now appears that one of the markings corresponds to the Maia nebula. The other irregularities seem to afford indications of the Merope nebula. There is also a faint narrow streak of light projecting from Electra on the following side.

Prof. Langley on the Emission-Spectra of Bodies at Low Temperatures.—Prof. Langley having traced the solar spectrum in the infra-red so far as λ = 0·0027mm., where it suddenly ceased, has since examined the emission-spectra of various terrestrial substances at temperatures from that of fusing platinum to that of melting ice, and more particularly of temperatures corresponding to the ordinary conditions of the soil. The result of his observations has been to show that the maximum of heat from cold and black bodies has in every case a wavelength greater than 0·0027mm.,—greater, that is to say, than that of the lowest solar heat which reaches us; and that further, that part of these spectra which has a greater wave-length than that of the point of maximum, represents a larger total amount of heat than the part with shorter wave-length. Prof. Langley believes that he has been able, by means of his bolometer, to trace out the emission-spectra of cold bodies so far as λ = 0·0150mm., a wavelength more than twenty times as great as that which Newton found for the lower limit of the spectrum, viz. λ = 0·0007mm.

Fabry's Comet.—Dr. H. Oppenheim has computed the following fresh elements and ephemeris for this comet:—

T = 1886 April 5·5398 Berlin Mean Time

$$\left.\begin{array}{rl}\omega = & 126^\circ\ 50'\ 27''\cdot6 \\ \Omega = & 36\ \ 19\ \ 54\cdot0 \\ i = & 82\ \ 11\ \ 15\cdot0\end{array}\right\}\ 1886\cdot0.$$

$$\log q = 9\cdot804021$$

Ephemeris for Berlin Midnight

1886	R.A. h. m. s.	Decl. ° ′	Log. r	Log. Δ	Brightness
March 7	23 19 34	31 19·6 N.	9·9441	0·1621	8
11	23 18 54	32 29·8	9·9171	0·1424	10
15	23 18 11	33 42·0	9·8904	0·1191	12
19	23 17 29	34 54·6 N.	9 8650	0·0916	16

The brightness on December 2 is taken as unity.

Barnard's Comet.—The following ephemeris by Dr. A. Krueger is in continuation of that given in Nature for February 18, p. 376:—

For Berlin Midnight

1886	R.A. h. m. s.	Decl. ° ′	Log. r	Log. Δ	Brightness
March 6	1 54 54	22 35·8 N.	0·1229	0·2415	4·10
10	1 53 55	23 45·9	0·1001	0·2390	4·61
14	1 53 6	24 58·9	0·0757	0·2352	5·25
18	1 52 26	26 14·9 N.	0·0497	0·2299	6·07

ASTRONOMICAL PHENOMENA FOR THE WEEK 1886 *MARCH* 7-13

(For the reckoning of time the civil day, commencing at Greenwich mean midnight, counting the hours on to 24, is here employed.)

At Greenwich on March 7

Sun rises, 6h. 34m.; souths, 12h. 11m. 10·0s.; sets, 17h. 48m.; decl. on meridian, 5° 11′ S.: Sidereal Time at Sunset, 4h. 49m.

Moon (two days after New) rises, 7h. 16m.; souths, 13h. 21m.; sets, 19h. 36m.; decl. on meridian, 0° 28′ N.

Planet	Rises h. m.	Souths h. m.	Sets h. m.	Decl. on meridian ° ′
Mercury	6 54	12 49	18 44	1 47 S.
Venus	5 1	10 30	15 59	6 48 S.
Mars	17 23*	0 15	7 7	9 24 N.
Jupiter	19 10*	1 15	7 20	0 16 N.
Saturn	10 54	19 5	3 16*	22 46 N.

* Indicates that the rising is that of the preceding evening and the setting that of the following morning.

Occultations of Stars by the Moon (visible at Greenwich)

March	Star	Mag.	Disap. h. m.	Reap. h. m.	Corresponding angles from vertex to right for inverted image ° °
8	B.A.C. 408	6½	18 11	near approach	54 —
9	64 Ceti	6	17 31	18 38	118 342
9	ξ′ Ceti	4½	18 35	19 39	156 310
13	130 Tauri	6	16 49	18 1	91 253

Saturn, March 7.—Outer major axis of outer ring 43″·0; outer minor axis of outer ring 19″·3; southern surface visible.

March	h.	
10	2	Venus stationary.

Variable-Stars

Star	R.A. h. m.	Decl. ° ′			h. m.	
T Cassiopeiæ	0 17·1	55 10 N.	Mar.	10,	0 0	m
U Cephei	0 52·2	81 16 N.	,,	8,	20 36	m
			,,		20 16	m
V Tauri	4 45·4	9 42 N.	,,	12,		M
ζ Geminorum	6 57·4	20 44 N.	,,	10,	0 0	m
δ Libræ	14 54·9	8 4 S.	,,	11,	22 10	m
R Coronæ	15 43·9	28 30 N.	,,	12,		M
U Ophiuchi	17 10·8	1 20 N.	,,	9,	2 22	m
			,,	9,	22 30	m
X Sagittarii	17 40·4	27 47 S.	,,	10,	0 0	m
			,,	12,	21 30	M
U Sagittarii	18 25·2	19 12 S.	,,	9,	22 30	m
			,,	12,	22 30	M
S Vulpeculæ	19 43·7	27 0 N.	,,	11,		m
η Aquilæ	19 46·7	0 7 N.	,,	8,	4 50	m
S Aquilæ	20 6·4	15 17 N.	,,	13,		m
δ Cephei	22 24·9	57 50 N.	,,	12,	2 30	m

M signifies maximum; m minimum.

Meteor Showers

Two showers may be looked for on March 7, viz near γ Libræ, R.A. 233°, Decl. 18° S.; and near γ Herculis, R.A. 244°, Decl. 15° N. Other showers of the week:—Near ε Cassiopeiæ, R.A. 36°, Decl. 67° N.; from Virgo, R.A. 190°, Decl. 1° N.; from Cepheus, R.A. 300°, Decl. 80° N.

Stars with Remarkable Spectra

Name of Star	R.A. 1886·0 h. m. s.	Decl. 1886·0 ° ′	Type of spectrum
124 Schjellerup	9 45 48	22 29·0 S.	IV.
132 Schjellerup	10 31 54	12 47·6 S.	IV.
D.M. +68°·617	10 37 9	68 0·6 N.	IV.
136 Schjellerup	10 46 5	20 38·8 S.	IV.
56 Leonis	10 50 5	6 47·7 N.	III.
R Crateris	10 54 58	17 42·8 S.	III.
ω Virginis	11 32 35	8 45·9 N.	III.
145 Schjellerup	12 19 24	1 24·1 N.	IV.
152 Schjellerup	12 39 46	46 3·8 N.	IV.
155*b* Schjellerup	12 51 57	66 36·6 N.	IV.
40 Comæ Ber.	13 0 49	23 13·8 N.	III.

THE SUN AND STARS[1]

II.

First Conclusions

The view of the solar constitution, which was based upon the early work to which I have referred—work which dates from about the year 1860, and is therefore about a quarter of a century old—the view which grouped together, and endeavoured to make a complete story of all the facts which were known then, was this: the chemical substances which had been found to exist in the sun's atmosphere existed quite close—relatively quite close at all events—to the photosphere. When subsequent work demonstrated the existence of hydrogen to a considerable height above this photospheric envelope, as I shall show presently, the idea was suggested that these chemical substances existed in the atmosphere, not pell-mell, not without order, because Nature is always full of the most exquisite order, but in the sequence of their vapour-densities, so that a very heavy vapour would be found low down in the atmosphere, and a very light one like hydrogen would be high up.

It was at first suggested that gaseous diffusion would prevent such a sorting out, until it was pointed out by an American mathematician, Prof. Pierce, that it was a good deal to ask that diffusion should act along a radius something like a million of miles long, and indeed he showed that it would not.

Before we go farther, I give tables of the different substances which so far have been traced in the sun's atmosphere by means of their spectral lines. The first gives the substances according to the results obtained by Kirchhoff,

---

[1] A Course of Lectures to Working Men delivered by J. Norman Lockyer, F.R.S., at the Museum of Practical Geology. Revised from shorthand notes. Continued from p. 403.

Ångström, and Thalèn, who were the first workers in this field of inquiry.

TABLE A.—*Elements present in the Sun according to Kirchhoff, Ångström, and Thalèn*

Kirchhoff	Ångström and Thalèn
Sodium	Sodium
Iron	Iron
Calcium	Calcium
Magnesium	Magnesium
Nickel	Nickel
Barium	—
Copper	—
Zinc	—
	Chromium
	Cobalt
	Hydrogen
	Manganese
	Titanium

Another gives the substances which were added to the preceding list by taking a special consideration into account. Some time after the first work on the chemical composition of the solar atmosphere was accomplished, a method was introduced by which it was easy to determine the existence of a small quantity of any particular vapour in a mixture of vapours, so that the substances indicated in the second table are those substances which possibly exist in the sun's atmosphere in a small quantity only.

TABLE B.—*Elements the Longest Lines of which coincide with Fraunhofer Lines*

Certainly coincident	Probably coincident
Aluminium	Indium
Strontium	Lithium
Lead	Rubidium
Cadmium	Cæsium
Cerium	Bismuth
Uranium	Tin
Potassium	Silver
Vanadium	Glucinum
Palladium	Lanthanum
Molybdenum	Yttrium or Erbium

It is important to call special attention to the fact that Ångström and Thalèn, who followed Kirchhoff, did not agree with regard to barium, or copper, or zinc, and they added chromium, cobalt, hydrogen (a very notable addition), manganese, and titanium, the existence of which Kirchhoff had not discovered in the solar atmosphere.

A detailed study of the facts recorded by Ångström gives a good idea of the immense difficulty of the research, and also of the doubts and of the difficulties which were suggested in the very first part of the inquiry. For instance, in the case of sodium, what Ångström did, of course, was to get the vapour of sodium incandescent in the laboratory, and he got the eight familiar lines. He then observed whether there were dark lines corresponding with all of them. He found that there were. With regard to cobalt he got nineteen lines, and he found nineteen lines in the sun coinciding with them. But when he studied the spectrum of barium in his laboratory he got twenty-six lines, but of these in the solar spectrum he found only eleven. When he came to aluminium, of the fourteen lines seen in the spectrum of the metal only two existed among the Fraunhofer lines. In zinc it is not yet quite decided whether we even have two out of twenty-seven; so that we see it was not all perfectly plain sailing.

A New View

So much, then, for the chemistry of the solar atmosphere, taken as a whole. Two observations suggest themselves: the first is, that it is perfectly clear that if we have in the sun's atmosphere incandescent iron vapour, and calcium vapour, and magnesium vapour, and the incandescent vapours of many other substances which we generally know here as solid bodies, there must be tremendously strong convection-currents somewhere; for were these vapours at rest they must cool on the outside, and if they get up high enough they will condense, first into liquid particles, and then into solid particles, and then they are bound to go down. So that we see there is a new world of motion in full front of us the moment we are driven to the conclusion that we are really dealing with a mixed mass of gases so intensely hot that its constituents exist in it, except in the coldest parts of it, in a state of vapour. To enable us to think this out a little, let us consider a small part of the sun where we will imagine that the statical condition is as nearly secured as possible, and that then we suddenly upset the temperature equilibrium. When we get any solid particles, say of iron, falling into a region where they will be gradually melted, and then driven into iron vapour, the vapour is bound to reascend—it will not continue in its downward flight; whereas if vapours, by ascending, gradually get cooler and cooler, they must afterwards redescend, falling first, as I have said before, as mist and then in big liquid drops, and finally as solids—as meteorites, if you like: they are bound to go down. To put this in the most general form, we may say that in the sun's atmosphere complex molecules are bound to go down, and simple molecules are bound to go up; so that we shall have convection-currents, as I have already hinted, produced in this kind of way, and these convection-currents must exist wherever the temperature equilibrium is broken. Of course we must assume that these more or less vertical convection-currents may be modified to a certain extent by the rotation of the sun, in the same way as the up and down currents of our own air, and even the currents pole-wise and equator-wise are modified by the rotation of the earth.

The other observation which suggests itself is as follows:—We need not limit ourselves to the general chemical ideas we have acquired; the chemistry of each part of the sun (always above the photosphere) can be examined bit by bit. The photosphere has spots in it; it has the chromosphere above it with the included prominences, the inner corona above that, the outer corona above all. As a matter of fact, all these have now been examined, bit by bit, by the spectroscope—that is from the chemical point of view.

The next point of importance to urge is that a view of the solar constitution has been arrived at in consequence of this new wealth of facts, on which something must be said before we go further.

The old view put the absorbing atmosphere above the photosphere, the various chemical substances being arranged in the order of their vapour-densities, so that hydrogen would be highest, then sodium, then magnesium, till finally we arrive at iron and platinum, and so on.

Now, if that view were correct, it would be perfectly easy to prove it at once by the new method of local examination. We have only during an eclipse, or even without an eclipse, to put the slit of a spectroscope on the edge of an image of the sun thrown by an object-glass, and observe the spectrum from each part of the sun; from the photosphere to as far above the photosphere as we can get. If that view were true, we should get, as short bright lines close to the photosphere, the lines of substances having a high atomic weight. Then higher and higher we should get longer lines indicating the existence at greater heights in the solar atmosphere of those substances which have a smaller atomic weight. Further, as we have evidence to show that the spots exist in a low part of the sun's atmosphere (how low we shall see by and by, when we come to consider them in detail), we should expect in those spots to find all the familiar lines of the substances having a high atomic weight to be affected. When we examine the chromosphere and the base of the prominences which arise out of it, we should find that at the same height or about the same height where the spots give us lines of the substances of high atomic weight, the chromosphere itself should be full of the same substances of high atomic weight.

Now the fact that not one of these expectations is realised—that none of these things are so—has necessitated the putting forward of the new view to which I have referred.

This can be stated in a very few words. It is that the temperature of the sun is not only sufficient to drive all our most refractory metals into vapour, as we can do in our laboratories on the earth, but that it goes very much further; it continues the work of our laboratories, and drives them into something else altogether finer than anything that we can separate with our terrestrial conditions. According to that view, what would happen would be this:—If we could lay hold of a solar meteorite, say a hundred thousand miles from the photosphere, and watch it in its downward flight, the solid would first become liquid, it would then be vaporised, and we should have the spectrum with which we are familiar in our laboratories; but after that the vapour would still go through a series of simplifications of which we can take no count in our laboratories, because we have not the same temperature. What would happen in that view is that obviously we should know nothing whatever of the spectrum of the lower part of the atmosphere open to our inquiries. Now that is practically the fact. The spectrum of the region just above the photosphere is one of the strangest things in solar physics. Almost everything there is strange. The lines which we see are lines either altogether unknown to us, or are seen without their usual terrestrial companions. Many are found in none of the maps prepared in any of our laboratories, and whether we read this story from the facts presented by spots, or those observed in prominences, we get the same apparently inexplicable riddle.

All this, then, by way of introduction. There will be a good deal to be said as to details in the sequel. What we have next to do is to commence our detailed examination of each portion of the sun.

Description of the General Surface

To do this it is proper that we should begin with that part with which we are most familiar: I mean the photosphere—the bright shining surface which represents to most of us the actual veritable sun.

When we look at the sun by means of an ordinary telescope, taking proper precautions,—it will never do to look straight at the sun with an ordinary telescope unless we wish to be instantly blinded,—what one sees is first a bright disk, which is slightly dimmed at the edge; here and there, it may be, will be seen dark objects, the *spots*, although it may happen that no spots will be visible; on examining the disk carefully, what we further see is a strange mottling of the whole surface. The mottling is very often very delicate; but everywhere, in all parts of the sun, near the poles, near the solar equator, and universally, we get this strange mottling. These fine mottlings sometimes take certain directions, in consequence of the existence of powerful currents. Here and there we get cyclonic swirls, and here and there there is an appearance of smudginess, apparently produced by tremendous overhead currents, so to speak, that is, currents between us and that part of the sun on which they appear.

Some photographs of the sun taken of late years by Dr. Janssen at the Physical Observatory at Meudon, near Paris, have thrown great light upon the general arrangement of this mottling.

An attentive examination of his photographs shows that the surface of the photosphere has not a constitution uniform in all its parts, but that it is divided into a series of figures more or less distant from each other, and presenting a peculiar constitution. These figures have contours more or less rounded, often very rectilinear, and generally resembling polygons. The dimensions of these figures are very variable; they sometimes attain a minute and more in diameter.

While in the interior of the figures of which we speak the grains are clear, distinctly terminated, although of very variable size, in the boundary the grains are as if half effaced, stretched, strained; for the most, indeed, they have disappeared to make way for trains of matter which have replaced the granulation. Everything indicates that in these spaces, as in the penumbræ of spots, as we shall see, the photospheric matter is submitted to violent movements which have confused the granular elements.

In these investigations the sun's appearance can be better studied by these photographs than by means of the eye and telescope. This is what Dr. Janssen says on this point:—

"The photospheric network cannot be discovered by optical means applied directly to the sun. In fact, to ascertain it from the plate, it is necessary to employ glasses which enable us to embrace a certain extent of the photographic image. Then, if the magnifying power is quite suitable, if the proof is quite pure, and especially if it has received rigorously the proper exposure, it will be seen that the granulation has not everywhere the same distinctness; that the parts consisting of well-formed grains appear as currents which circulate so as to circumscribe spaces where the phenomena present the aspect we have described. But to establish this fact it is necessary to embrace a considerable portion of the solar disk, and it is this which it is impossible to realise when we look at the sun in a very powerful instrument, the field of which is, by the very fact of its power, very small. In these conditions we may very easily conclude that there exist portions where the granulation ceases to be distinct or even visible; but it is impossible to suppose that this fact is connected with a general system."

Independently, then, of the phenomena of spots (about which presently), the verdict of minute examination is that the whole photosphere is riddled by convection-currents; because I shall have to show that each of those dark markings which we will call *pores*, is the seat of a downrush, and each of those *domes*, as we will call the intervening brighter portions, is, in all probability, a dome produced by the very same cause that gives us the grand domes of our cumulus clouds on a summer's day.

The Cause of the Photosphere

In discussing any subject, especially such a subject as the sun, it does not do to avoid difficulties, and therefore I may very frankly say that one of the greatest difficulties which students of solar physics have met with up to the present time has been the absence of an easy and satisfactory way of explaining the existence, and the sharp boundary, and the intense brilliancy of the photosphere.

The photosphere, as already stated, is about 400,000 miles—in round numbers—from the sun's centre. If we take the average density of the sun at a pretty low figure, as we found reason to do in the last lecture, we note that the photosphere, assuming it to be a shell, exists in a region of low pressure, and we see in a moment that, unless we suppose the photosphere, or something immediately inside the photosphere, to be solid, there is no reason for supposing any very great increase of pressure at the photosphere itself. In fact, there are a great many reasons for regarding this as improbable, not to say impossible.

Now, if that is so, we are driven to another line of inquiry, and it is this. If there can be no sudden increase of pressure at the photospheric level to account for the sudden luminosity, to what other cause must we look? Driven to our supports, it is fair to ask whether any sudden increase of temperature will help us?

In an ordinary gas-jet we have coal-gas burning. When we examine the coal-gas flame in an ordinary fish-tail burner, with the spectroscope, what we find is this: Up to the part where the luminosity—the white light—suddenly begins, about halfway up, we get the flutings of acetylene and marsh-gas, and above that we get nothing whatever except a continuous spectrum; therefore, according to the books, we have now either a solid, or a liquid, or a densely gaseous substance to deal with. That is an obvious suggestion, and one apparently in harmony with all the facts. I think that is the general opinion now. Hence in a flame, in the non-luminous portion, we have got hydrocarbons ascending. So long as they are not dissociated they are feebly luminous. The light which they give is chiefly a fluted light, by which I mean that if we observe it with the spectroscope we do not get much continuous spectrum. When the hydrocarbons reach a certain height in the flame, their dissociation becomes possible, the solid particles of carbon are set free; these solid particles of carbon when free give a continuous spectrum totally different from that which they gave when they were associated with the hydrogen in its various proportions in the lower part of the flame.

Now, it is obvious that, generally, everything above the photosphere must be cooler than the photosphere itself. Have we then a relatively non-luminous gas going down, which at a distance of 430,000 miles from the sun's centre finds a region where chemical combination is destroyed, the effect being exactly the same—different in degree, but not different in kind—from that which we watch in a candle or gas-flame, imagining the gas-flame to be inverted for the sake of simplicity? That is the question. Is it along such a line as this one is to look for the solution of the mystery of the sudden brightening of the photosphere, rather than along that other one which attributes the increase of brilliancy to the sudden increase of pressure, for which really one sees no physical basis at all?

The Faculæ

It was stated that the pores were supposed to be the seats of downrushes, and that the domes between the pores were the equivalents of our cumulus clouds.

The brighter portions of the photosphere, called *faculæ*, consist of domes heaped up together, or arranged in certain directions. We shall find by and by that they are associated with a certain stage in the history of every spot. But they are by no means limited to the vicinity of spots. We may have some development of these faculæ in parts of the sun where there are no spots at all.

Those who are familiar with this class of observations will remember that it is much easier to see the faculæ near the sun's limb than in the centre of the sun. Also it is easier to get a photograph of the faculæ using a collodion or a dry plate which works very far up in the blue, than it is with a collodion or a dry plate which works in the green or the blue-green; this latter fact proves to us quite conclusively, as it was pointed out a good many years ago now,[1] that the difference between the light at the top of a dome, so to speak, or the bottom, or between the top of the cumulus and the base of the pore, is a difference chiefly of that kind of light which writes its record by means of the absorption of the blue end of the spectrum.

The reason that we see the sun red at sunrise and sunset frequently is not that there is anything different in our air at that moment, but because we are looking at the sun through a greater thickness of the air; and the redness of the sun is the balance left after our atmosphere has done all it can in the way of absorbing the blue. We do not expect to get the sun red at midday. Of course a London fog will do anything; but I am talking of our ordinary atmosphere; and the fact that we do not get the sun red in the middle of the day is one of the same kind as the other one that we do not so easily see the faculæ on the centre of the sun as we do at the edge of it. There is absorption going on between the top of a facula and the bottom of a pore; and, as you know, to get that out in its greatest vigour and quantity we must take the greatest possible thickness of atmosphere. We see in a moment that the only way to have a considerable thickness of solar atmosphere to work this for is to make observations near the sun's limb.

These faculæ exist on an enormous scale. It is quite common to see reaches of them tens of thousands of miles long, lasting for days, and perhaps weeks; we get in that fact an indication of the enormous amount of energy which may still be changing places in the solar atmosphere, even though we do not get other phenomena which appear to us to be more important. By "other phenomena" of course I mean the spots.

J. Norman Lockyer

(*To be continued.*)

BARK BREAD

MOST travellers in Norway have probably had more than sufficient opportunities of becoming acquainted with the so-called "Fladbröd," flat bread, of the country. Few, however, among them who have partaken of this dry and insipid food may possibly be aware that in many districts, more especially in Hardanger, the chief ingredient in its composition is the bark of trees. This substitution of an indigestible product for *bonâ fide* flour is not necessarily a proof of the scarcity of cereals, but is to be ascribed rather to an opinion prevalent among the peasant women that the bark of young pine branches, or twigs of the elm, are capable of being made into a thinner paste than unadulterated barley or rye-meal, of which the Norse housewife, who prides herself on the lightness of her "Fladbröd," puts in only enough to make the compound hold together.

The absence of any nutritive property in bark bread, whether made with elm or pine bark, and the positive injury it may do the digestive organs, has of late attracted much notice among Norwegian physiologists, and the editor of *Naturen*, with a view of calling the attention of the public to the subject, has, with the author's permission, reprinted some remarks by Dr. Schübeler on the history and character of the bark bread of Scandinavia. From this source we learn that the oldest reference to the use of bark bread in Norway occurs in a poem, ascribed to the Skald Sighvat, who lived in the first half of the eleventh century. In the year 1300 the annals of Gothland record a season of dearth, in which men were forced to eat the bark and leaf-buds of trees, while then, and during the later periods of the Middle Ages, the frequent failure of the crops in all parts of Scandinavia led to the systematic use of the bones and roe of fishes, as well as the bark of trees as a substitute for genuine flour; and so extensively was the latter substance used that Pastor Herman Ruge, who in 1762 wrote a treatise on the preservation of woods, has drawn attention to the almost complete disappearance of the elm in the Bohus district, which he ascribes to the universal practice in bygone times of stripping the bark for the preparation of bread.

In Nordland and Finmark the root of *Struthiopteris germanica* and other ferns, as well as the leaves of various species of Rumex, have been largely used with barley-meal in making ordinary bread as well as "Fladbröd." In Finland the national "pettuleipa" (bark bread), which was in former times almost the only breadstuff of the country, still ranks as an ordinary article of food in Kajana, and in the forest-regions of Oesterbotten, and Tavastland. Here it is usually made of the inner layers of the pine-bark, ground to a meal, which is mixed with a small quantity of rye-flour to give the requisite tenacity to the dough. The Finlanders of an older generation showed marvellous ingenuity in composing breadstuffs, in which scarcely a trace of any cereal could be detected in the mixture of bark, berries, seeds, bulbs, and roots of wild plants, which they seem to have accepted as a perfectly legitimate substitute for corn-bread. In the interior of Sweden, according to Prof. Säve, the *best* bread of the peasants consisted till the middle of this century of pease, oats, and barley-meal in equal proportions, while in the ordinary daily bread the husks, chaff, and spikes of the oats were all ground down together. In bad seasons even this was unattainable by the Dalekarlian labourer, who had to content himself with pine-bark bread.

DILATANCY[1]

THE principal object of this lecture was to show experimental evidence of a hitherto unrecognised fact of fundamental importance in mechanical philosophy. This newly-recognised property peculiar to granular masses (named by the author "Dilatancy") would be rendered clear by the experiments. But it was not from these experiments that it had been discovered. This discovery was the result of an endeavour to conceive the mechanical properties a medium must possess in order to act the part of the all-pervading ether—transmitting waves such as light, but not such as sound, allowing free motion of bodies, causing distant bodies to gravitate, and causing forces like cohesion, elasticity, and friction between adjacent molecules, together with electricity and magnetism.

As the result of this endeavour, it appeared that the simplest conceivable medium, a mass of rigid granules in contact with each other, would answer not only one but all of these requirements, provided such shape or fit could be given to the grains that, while these rigidly preserved their shape, the medium should possess the apparently paradoxical or anti-sponge-like property of swelling in bulk when its shape was altered.

This required that the grains should so interlock that, when any change in the shape of the mass occurred, the interstices between the grains should increase. Having recognised this property as a necessity of the ether, the next question became, What must be the shape and fit of the grains so that the mass might possess this unique property? At first it seemed that there must be something special and intricate in this structure. It would obviously be possessed by grains shaped to fit into each other's interstices: this was illustrated by a model of bricks arranged to bond as in a wall; when the pile was distorted, interstices appeared. Subsequent consideration revealed this striking fact—that any shape of grains resulted in a medium possessing this property of dilatancy so long as the medium was continuous, or so long as precautions were taken to prevent rearrangement of the grains, commencing at the outside. All that was wanted was a mass of smooth hard grains, each grain being held by the adjacent grains, and the grains on the outside being so controlled as to prevent rearrangement. This was illustrated by a model of a pile of shot, which, when in closest order, could not have its shape changed without opening the order and increasing the interstices. The pile being brought from closest to most open order by simply distorting its shape, the outside balls being forced, those in the interior were constrained to follow, showing that in no case could a rearrangement start in the interior.

Considering the generality of this conclusion, it was necessary to explain how it was that dilatancy was not a property of ordinary atomic or molecular matter. This was owing to the elasticity, cohesion, and friction which rendered molecules in-

---

[1] In 1872; see "Solar Physics," p. 404.

[1] Abstract of a Lecture delivered at the Royal Institution of Great Britain, on Friday evening, February 12, 1886. By Prof. Osborne Reynolds, LL.D., F.R.S.