements.

I have tried the effect of many other substances along with zirconia and the oxides of uranium, and find that most of them have no sensible influence, unless they are present in considerable relative quantity. The most striking effect is that of oxide of tin, which causes the two absorption-bands in the yellow and yellow end of the green in the spectrum of the uranous oxide compound to be nearly equally dark, whereas without the oxide of tin that in the yellow is comparatively faint. This is another illustration of the manner in which certain substances, having no special action on light, influence by their presence the properties of another. The oxides of uranium are unusually sensitive to such actions, and thus not only lend themselves to us as blowpipe-reagents, but also seem more than any others to afford the means of explaining the relation between the physical conditions of compounds and their action on light.

The only compound of zirconia with any other oxide to which I need now draw attention is that with chromic oxide, as deposited from a borax blowpipe-bead. After treatment in the deoxidizing flame, when the cooled very pale-green bead is gently reheated, this compound crystallizes out

\* See my paper, *Monthly Microscopical Journal*, vol. i. p. 349.

so as to give a fine red-pink colour by transmitted light, even when so little chromium is present that the glassy bead is scarcely at all green. If too strongly heated the pink tint is lost. This compound is of interest in connexion with the colour of rubies and other minerals coloured red by chromic oxide. To others, like the emerald, it imparts a green colour, and on the whole it acts on light in such a variable manner according to the presence of other substances, that the spectra may be made use of as a means of identifying particular minerals, though they do not present anything like such striking anomalies as those met with in the compounds of zirconia with the oxides of uranium.

- II. "On the Mathematical Theory of Stream-lines, especially those with four Foci and upwards." By WILLIAM JOHN MACQUORN RANKINE, C.E., LL.D., F.R.SS. Lond. and Edinb., &c. Received January 1, 1870.

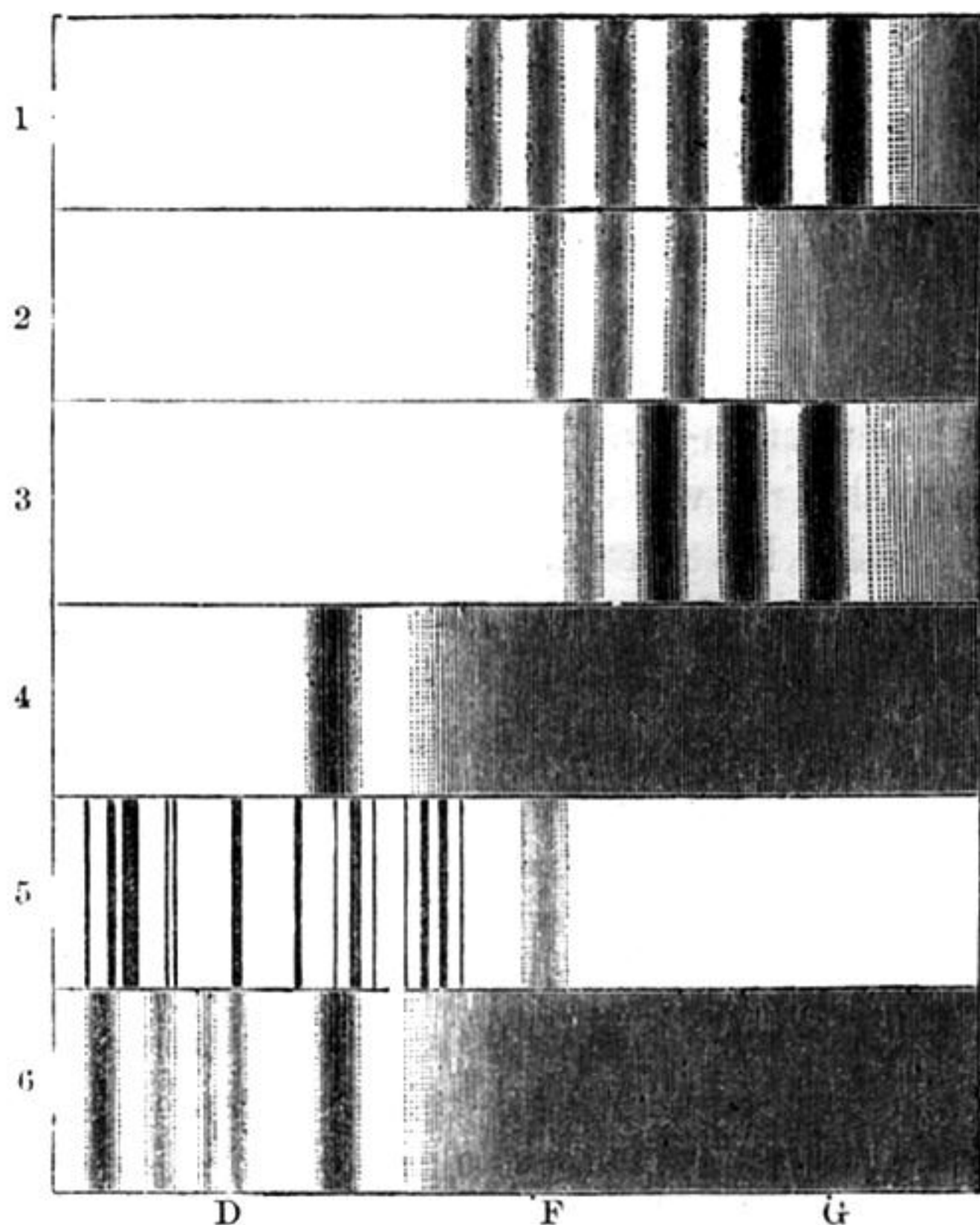
(Abstract.)

A *Stream-line* is the line that is traced by a particle in a current of fluid. In a steady current each individual stream-line preserves its figure and position unchanged, and marks the track of a filament or continuous series of particles that follow each other. The motions in different parts of a steady current may be represented to the eye and to the mind by means of a group of stream-lines.

Stream-lines are important in connexion with naval architecture; for the curves which the particles of water describe relatively to a ship, in moving past her, are stream-lines; and if the figure of a ship is such that the particles of water glide smoothly over her skin, that figure is a *stream-line surface*, being a surface which contains an indefinite number of stream-lines.

The author in a previous paper proposed to call such stream-lines *Neoïds*; that is, ship-shape lines.

The author refers to previous investigations relating to stream-lines, and especially to those of Mr. Stokes, in the Cambridge Transactions for 1842 and 1850, on the "Motion of a Liquid past a Solid," and of Dr. Hoppe, on the "Stream-lines generated by a Sphere," in the Quarterly Journal of Mathematics for 1856, and to his own previous papers on "Plane Water-lines in Two Dimensions," in the Philosophical Transactions for 1864, and on "Stream-lines," in the Philosophical Magazine for that year. He states that all the neoïd or ship-shape stream-lines whose properties have hitherto been investigated in detail are either *unifocal* or *bifocal*; that is to say, they may be conceived to be generated by the combination of a uniform progressive motion, with another motion consisting in a divergence of the particles from a certain point or focus, followed by a convergence either towards the same point or towards a second point. Those which are



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