XIII. *Observations tending to investigate the Nature of the Sun, in order to find the Causes or Symptoms of its variable Emission of Light and Heat; with Remarks on the Use that may possibly be drawn from Solar Observations. By* William Herschel, *L.L.D. F.R.S.*

Read April 16, 1801.

On a former occasion I have shewn, that we have great reason to look upon the sun as a most magnificent habitable globe; and, from the observations which will be related in this Paper, it will now be seen, that all the arguments we have used before are not only confirmed, but that we are encouraged to go a considerable step farther, in the investigation of the physical and planetary construction of the sun. The influence of this eminent body, on the globe we inhabit, is so great, and so widely diffused, that it becomes almost a duty for us to study the operations which are carried on upon the solar surface. Since light and heat are so essential to our well-being, it must certainly be right for us to look into the source from whence they are derived, in order to see whether some material advantage may not be drawn from a thorough acquaintance with the causes from which they originate.

A similar motive engaged the Egyptians formerly to study and watch the motions of the Nile; and to construct instruments for measuring its rise with accuracy. They knew very well, that it was not in their power to add a single inch to the flowing waters of that wonderful river; and so, in the case of the sun's influence, we are likewise fully aware, that we shall never be able to occasion the least alteration in the operations which are carried on in the solar atmosphere. But, if the Egyptians could avail themselves of the indications of a good Nilometer, what should hinder us from drawing as profitable consequences from solar observations? We are not only in possession of photometers and thermometers, by which we can measure from time to time the light and heat actually received from the sun, but have more especially telescopes, that may lead us to a discovery of the causes which dispose the sun to emit more or less copiously the rays which occasion either of them. And, if we should even fail in this respect, we may at least succeed in becoming acquainted with certain symptoms or indications, from which some judgment might be formed of the temperature of the seasons we are likely to have.

Perhaps our confidence in solar observations made with this view, might not exceed that which we now place on the indications of a good barometer, with regard to rain or fair weather; but, even then, a probability of a hot summer, or its contrary, would always be of greater consequence than the expectation of a few fair or rainy days.

It will be easily perceived, that in order to obtain such an intimate knowledge of the sun as that which is required for the purpose here pointed out, a true information must be first procured of all the phenomena that usually appear on its surface. I have therefore attended to many circumstances, that have either not been noticed at all before, or have not been examined with any particular view of information. The improvement also in the solar apparatus of my ten-feet telescope, by which I can take away as much light and heat as required, has given me additional facility of making a great number of particular observations ; and, as they have been all directed to an investigation of certain points, I shall give them here, in the order which the arrangement of my subject will require.

It will be necessary, before I can enter into a detail of the observations, to give notice that, from an improved knowledge of the physical construction of the sun, I have found it convenient to lay aside the old names of *spots*, *nuclei*, *penumbræ*, *faculæ*, and *luculi*, which can only be looked upon as figurative expressions that may lead to error. Nor were these few terms sufficient to describe the more minute appearances on the sun, which I have to point out.

The expressions I have used are *openings*, *shallows*, *ridges*, *nodules*, *corrugations*, *indentations*, and *pores*. It will not be amiss to give a short explanation of these terms.

Openings are those places where, by the accidental removal of the luminous clouds of the sun, its own solid body may be seen; and this not being lucid, the openings through which we see it may, by a common telescope, be mistaken for mere black spots, or their nuclei.

Shallows are extensive and level depressions of the luminous solar clouds, generally surrounding the openings to a considerable distance. As they are less luminous than the rest of the sun, they seem to have some distant, though very imperfect, resemblance to penumbræ; which might occasion their having been called so formerly.

Ridges are bright elevations of luminous matter, extended in rows of an irregular arrangement.

Nodules are also bright elevations of luminous matter, but confined to a small space. These nodules, and ridges, on account of their being brighter than the general surface of the sun, and also differing a little from it in colour, have been called faculæ, and luculi.

Corrugations, I call that very particular and remarkable unevenness, ruggedness, or asperity, which is peculiar to the luminous solar clouds, and extends all over the surface of the globe of the sun. As the depressed parts of the corrugations are less luminous than the elevated ones, the disk of the sun has an appearance which may be called mottled.

Indentations are the depressed or low parts of the corrugations; they also extend over the whole surface of the luminous solar clouds.

Pores are very small holes or openings, about the middle of the indentations.

Any other terms I may hereafter use, will be sufficiently explained by the observations in which they occur.

I shall now enter into an examination of all the phenomena that may be observed in viewing the sun through a good telescope, beginning with those that are most common; a critical investigation of which will lead us gradually to such as are more intricate.

It will be seen that I have brought my observations under a number of short heads, or propositions, such as my subject requires. The advantage of this method is, that the tendency of every observation will be immediately understood, while it is read; whereas, had I arranged these observations in the order in which they were made, the mixture of the various points to be ascertained by them must have brought on a considerable obscurity; and, in drawing conclusions from them afterwards, a repetition of the observations which were to support them would have been unavoidable.

I must take notice of what will perhaps be censured in many of the observations; they may be said to be accompanied with surmises, suppositions, or hypotheses which should have been kept separate. In defence of this seeming impropriety, I must say, that the observations are of such a nature, that I found it impossible, at the very time of seeing the new objects that presented themselves to my view, to refrain from ideas that would obtrude themselves. It may even be said, that since observations are made with no other view than to draw such conclusions from them as may instruct us in the nature of the things we see, there cannot be a more proper time for entertaining surmises than when the object itself is in view.

Now, since the suggestions that have been inserted were always such as arose at the moment of the observations, they are so blended with them, that they would lose much of their value as arguments, if they were given separately.

In order not to lengthen this Paper unnecessarily, I have given but a few observations under each head; especially with those propositions which may be looked upon as already sufficiently established by the observations of other astronomers. The whole tenor of the observations I have given, though divided under such numerous heads, is indeed such as must produce a mutual support; so that, frequently, one or two particular observations were thought sufficient to establish my point, when I might have added many more, from my journals, in support of it.

OF OPENINGS.

Openings are Places where the luminous Clouds of the Sun are removed.

That those appearances which have been called spots in the sun, are real openings in the luminous clouds of the solar atmosphere, may be concluded from the following observations, where the sides or thicknesses of the borders which limit the openings are distinctly described.

Jan. 4, 1801. There is a large opening much past the centre of the sun, with a shallow about it.* On the preceding side, I see the thickness of the shallow, from its surface downwards. On the following side, I also see the edge of the shallow near the opening; but it is sharp, and its thickness cannot be seen.

I see also the side of the elevation surrounding the shallow, going curvedly down to the surface of the shallow, on its preceding side.

A large collection of openings, of very different sizes, are near the following limb. They all manifest the same kind of optical appearance, but on the side which is contrary to that in the opening before mentioned; for here the thicknesses or depths of the shallows, and of the slopes going down from the upper surface to the shallows, are only visible on the following side, but not on the preceding one.†

* See Plate XVIII. Fig. 1 and 2.

† For a geometrical proof of the depression of the nucleus of a *spot*, as an opening was formerly called, see a most valuable paper of Observations on the Solar Spots, by the late ALEXANDER WILSON, M. D. Professor of Practical Astronomy in the University of Glasgow. Phil. Trans. Vol. LXIV. Part I.

Large Openings have generally Shallows about them.

Jan. 24, 1801. The two largest openings of January 19, are completely surrounded by shallows.

Many Openings are without Shallows.

Jan. 22, 1800. There are two openings which have not the least shallow about them. The corrugations go equally between and around them.

Feb. 7, 1800. There are two considerable openings not far from each other: they have no shallows about them.

Small Openings are generally without Shallows.

Dec. 2, 1800. There are a great number of large and small openings: the large ones have shallows about them; the small ones are mostly without.

Openings have generally Ridges and Nodules about them.

Dec. 20, 1794. There are two openings near the preceding margin of the sun; they have elevated extensive luminous ridges about them.

Dec. 23, 1799. A pretty considerable opening, on the following side of the disk, is surrounded by many ridges.

Feb. 7, 1800. Following two considerable openings, which are not far from each other, are several irregularly dispersed ridges, more bright than the rest of the sun.

Jan, 4, 1801. Many clustering openings are lately come into the disk; a crowd of ridges and nodules surround, and are interspersed among them.

Openings have a Tendency to run into each other.

Dec. 25, 1799. The large opening of December 23, and the small one near it, are now nearly run into each other.

Jan. 4, 1801. The two largest openings of Jan. 2, are nearly joined into one.

Jan. 6, 1801. The largest of the preceding openings, of a set observed Jan. 4, has drawn together all the small ones, and is increased in dimensions.

Jan. 29, 1801. $2^h\ 10'$. A longish opening, observed at 12^h, is increased by the addition of two projections. With more attention, however, I perceive that these projections are united to each other, but separated from the longish opening, by a narrow luminous bridge, or compressed row of luminous clouds.

Jan. 30, 1801. The two united projections of yesterday are now joined to the longish opening.

New Openings break out near other Openings.

Dec. 23, 1799. There is a small opening near the large one observed yesterday, which then was not visible.

Jan. 21, 1800. The preceding of two openings observed before, has now two other small ones near it.

Probable Cause of Openings.

Jan. 18, 1801. Between two clusters of openings, near each other, there are some, as I suspect, incipient openings: they resemble coarse pores of indentations.

Jan. 19, 1801. The incipient openings, between the clusters of yesterday's observation, are completely turned into considerable openings. It seems as if an elastic, but not luminous gas, had come up through the pores or incipient openings, and spread itself on the luminous clouds, forcing them out of the way, and widening its passage.

Feb. 18, 1801, $7^h\ 44'$. The south preceding one of three large connected openings,* has a narrow branch coming from its shallow.

$9^h\ 55'$. The opening is broken out at three places;† and the shallow has three projections just opposite. It is plain that the breakings-out and the projections must have the same cause; which probably acts first at the opening, and widens it, then goes forward, and occasions the corresponding projections in the shallows.

The shallow is very large on that side where the breakings-out are situated; and, on the contrary, very narrow on the opposite, or, as it may be called, the quiescent side.

$10^h\ 12'$. The broadest of the little sprouting shallows is opposite the broadest of the breakings-out, or encroachments of the opening on the general shallow.

Direction and Operation of the disturbing Cause.

Jan. 24, 1801. A small oblong opening, near a preceding large one, has on its north side a very long shallow. This made me surmise, that the elastic fluid coming out of it might have a strong direction from below, towards that side. Examining therefore this opening all round, I found that the shallow extended only to one side, leaving the other parts full of luminous matter close to the margin of the opening. And, on examining the large opening, I found that the shallow about it was also larger, in the same direction as the shallow about the small one

* See Plate XVIII. Fig. 3. † See Fig. 4.

Eight other small openings, forming together a cluster with the former two, have every one also their incipient shallows on the same side; that is, towards the north-following; and none at all on the other parts of their margins.

3^h 15′. The shallow about the small opening has changed its direction. It was like Fig. 5, and is now as in Fig. 6. (Plate XVIII.) In the farthest end of it, I expect an opening to be coming on.

4^h 30′. There is already the appearance of an incipient opening.*

Jan. 6, 1801. The shallows about the large opening and the small one near it, are much altered in situation and dimensions. All the smaller openings near them have undergone great changes; some being gone, and new ones come in different places, while others have altered their appearance. The bias in the direction of the shallows is also considerably changed.

Jan. 30, 1801. 9^h 20′. There is a cluster of small openings, which I expect to see united into one, by the breaking down, driving away, or dissolution, of the intermediate communications of luminous clouds. From having seen it yesterday, I know the largest of the openings to be a generating one. It has an increasing shallow; and the next largest opening of the cluster has an incipient one.

10^h 40′. The incipient shallow is now pretty large.

11^h 2′. There is now also an incipient shallow about the most south of the small openings.

11^h 6′. The shallow of the largest opening is increased.

Maxima of Openings.

Jan. 29, 1801, 11^h 0′. The shallow of the largest of many

* See Plate XVIII. Fig. 7.

openings that are visible, is most extended towards the north-following side.* It affects a circular form more than the opening, but is not concentric with it. It has a small lip on the north, which I suppose denotes the direction of the gas coming out of the opening. A similar lip is visible in the opening itself, as if the gas, in coming out, pressed against the luminous clouds which limit the opening, and belong to the flat.

2^h 10′. The lip or projection of the shallow about the opening is filled up at the sides; they being now as broad as the lip's projection. The filling up is marked with points in the figure.

Jan. 30, 1801. The large opening observed yesterday is no longer increased; but seems to be nearly at its maximum.

Feb. 4, 1801, 1^h 10′ The shallow of the large opening is much more round than the opening, though not concentric with it. Hence, its figure being no longer disturbed, I guess that the opening is near its maximum.

There is some Difference in the Colour of Openings.

March 1, 1800. There are two large openings, which seem to be partially covered, or rather to have a thin, semi-transparent, luminous veil of clouds still hovering over them; this gives them a fainter black colour than openings generally have.

Openings divide when they are decaying.

Dec. 26, 1799. An opening observed the 25th is reduced; and is divided in the middle by a lucid line.†

Dec. 27, 1799. The luminous bridge or passage across the opening is pretty broad, and has a branch about the middle. This branch of light has the appearance of a luminous cloud,

* See Plate XVIII. Fig. 8. † See Fig. 9.

irregularly breaking out from the passage, towards the southern half of the opening.

Dec. 28, 1799. The opening is so completely vanished, that I cannot find the least mark of its former existence. From the appearance of the branch yesterday, in the luminous division resembling a bridge thrown over a cave, I surmise that this branch, as well as the sides of what I call the bridge, have extended themselves, and as it were drawn a lucid curtain over the opaque surface of the sun.

Decaying Openings sometimes increase again.

Feb. 8, 1801. The great opening, which has been gradually diminishing since Feb. 4, is now enlarged again.

When Openings are divided, they grow less, and vanish.

Dec. 29, 1799. The south preceding of two openings observed yesterday is divided into three small ones.

Dec. 31, 1799. The divided opening of the 29th exists no longer.

Feb. 9, 1800. Of two considerable openings observed Feb. 7, the preceding one is divided into several smaller parts.

Feb. 10, 1800. The divided opening observed yesterday is in a vanishing state.

Feb. 11, 1800. The openings are all covered in, and no trace of them can be found.

Decayed Openings sometimes become large Indentations.

Feb. 9, 1800. The preceding of two openings observed the 7th of February is now about half filled up; and that half contains two indentations, with black pores, or rather remaining small openings. They are nearly of the size of the general corrugations of the solar surface at present.

Decaying Openings turn sometimes into Pores.

Feb. 10, 1800. $1^h\ 0'$. Between the half of the opening and that part which was nearly covered in yesterday, is a set of indentations, with pores rather larger than they are in general.

When Openings are vanished, they leave Disturbance behind.

Dec. 28, 1799. $12^h\ 10'$. There is a place among the corrugations, where they are coarser now than they were an hour ago.

1^h. Two considerable openings are broken out, in the place where the corrugations were coarse. They are both so completely dark, and free from thin luminous clouds, that it appears very plainly they were only hidden behind the slight covering of luminous obstructions; one of them is about the place where the opening of yesterday was situated.

Jan. 24, 1800. There is a pretty large place, which contained the openings observed the 22d, the luminous clouds of which are in a state of disturbance: it includes five or six places, where the pores of indentations assume the shapes of incipient openings, and after some time lose them again, more or less.

Feb. 11, 1800. There is a place which I suppose to be that where the now vanished openings were yesterday: it seems to be rather disturbed in the arrangement of its corrugations. One of the indentations is probably an evanescent opening, as it still shews a considerable pore.

Apparent View into the Openings, under luminous Bridges and Shallows.

Dec. 27, 1799. A luminous passage across a large opening has all the appearance of a bridge going over a hollow space; and I have no doubt but that it is at a considerable distance from the opaque surface of the sun.

Jan. 4, 1801. A ridge which separates two openings much past the centre, shews its thickness on the following side: it has a shallow, the preceding side of which I see going down to the opening; and it appears to me, that there is a considerable distance between the lowest part of that shallow and the dark surface of the sun under it. Nor can I help believing that I see aslant under it, towards the preceding side; though I find it difficult to account for such vision, on the principles of solar perspective.

Jan. 6, 1801. The same opening is now further advanced towards the limb of the sun. It appears again to me, that on the preceding side I see far under the shallow. I suspect the part towards P to be of a deeper dark colour than that towards F;* but the difference, if there be any, is not marked enough to be decisive.

Depth of the Openings, indicated by their Darkness.

Jan. 15, 1801. $11^h\ 10'$. One of the openings, which is near the preceding limb of the sun, is remarkably black. The tint of openings may perhaps assist us to infer their depth; which must be greater in a direction towards us, when the opening is near the circumference, than when it is near the centre, if the

* See Plate XVIII. Fig. 1 and 2.

distance from the shallows to the opaque surface should be considerable.

I have compared the darkness of two openings near the centre, with the appearance of that near the preceding limb. It is decidedly in favour of the blackness of the latter: this is however larger than the former two; which may occasion deceptions.

The opening near the limb is certainly darker than the two which are near the centre.

Feb. 5, 1801. An opening very near the preceding margin is of a deep black colour; certainly more so than another which is not far off, but is more towards the centre of the sun.

Feb. 8, 1801. The large opening near the margin, is darker than two other openings which are about the centre of the solar disk: the difference, however, is hardly sufficient to be decisive. The two openings are also much smaller; which may occasion a deception.

Distance between the Shallows and solar Surface, indicated by the free Motion of low Clouds.

Jan. 25, 1801. 9^h $22'$. A large opening, which I have been observing since the 19th, is now much advanced towards the limb.* I can see into it; and, on the preceding side, as it appears to me, a good way under the lowest regions of the clouds of which the shallow consists. The upper margin of the shallow is very sharply determined; but the clouds of the lower part of it, on the contrary, are more dispersed; some of them hanging a good way down, towards the surface of the sun's body.†

10^h $20'$. The preceding side of the shallow of the large

* See Plate XIX. Fig. 10. † See Fig. 11.

opening, is now more abruptly terminated at the bottom of its thickness; the hanging or projecting clouds being removed towards the following side.*

OF SHALLOWS.

Shallows are depressed below the general Surface of the Sun; and are Places where the luminous solar Clouds of the upper Regions are removed.

That those appearances which have been called penumbræ are real depressions, or shallows, may already be concluded, from what has been related with regard to the slopes from the upper surface of the sun, down to the top of these shallows; and will follow still more evidently, from an observation of one of them on the very limb of the sun.

Dec. 3, 1800. There is a considerable opening just come into the disk, which is followed by another that is actually in the limb of the sun. The uniformity of the circular termination of the limb suffers a small deviation; it being somewhat depressed, owing to the shallow about the opening. I do not yet perceive the opening itself with certainty; but suppose it will appear to be one, when it advances more into the disk.

The Thickness of the Shallows is visible.

Jan. 6, 1801. There is a large opening much advanced beyond the centre, with a shallow round it. On the preceding side of the shallow, its descent down towards the opening is visible; but, on the following side, I see abruptly into the opening.

* See Plate XIX. Fig. 12.

Sometimes there are Shallows without Openings in them.

Feb. 7, 1801. There is a pretty large shallow inclosed by the ridges which follow some preceding openings.

Feb. 12, 1800. A place where yesterday I saw five or more nodules, at present contains low ridges inclosing some shallows.

Incipient Shallows come from the Openings, or branch out from Shallows already formed, and go forwards.

Jan. 18, 1801. In a cluster of openings, there is an incipient shallow, coming from one of them.

Jan. 19, 1801. The incipient shallow is increased, and has now spread all round the opening.

Jan. 24, 1801. A large opening sends from its shallow already formed, a narrow projection, towards the end of a neighbouring shallow belonging to a smaller opening, as if they were going to meet.

Probable Cause of Shallows.

Jan. 25, 1801, 9^h 20′. Two branches A B,* of a shallow coming from an opening C, are going towards the south. It seems as if they were destined to meet the incipient shallow of a south-following opening D.

9^h 50′. The shallow B is now very nearly united to the narrow part of the shallow surrounding the opening D. The shallow A seems to advance, in a direction towards the farthest south-following opening E.

10^h 20′. The shallow B is now completely run into the shallow about D; † and the shallow A is grown broader towards F.

11^h 30′. The shallow B is so completely joined to the shallow

* See Plate XIX. Fig. 13. † Fig. 14.

about D, that it appears as if it had not come from the opening C. The shallow A now ends in a sharp point.*

$12^h\ 50'$. The shape of the shallow A is again much changed; it is no longer pointed, but very broad at the end; † and there is a new branch breaking out at G. These changes seem all to denote, that the shallows are occasioned by something coming out of the openings, which, by its propelling motion, drives away the luminous clouds from the place where it meets with the least resistance; or which, by its nature, dissolves them as it comes up to them. If it be an elastic gas, its levity must be such as to make it ascend through the inferior region of the solar clouds, and diffuse itself among the superior luminous matter.

$1^h\ 10'$. The new branch G increases; and the openings C, D, E, are enlarged. A new branch is also breaking out from the shallow about E. It is marked H in Fig. 14, and denoted with points. These changes seem to prove, that the same gas which diffuses itself over the shallows has forced open the passages at first, and is now widening them. Hence, the increase of the openings is an additional circumstance which points out the cause of the shallows.

$1^h\ 20'$. From the shallow of a very large preceding opening, which is in an increasing state, are lately projected three small branches *a*, *b*, *c*. ‡

$2^h\ 30'$. The vacancies between the three small projecting shallows are now filled up by the same cause that occasioned them, so as to have given them the shape of an uniform but broader shallow, on the side where the branches come out, as denoted by points.

* See Plate XIX. Fig. 15. † Fig. 16. ‡ Fig. 17.

Shallows have no Corrugations, but are tufted.

Feb. 4, 1801. The great shallow about a large opening has no corrugations.

Feb. 18, 1801. The lower clouds of the shallow of a large opening, though not corrugated, are not smooth, but tufted. They are so closely connected in their tufts, that it makes them appear as if, in every vacancy, there were clouds under clouds, that prevent our looking far into them.

Decay of Shallows.

Jan. 30, 1801. The borders of the shallow belonging to the large opening observed Jan. 29, seem to be remarkably high; so that, if the opening were near the limb, they would probably appear like ridges. The shallow has again a lip, nearly in the place where there was one yesterday. But it seems as if the lip, which is visible now, had a cause contrary to what produced it yesterday. For the luminous clouds all round the shallow seem no longer to be kept off by an issuing elastic fluid, but are probably now breaking in upon the shallow, except in the place of the lip, where some energy, like that exerted yesterday, may still remain in action; in that case, the shallow, as well as the opening, is past its maximum.

OF RIDGES.

Ridges are Elevations above the general Surface of the luminous Clouds of the Sun.

Dec. 27, 1799. On the south-following side of the sun's disk, close to the margin, are some bright ridges. They are all in a direction parallel, or nearly parallel, to the margin; and have the appearance of elevations.

Jan. 29, 1801. Two sets of openings, near the north-following limb, have wide-spreading ridges about them: four other sets, being farther advanced into the disk, do not shew any. This denotes them to be thin elevations, which can only be seen near the circumference, by a side view.

Feb. 8, 1801. Many ridges and nodules are now to be seen about the large opening, which yesterday had none. I suppose they are become visible by its advancement towards the margin, to which it draws near.

Length of a Ridge.

Dec. 27, 1799. I measured one of the longest ridges in view. It extended over an angular space of 2′, 45″,9, which is nearly 75000 miles.

Ridges generally accompany Openings.

Feb. 5, 1801. Three sets of openings near the preceding limb, and two near the following one, are surrounded by luminous ridges.

Ridges are also often in Places where there are no Openings.

Dec. 22, 1799. On the following side of the sun are luminous ridges; but not within 50 or 60 degrees of an opening.

Jan. 4, 1801. Towards the north, near the limb, is a collection of ridges without openings.

Feb. 5. Two of the sets of openings of yesterday are gone; but have left extensive ridges behind.

Ridges disperse very soon.

Dec. 28, 1799. The appearance of the ridges I saw yesterday is much changed: they are less luminous and extensive than they were. The range is much broken; and they appear more in detached irregular elevations.

Dec. 29, 1799. The ridges are so much reduced to the resemblance of the rest of the sun, that had I not known where to look for them, I should hardly have been able to trace any vestige of them.

Feb. 9, 1800. The ridges which followed some openings Feb. 7, exist no longer.

Different Causes of Ridges hinted at.

Jan. 4, 1801. A crowd of ridges and nodules surround, and are interspersed among, a cluster of openings. A ridge which crosses one of the openings like a bar or bridge, is sharp on the following side, but shews thickness on the preceding. It seems probable, that the openings permit a transparent elastic fluid to come out, which disturbs the luminous matter on the top, so as to occasion ridges and nodules. There are not less than 17 openings in the cluster.

Jan. 6, 1801. Following a set of openings lately come into the disk, are many luminous and broad, that is to say, high ridges, without any openings among them; so that the cause which produces them acts probably below the shining matter. Their own levity also may occasion them to go into the higher regions.

Jan. 30, 1801. Near the following margin is an extended plane, full of bright ridges and nodules, with a great number of openings lately broken out, and still breaking out among them. This leads us to suppose that some elastic gas, acting below the luminous clouds, lifts them up, or increases them; and at last forces itself a passage through them, by throwing them aside.

OF NODULES.

Nodules are small, but highly elevated, luminous Places.

Jan. 24, 1800. On the south, near the limb of the sun, is a nodule; and on the south-following side is another, with two smaller ones near it. They are round, or roundish, bright elevations, of the same nature as the ridges.

Feb. 19, 1800. There are two small bright nodules, on the preceding limb of the sun. Why they should only be seen near the sun's margin, can only be explained by admitting their elevation.

Nodules may be Ridges foreshortened.

Dec. 27, 1799. Mixed with many ridges, nearly parallel to the margin of the sun, are here and there small thicknesses or knotty places. I take them to be ridges in a more central direction, which gives them the shape of nodules.

The most north of three nodules, in one of the ridges, seems to be highest in elevation. If it should last till to-morrow, it will then appear whether that nodule is really more elevated than the rest, or whether it is the foreshortening of a ridge extended in the direction of a radius.

OF CORRUGATIONS.

Corrugations consist of Elevations and Depressions.

Dec. 23, 1799. The corrugations have a mottled appearance. I see the figure of the dark and bright places. Many of the dark places are not round, but a little extended in different directions, and appear to be lower than the bright places. This, if admitted, will explain why the corrugations towards the margin of the sun, cannot so readily be seen as about the middle of the disk.

Jan. 4, 1800. The day being very favourable, I saw the sun uncommonly well. The corrugated surface presented its elevations and depressions, with as much distinctness as the rough surface of the moon.

Corrugations extend all over the Surface of the Sun.

Dec. 23, 1799. The corrugations extend all over the sun. They are less distinct all around towards the limb, than at the centre.

Jan. 22, 1800. I followed the corrugations from the centre to the circumference; and could trace them every where to within, I suppose, two minutes of the margin.

Jan. 24, 1800. The corrugations are equally spread over the whole surface of the sun. I viewed them distinctly in every part of it; and traced them with much attention to within, I suppose, half a minute of the margin.

Jan. 4, 1801. The corrugations are extended all over the disk of the sun, and go to the polar regions, as well as to the equatorial parts.

Dispersed Ridges or Nodules make Corrugations.

Nov. 17, 1800. The surface of the sun appears richly filled with very small broken or dispersed ridges, which produce the corrugated appearance.

Feb. 18, 1801. The high parts of the corrugations contain numberless separations, like small nodules, which leave room for the indentations to be seen between them.

Corrugations change their Shape and Situation; they increase, diminish, divide, and vanish quickly.

Dec. 27, 1800. $1^h\ 0'$. There is a pretty large corrugation near a small opening, which serves me as a direction to find the place. Its indentation is about four diameters of the opening from it; and 10 or 16 degrees north-preceding.

$1^h\ 5'$. I have seen the corrugation again; and find its indentation larger than it was, and farther from the opening.

$1^h\ 10'$. It is vanished; and several other such very minute changes have taken place.

$1^h\ 12'$. Within a diameter of the opening, and a little north-following it, is an oval indentation, nearly as large as the small opening.

$1^h\ 15'$. Its shape is altered; and it is divided into a corrugation, with two indentations.

$1^h\ 35'$. Both are entirely gone.

Jan. 18, 1801. Between two clusters of openings, that are near each other, there are some incipient openings, which resemble coarse corrugations, and establish a step between small openings and pores of indentations. I shewed them to my friend Dr. WILSON, who happened to be upon a visit to me, at Slough. He saw the same phenomena; and judged of their being a link in the chain of appearances, as I did.

We drew a small sketch of the place of the phenomena, merely to serve us to communicate our observations to each other.*

1^h 19′. A, is a small opening, without a shallow, which we had fixed upon, by way of enabling us to find again the minute objects which were to be examined. B, is the indentation, or dark place, of a corrugation I pointed out to Dr. WILSON. C, is a dark place of a corrugation he pointed out to me.

1^h 24′. We both found the dark part of the corrugation B gone; and C had either changed its place or was vanished.

1^h 34′. C, was certainly gone.

Dr. WILSON pointed out another round pore, which we had not perceived before, at some distance; also a largish indentation near the opening, which guided our research. Shortly after, we found the indentation gone; and the pore was further removed from the opening.

OF INDENTATIONS.

The dark Places of Corrugations are Indentations.

Dec. 27, 1799. That the low places of the corrugations are not much depressed, is evident from their visibility pretty near the margin of the sun.

Jan. 27, 1800. The corrugations in many places are so coarse, that their indentations resemble small shallows. The

* See Plate XIX. Fig. 18.

indentations go down at the sides, like circular arches, presenting their concavities to us; but the bottom of them is nearly flat.*

Indentations are without Openings.

Jan. 15, 1801. The low places of corrugations do not contain punctures; but seem to be irregularly shaped places, of less luminous matter than the borders which inclose them.

In some Places the Indentations contain small Openings.

Dec. 27, 1799. On examining some of the largest corrugations with a high magnifying power, I see plainly, that the less bright parts, or indentations, are small openings; and that those dark places, which were the coarsest, shew the opaque surface of the sun best: some of them are as black as the large openings.

The Elevations and Indentations of Corrugations are of different Figures.

Feb. 18, 1800. Among all the corrugations, I could hardly perceive any that were round: they were of all shapes; chiefly lengthened.

Indentations change to Openings.

Feb. 10, 1800. Three corrugations, observed an hour ago, are now so enlarged, that their indentations are passed over from their former state, to small openings.

* See Plate XIX. Fig. 19.

Indentations are of the same Nature as Shallows.

Jan. 30, 1801. The depressed parts, or indentations, of corrugations, are of the colour of shallows; and are probably of the same depth below their elevations, as shallows are below the general surface of the sun.

Indentations are low Places, which often contain very small Openings.

Jan. 2. 1801. That indentations are small hollow places, and that the pores in them are little openings, may be concluded from a set of real openings of different sizes, of which I see no less than 13. Four of them are visible openings; five of them are less than the smallest openings, and larger than the indentations of corrugations; the remaining four may already be called large pores. We cannot expect to see into these pores, as we do into holes, their diameter being too small.

Indentations are of different Sizes.

Jan. 31, 1800. The indentations are very uniform, but not round. It seems they admit of every possible shape.

Indentations are extended all over the Sun.

Dec. 20, 1794. I can follow the indentations, from the centre up to the margin of the sun; but it requires great attention, as, on account of the sphericity of the disk, they become gradually less conspicuous, the nearer we go to the circumference. I saw them equally well at the north pole of the sun.

Dec. 22, 1799. The whole disk of the sun is strongly indented.

With low magnifying Powers, Indentations will appear like Points.

Feb. 4, 1800. I tried a magnifying power of only 45 times, and the sun then appeared punctulated, instead of indented. The points, or rather darker coloured places in the punctulations, were of different figures; few of them being round.

OF PORES.

The low Places of Indentations are Pores.

Dec. 20, 1794. The lowest parts of the indented appearances, are almost dark and depressed enough to be called very minute openings.

Pores increase sometimes, and become Openings.

Feb. 10, 1800. Two indentations, observed an hour ago, are increased, and contain large pores, as if they were going to be converted into visible openings, like the indentations of three neighbouring corrugations mentioned under a former article.

Jan. 22, 1800. Between some large and small openings were two pores, that grew darker while I looked at them, and may now be taken for very small openings. This seems to trace the openings to their origin, and perfectly connects the pores with them.

Pores vanish quickly.

Dec. 27, 1800. A small pore, that was north-following a very small opening, which served me as a direction for finding it again, $1^h\ 30'$ ago, is no longer to be seen.

$12^h\ 30'$. There were two pores north-preceding the same opening. When I returned to the telescope, in order to describe their situation exactly, they were vanished.

OF THE REGIONS OF SOLAR CLOUDS.

It must be sufficiently evident, from what we have shewn of the nature of openings, shallows, ridges, nodules, corrugations, indentations, and pores, that these phenomena could not appear, if the shining matter of the sun were a liquid; since, by the laws of hydrostatics, the openings, shallows, indentations, and pores, would instantly be filled up; nor could ridges and nodules preserve their elevation for a single moment. Whereas, many openings have been known to last for a whole revolution of the sun; and extensive elevations have remained supported for several days. Much less can it be an elastic fluid of an atmospheric nature: this would be still more ready to fill up the low places, and to expand itself to a level at the top. It remains, therefore, only for us to admit this shining matter to exist in the manner of empyreal, luminous, or phosphoric clouds, residing in the higher regions of the solar atmosphere. The following observations, will explain and support this idea more at large.

Changes in the Solar Clouds happen continually.

Feb. 19, 1800. In order to find whether the solar clouds were subject to very quick changes, I fixed my attention on several places; but, on looking off, even for a moment, the spots I had marked for the purpose could not be found again.*

* See what has been said of the quick changes among the corrugations and indentations, under the former articles.

There are two different Regions of Solar Clouds.

Feb. 19, 1800. It is not possible to see the sun more distinctly than I do at present. The corrugations are evidently caused by a double stratum of clouds; the lower whereof, or that which is next to the sun, consists of clouds less bright than those which compose the upper stratum. The lower clouds are also more closely connected; while the upper ones are chiefly detached from each other, and permit us to see every where through them.

Feb. 5, 1801. An opening near the preceding limb has no shallow about it. I can see the thickness of the preceding partition, from the top of the luminous clouds down to the vacancy; and perceive that the lower part of the descent is of a less bright nature than the upper one: it is of the colour of an incipient shallow.

The inferior Clouds are opaque, and probably not unlike those of our Planet.

Feb. 5, 1801. The shallows about three considerable openings, on the following side of the sun, are of the same colour with that of a large opening on the preceding side.

Feb. 18, 1801. The tufts of the shallows, or lower clouds, are all of the same colour.

The shallows about the three largest openings are all of the same colour, which is that of all the shallows I have ever seen.

Feb. 4, 1801. The colour of a very small shallow about a little opening, is as faint as that of a large shallow of a very large opening now in view; and, as far as I can remember, all the shallows I have seen have been nearly of the same colour.

Hence we have reason to conclude, that there are two different regions of clouds, the lowest whereof is never affected in colour by the cause which acts upon the upper one, when shallows are generated. If so, these clouds are probably of a very different nature; for, were they not different, they would not be differently affected by the same cause. Perhaps this lower region is a set of dense opaque planetary clouds, like those upon our globe. In that case, their light is only the uniform reflection of the surrounding superior self-luminous region. If this be admitted, it will at once account for the sameness of the colour of the shallows, and of their tufts; and for many other phenomena.

Quantity of Light reflected from the inferior Planetary Clouds.

Feb. 7, 1801. I made an artificial contrivance, for the use of my photometer, to represent a portion of the bright surface of the sun, and of an opening with a shallow surrounding it. The opening was represented by a small patch of black velvet, resembling nearly, in shape, the large opening in the sun which is now visible. This was fastened on the farthest vane of my photometer, covered with white paper, and arranged so as to be in the line of the centre. In the nearest vane, covered with the same paper, and equally prepared so as to move in the centre of the photometer, I cut a hole large enough to shew the black velvet on the farthest vane, with a small margin of its paper about it, which was intended to represent the shallow about the opening. The illumination of the nearest vane was to represent the brightness of the sun. The two vanes were arranged so as to be one behind the other, in a straight line;

and a single hole was made in the middle of the moveable piece No. 4, of the photometer described in my last paper..*

I now viewed the opening and shallow in the sun, and immediately after went to the photometer, to examine the artificial phenomenon. By withdrawing the farthest vane, I diminished its illumination, till I found the small visible rim about the velvet less luminous than the paper of the first vane, in the same proportion as I judged the shallow to be less bright than the rest of the sun. Then, going alternately many times to the telescope and to the photometer, and making such little alterations in the apparatus as I thought necessary, I obtained at last a result, which shewed that the rim of paper representing the shallow reflected 469 parts of the incident light.

Hence, if the superior self-luminous clouds of the sun throw the same quantity of light on the inferior region of opaque solar clouds as they send to us, it follows, that those inferior clouds of which the shallows are composed, reflect about 469 rays out of every thousand they receive.

With regard to the solar surface which we see in the openings, I also found that black worsted, which, by my lately published tables, reflects 16 rays out of a thousand, was not dark enough, compared to the blackness of the opening, but that black velvet seemed to be nearly of the same intensity; so that, probably, when the luminous surface of the sun sends us 1000, and the flats 469 rays, the solid surface seen in the openings reflects no more than about seven.

* See Phil. Trans. for 1800. p. 528.

Indentations are planetary Clouds, reflecting Light through the open Parts of the Corrugations.

Jan. 15, 1801. The corrugations do not contain pores, but irregularly shaped depressed places, of a darker or rather less luminous matter than the borders of the corrugations; probably owing to the same cause that makes the shallows appear less bright than the general surface.

Feb. 7, 1801. The corrugations go up to the borders of the shallow of an opening observed since Feb. 4. Indeed the high parts of the corrugations themselves consist of the upper self-luminous clouds; while their indentations are the reflection of light from the lower regions of the opaque ones.

The opaque inferior Clouds probably suffer but little of the Light of the self-luminous superior Clouds to come to the Body of the Sun.

Feb. 5, 1801. The shallow of a large opening, though already contracted, is still sufficiently broad not to permit a single direct ray of the superior self-luminous clouds to enter this opening; and the blackness of the opening shews, that but little light can penetrate through the inferior region of planetary clouds of which the shallow consists.

Motion of the inferior Clouds.

Feb. 6, 1801. The great opening of Feb. 4, is much diminished: it is now divided by a branch of the inferior clouds of the shallow, with a few superior ones upon the following half of the division or bridge. The shallow on the other side of the bridge is plainly still free from self-luminous clouds.

$11^h\,53'$. On the preceding side, more of the planetary clouds are advancing to draw themselves over the opening; they are very faint.

Feb. 7, 1801. Another passage is now thrown over the great opening, consisting evidently of the lower clouds. Perhaps a few clouds of the upper regions may be drawn upon it; but, at both sides, the shallow continues to be visible from the bridge to its margin, or confinement by the surrounding self-luminous clouds.

$10^h\,40'$. A third passage is beginning to come on from the following side, also consisting of lower clouds. It seems that the curtain will be closely drawn over the opening, before many of the self-luminous clouds can advance.

Motion of the superior Clouds.

Feb. 5, 1801. The large opening of Feb. 4, is in a diminishing state. Its shallow is contracted; and, though it has no corrugations, it seems as if a few self-luminous clouds of the upper regions were here and there scattered over it. I see their superior brightness, and their elevation above the shallow in the places where they are.

$1^h\,42'$. More of the clouds of the upper regions have scattered themselves over the shallow; and one of them faintly passes over part of the opening, almost across it. This will probably form a division.

$1^h\,50'$. There is an opposite cloud advancing to meet the former one; probably that part of the opening where they are, opposes less resistance than the rest.

$1^h\,53'$. The shallow contracts very fast; the sides of the upper regions of clouds press on; the borders become irregular, and jagged, according to the advancement of the clouds; but a coarsely circular form of the shallow in general is still preserved.

Eminent Use of the planetary Clouds.

It has been shewn that the openings, compared to the luminous surface of the sun, reflect less than 16 rays out of a thousand, and probably not more than seven. To account for this extraordinary darkness, it must be remembered, that according to the observations which have been given, hardly any but transmitted rays can ever come to the body of the sun. The shallows about large openings are generally of such a size, as hardly to permit any direct illumination from the superior clouds to pass over them into the openings; and the great height and closeness of the sides of small ones, though not often guarded by shallows, must also have nearly the same effect. By this it appears, that the planetary clouds are indeed a most effectual curtain, to keep the brightness of the superior regions from the body of the sun.

Another advantage arising from the planetary clouds of the sun, is of no less importance to the whole solar system. We have shewn that corrugations are every where dispersed over the sun; and that their indentations may be called shallows in miniature. From this we may conclude, that the immense curtain of the planetary solar clouds is every where closely drawn; and, as our photometrical experiments have proved that these clouds reflect no less than 469 rays out of a thousand, it is evident that they must add a most capital support to the splendour of the sun, by throwing back so great a share of the brightness coming to them from the illumination of the whole superior regions.

OF THE SOLAR ATMOSPHERE.

The Sun has a planetary Atmosphere.

Our observations on the double regions of clouds in the sun, are certainly a sufficient proof of the existence of a solar atmosphere. The clouds of the lower regions of the sun bear such a resemblance to our own, that they can only, like ours, be upheld by a thin elastic medium, in which, like ours in air, they may freely move about in all directions.

The Sun's planetary Atmosphere extends to a great Height.

If we have concluded, from the appearance of the clouds of the lower regions, that they were supported by an atmosphere, the same will hold good with regard to the self-luminous clouds of the upper regions. For, though probably they do not swim or float in the planetary atmosphere of the sun, like the lower ones, it is evident, from observation, that they arrange themselves regularly at certain given altitudes; which can only be ascribed to the specific gravity of the gases to which they owe their existence. Besides, as the solar atmosphere is elastic, it can be no otherwise confined than by its gravitation to the sun, in the same manner as the air, by its own weight, is kept down to the earth; and the solar atmosphere must therefore expand itself considerably above the highest ridges and nodules.

The planetary Atmosphere of the Sun is of a great Density.

This may be deduced directly from the known quantity of matter in the sun. Sir ISAAC NEWTON has proved, that the gravitation of bodies on the surface of the sun, is 27 times stronger than it is with us. Hence, the compression of the elastic gases of which the solar atmosphere consists, if similar to our own, must be greater than that of ours, in proportion to the superior force by which they are compressed, namely, their own powerful gravitation towards the sun.

The Solar Atmosphere, like ours, is subject to Agitations, such as with us are occasioned by Winds.

A proof of this may be drawn from the observations which have been given. In several instances, we have seen the planetary clouds move over the openings; which could not have happened, unless the atmosphere in which they floated had been considerably agitated. In many other instances, we have shewn that a strong bias existed in the direction of the cause which generates the shallows. This indeed is so evident, that I have hardly ever seen a single shallow which had not some excentricity; the smallest segments of these shallows being always turned towards what I have called the quiescent side of the openings. To this may be added, that the continual luminous decompositions in the superior regions, and the consequent necessary regeneration of the atmospheric gases that serve to carry them on, and which probably are produced below the inferior cloudy regions, near the surface of the sun's body, must unavoidably be attended with great agitations, such as with us might even be called hurricanes.

There is some clear Atmospheric Space, between the solid Body of the Sun and the lowest Region of the Clouds.

From what has just now been said of the agitations which appear to take place in the solar atmosphere, it follows, that those biases which have been shewn to affect the direction of a number of shallows at the same time, must have arisen from a motion of the atmospheric gases under the clouds; and, that there is a considerable vacant space between these clouds and the solid body of the sun, is also to be inferred, from the free motion of clouds considerably lower than usual, which were seen to pass over an opening, and which cannot be supposed to have rolled over the ground in contact with it. Without, however, entering into any particular examination of the amount of the distance from the sun to the first cloudy regions, which, were I to guess by some pretty obvious circumstances, would not be less than some hundreds of miles, we may take it for granted, that the altitude of the clouds will every where be determined by their own density, and by that of the atmosphere in which they are suspended.

The Sun's planetary Atmosphere is transparent.

It will be easily shewn, that the gases of the solar atmosphere are transparent; for we have already given observations that prove our being able to see the reflected light of the corrugations from their indentations; and of the self-luminous regions in general, from the shallows which they surround and illuminate. To this may be added, that we also see clearly down through the space which leads through the openings, as fully appears from our being able to see the thicknesses of the borders which inclose them. We have likewise given an instance of seeing the limb of the sun broken by a vacancy proceeding from a large shallow; though undoubtedly that shallow must have been covered with the solar atmospheric gases.

THEORETICAL EXPLANATION OF THE SOLAR PHENOMENA.

We have admitted, in order to explain the generation of shallows, that a transparent elastic gas comes up through the openings, by forcing itself a passage through the planetary clouds. Our observations seemed naturally to lead to this supposition, or rather to prove it; for, in tracing the shallows to their origin, it has been shewn, that they always begin from the openings, and go forwards. We have also seen, that in one case, a particular bias given to incipient shallows, lengthened a number of them out in one certain direction, which evidently denoted a propelling force acting the same way in them all. I am, however, well prepared to distinguish between facts observed, and the consequences that in reasoning upon them we may draw from them; and it will be easy to separate them, if that should hereafter be required.

If however, it be now allowed, that the cause we have assigned may be the true one, it will then appear, that the operations which are carried on in the atmosphere of the sun are very simple and uniform.

Generation of Pores.

By the nature and construction of the sun, an elastic gas, which may be called empyreal, is constantly formed. This ascends every where, by a specific gravity less than that of the general solar atmospheric gas contained in the lower regions. When it goes up in moderate quantities, it makes itself small passages among the lower regions of clouds: these we have frequently observed, and have called them pores. We have shewn that they are liable to continual and quick changes, which must be a natural consequence of their fleeting generation.

Formation of Corrugations.

When this empyreal gas has reached the higher regions of the sun's atmosphere, it mixes with other gases, which, from their specific gravity, have their residence there, and occasions decompositions which produce the appearance of corrugations. It has been shewn, that the elevated parts of the corrugations are small self-luminous nodules, or broken ridges; and I have used the name of self-luminous clouds, as a general expression for all phenomena of the sun, in what shape soever they may appear, that shine by their own light. These terms do not exactly convey the idea affixed to them; but those of meteors, coruscations, inflammations, luminous wisps, or others, which I might have selected, would have been liable to still greater objections. It is true, that when speaking of clouds, we generally conceive something too gross, and even too permanent, to permit us to apply that expression properly to luminous decompositions, which cannot float or swim in air, as we are used to see our planetary clouds do. But it should be remembered, that, on account of the great compression arising from the force of gravity, all the elastic solar gases must be much condensed; and that, consequently, phenomena in the sun's atmosphere, which in ours would be mere transitory coruscations, such as those of the aurora borealis, will be so compressed as to become much more efficacious and permanent.

Cause of Indentations.

The great light occasioned by the brilliant superior regions, must scatter itself on the tops of the inferior planetary clouds, and, on account of their great density, bring on a very vivid reflection. Between the interstices of the elevated parts of the corrugations, or self-luminous clouds, which, according to the observations that have been given, are not closely connected, the light reflected from the lower clouds will be plainly visible, and, being considerably less intense than the direct illumination from the upper regions, will occasion that faint appearance which we have called indentations.

Cause of the mottled Appearance of the Sun.

This mixture of the light reflected from the indentations and that which is emitted directly from the higher parts of the corrugations, unless very attentively examined by a superior telescope, will only have the resemblance of a mottled surface.

Formation of small Openings, Ridges, and Nodules.

When a quantity of empyreal gas, more than what produces only pores in ascending, is formed, it will make itself small openings; or, meeting perhaps with some resistance in passing upwards, it may exert its action in the production of ridges and nodules.

Production of large Openings and Shallows.

Lastly, if still further an uncommon quantity of this gas should be formed, it will burst through the planetary regions of clouds, and thus will produce great openings; then, spreading itself above them, it will occasion large shallows, and, mixing afterwards gradually with other superior gases, it will promote the increase, and assist in the maintenance, of the general luminous phenomena.

If this account of the solar appearances should be well founded, we shall have no difficulty in ascertaining the actual state of the sun, with regard to its energy in giving light and heat to our globe; and nothing will now remain, but to decide the question which will naturally occur, whether there be actually any considerable difference in the quantity of light and heat emitted from the sun at different times. But, since experience has already convinced us, that our seasons are sometimes very severe, and at other times very mild, it remains only to be considered, whether we should ascribe this difference immediately to a more or less copious emission of the solar beams. Now, as we have lately had seasons of deficiency, that seem to indicate a want of the vivifying principles of light and heat, and as, from the appearance of last summer, and the present mild winter, there seems to be a change that may be in our favour, it will be proper to have recourse to solar observations, in order to compare the phenomena which indicate the state of the sun, with the seasons of these remarkable times. The following two sets, which are selected from my journals, I believe will assist us materially in this inquiry.

SIGNS OF SCARCITY OF LUMINOUS MATTER IN THE SUN.

Visible Deficiency of empyreal Clouds.

July 5, 1795. $1^h\ 6'$. The appearance of the sun is very different from what I have ever seen it before. There is not a single opening in the whole disk; there are no ridges or nodules; there are no corrugations.

A perfect Calm in the upper Regions of solar Clouds.

Dec 9, 1798. $12^h\ 33'$. The sun has no openings of any kind; nor can I perceive any places that look disturbed, like those where openings have lately been.

Want of Openings, Ridges, and Nodules.

Sept. 18, 1795. There is no opening in the sun. I viewed it with powers from 90 to 460.

April 1, 1798. 11^h 49′. I examined the sun with a power of 230; but could find no openings.

Nov. 27, 1799. The sun is without openings. I cannot however perceive any indication that, by the mere look, would denote a deficiency of light.

Dec. 31, 1799. There are no openings in the disk of the sun.

Jan. 3. 1800. There is no opening visible any where.

Jan. 27, 1800. There is no opening. There are no ridges; nor is there a single nodule any where.

Jan. 30, 1800. There are neither openings, ridges, nor nodules, in the sun.

Jan 31, 1800. There are neither openings, nor ridges, in the sun.

Feb. 4, 1800. There are neither openings, ridges, nor nodules, any where.

Feb. 11, 1800. There is not an opening, ridge, or nodule, any where in the sun.

Feb. 18, 1800. There are no openings, no ridges, or nodules.

Dec. 22, 1799. In one part of the sun are some vivid ridges; but I cannot find any of them in other parts.

Dec. 27, 1799. Near the following margin are some bright ridges; but there is not a single one to be seen in any other part of the sun's disk.

Many Indentations without, and others with, changeable Pores.

Jan. 3, 1800. The indentations contain fewer black points than last week.

Jan. 4, 1800. The corrugations are punctured with blackish indentations. The sun is more affected in this manner than it was yesterday.

Jan. 27, 1800. The sun is every where coarsely indented, but not punctured; there being no black points in the indentations.

SIGNS OF ABUNDANCE OF LUMINOUS MATTER IN THE SUN.

Visible Increase of empyreal Clouds.

Feb. 12, 1800. The indentations, in many parts, are changed to small shallows of corrugations. There seems to have been a gradual increase of the luminous clouds for some time past. The reason why I am not positively assured of this increase is, that my present method of viewing the sun is so much better than formerly, that, by seeing things to greater advantage, there may be some deception in the seeming change of appearances.

March 5, 1800. I can now entertain no doubt that the luminous clouds are more copious than they were some time ago. The corrugations seem all to be better filled. Hardly any of the indentations have pores.

Many Openings, Ridges, and Nodules.

March 5, 1800. A range of openings has a very fine appearance; there are 55 of them. The most south and largest has a considerable shallow about it. Two, just north of it, have shallows on the northern side, but not towards the south, where the borders of the openings seem to be full as elevated as the highest luminous clouds. Near the south-following margin are extensive ridges, studded here and there with nodules.

Nov. 17, 1800. The sun is beautifully ornamented with openings, shallows, ridges, and nodules.

Dec. 2, 1800. The sun is every where richly covered by luminous clouds. Ridges and nodules are also to be seen in many places.

Dec. 27. A large opening is lately come into the disk; several other small ones are visible; and there are, near the preceding and following limbs, many extensive ridges. The luminous clouds are very plentifully and richly scattered all over.

Jan. 15, 1800. There are three collections of openings in different parts of the disk of the sun, and many ridges and nodules. The small indentations, as I have formerly called them, are so coarse, and of such irregular shapes, that they can be called so no longer. Corrugations, therefore, are that variety and unevenness of the whole surface of the sun, when it appears richly furnished with luminous clouds.

I am now much inclined to believe, that openings with great shallows, ridges, nodules, and corrugations, instead of small indentations, may lead us to expect a copious emission of heat, and therefore mild seasons. And that, on the contrary, pores, small indentations, and a poor appearance of the luminous clouds, the absence of ridges and nodules, and of large openings and shallows, will denote a spare emission of heat, and may induce us to expect severe seasons. A constant observation of the sun with this view, and a proper information respecting the general mildness or severity of the seasons, in all parts of the world, may bring this theory to perfection, or refute it, if it be not well founded.

Jan. 24, 1801. The surface of the sun is every where richly decked out with luminous clouds. An additional opening is lately come into view, attended by many spreading ridges.

Jan. 29, 1801. If openings be a sign of richness in the illuminating and heating disposition of the sun, there are enough of them: considerable ones are scattered in six different regions, taking up a broad zone.

Feb. 4, 1801. Between flying clouds, I counted 31 openings in the sun.

March 2, 1801. There are six different sets of openings in the sun. One of them consists of ten; another of two; the rest are single.

Coarse and luminous Corrugations.

Jan. 4, 1801. The corrugations are very coarse; and the luminous clouds seem to be very rich.

Jan. 3, 1801. The elevations of the corrugations are all very luminous, like so many nodules.

Feb. 18, 1801. The corrugations are every where very luminous.

March 2. The general surface of the sun is so rich, that the indentations are a good deal covered by self-luminous clouds.

From these two last sets of observations, one of which establishes the scarcity of the luminous clouds, while the other shews their great abundance, I think we may reasonably conclude, that there must be a manifest difference in the emission of light and heat from the sun. It appears to me, if I may be permitted the metaphor, that our sun has for some time past been labouring under an indisposition, from which it is now in a fair way of recovering. An application of the foregoing method, however, even if we were perfectly assured of its being well founded, will still remain attended with considerable difficulties.

We see how, in that simple instrument the barometer, our expectations of rain or fair weather, are only to be had by a consideration of many circumstances, besides its actual elevation at the moment of inspection.

The tides also present us with the most complicated varieties in their greatest elevation, as well as in the time when they happen on the coasts of different parts of this globe. The simplicity of their cause, the solar and lunar attractions, we might have expected, would have precluded every extraordinary and seemingly discordant result.

In a much higher degree, may the influence of more or less light and heat from the sun, be liable to produce a great variety in the severity or mildness of the seasons of different climates, and under different local circumstances; yet, when many things which are already known to affect the temperature of different countries, and others which future attention may still discover, come to be properly combined with the results we propose to draw from solar observations, we may possibly find this subject less intricate than we might apprehend on a first view of it.

If, for instance, we should have a warm summer in this country, when phenomena observed in the sun indicate the expectation of it, I should by no means consider it as an unsurmountable objection, if it were shewn that in another country the weather had not been so favourable. And, if it were generally found that our prognostication from solar observations held good in any one given place, I should be ready to say that, with proper modifications, they would equally succeed in every other situation.

Before we can generalize the influence of a certain cause, we ought to confine our experiment to one permanent situation, where local circumstances may be supposed to act nearly alike at all times, which will remove a number of difficulties.

To recur to our instance of the tides, if we were to examine the phenomena which they offer to our inspection in any one given place, such as the mouth of the Thames, we should soon be convinced of their agreement with the motion of the sun and moon. A little reflection would easily reconcile us to every deviation from regularity, by taking into account the direction and violence of winds, the situation of the coast, and other circumstances. Nor should we doubt the truth of the theory of the tides, though high water at Bristol, Liverpool, or Hull, should have been very deficient, at a time when, in the place of our experiments, it had happened to be uncommonly abundant.

Now, with regard to the effects of the influence of the sun, we know already, that in the same latitudes the seasons differ widely in temperature; that it is not hottest at noon, or coldest at midnight; that the shortest day is neither attended with the severest frosts, nor the longest day with the most oppressing heats; that large forests, lakes, morasses, and swamps, affect the temperature one way; and rocky, sandy, gravelly, and barren situations, in a contrary manner; that the seasons of islands are considerably different from those of large continents, and so forth.

But it will now be necessary to examine the accounts we already have of the appearance and disappearance of the solar spots, and to compare them with the temperature of the respective times, as far as history will furnish us with records.

The first thing which appears from astronomical observations is, that the periods of the disappearance of spots on the sun are of much shorter duration than those of their appearance; so that, if the symptoms which have been pointed out, as denoting the state of the sun with regard to light and heat, should be well founded, we ought rather to look upon the absence of spots as a sign of deficiency, than on their presence as one of abundance; and this would justify my expression, of the recovery of the sun from an indisposition, as being a return to its usual splendour.

In going back to early observations, we cannot expect to meet with a record of such minute phenomena as we have attended to. The method of viewing spots on the sun, by throwing their picture, in a dark room, on a sheet of white paper, is not capable of delicacy; nor were the direct views of former astronomers so distinct as, in the present improved state of the telescope, we can have them; a very imperfect account of solar spots may therefore be expected, considering our present inquiry, which would require complete observations of every spot, great or small, that has been on the sun during such periods as will be examined.

With regard to the contemporary severity and mildness of the seasons, it will hardly be necessary to remark, that nothing decisive can be obtained. But, if we are deficient here, an indirect source of information is opened to us, by applying to the influence of the sun-beams on the vegetation of wheat in this country. I do not mean to say, that this is a real criterion of the quantity of light and heat emanated from the sun; much less will the price of this article completely represent the scarcity or abundance of the absolute produce of the country. For the price of commodities will certainly be regulated by the demand for them; and this we know is liable to be affected by many fortuitous circumstances. However, although an argument drawn from a well ascertained price of wheat, may not apply directly to our present purpose, yet, admitting the sun to be the ultimate fountain of fertility, this subject may deserve a short investigation, especially as, for want of proper thermometrical observations, no other method is left for our choice.

Our historical account of the disappearance of the spots in the sun, contains five very irregular and very unequal periods.* The first takes in a series of 21 years, from 1650 to 1670, both included. But it is so imperfectly recorded, that it is hardly safe to draw any conclusions from it; for we have only a few observations of one or two spots that were seen in all that time, and those were only observed for a short continuance. However, on examining the table of the prices of the quarter of nine bushels of the best or highest priced wheat at Windsor, marked in Dr. ADAM SMITH'S valuable Inquiry into the nature and causes of the wealth of nations,† we find that wheat, during the time of the 21 years above mentioned, bore a very high price; the average of the quarter being £2. 10*s*. $5\frac{12}{21}$*d*. This period is much too long to suppose that we might safely compare it with a preceding or following one of equal duration. Besides, no particulars having been given of the time preceding, except that spots in the sun, a good while before, began to grow very scarce, there might even be fewer of them than from the year 1650 to 1670. Of the 21 years immediately following, we know that they certainly comprehend two short periods, in which there were no spots on the sun; of these, more will be said hereafter; but, including even them, we have the average price of wheat, from 1671 to 1691, only £ 2. 4*s*. $4\frac{2}{3}$*d*. the quarter. The difference, which is a little more than as 9 to 8, is therefore still a proof of a temporary scarcity.

Our next period is much better ascertained. It begins in December 1676, which year therefore we should not take in, and goes to April 1684; in all which time, Flamsteed, who was then observing, saw no spot in the sun. The average price of wheat, during these 8 years, was £ 2. 7*s*. 7*d*. the quarter. We

* See Astronomie par M. De la Lande, § 3235.

† See Book I. Chap. XI.

cannot justly compare this price with that of the preceding 8 years, as some of the former years of scarcity would come into that period; but the 8 years immediately following, that is, from 1685 to 1691, both included, give an average price of no more than £ 1. 17*s.* 1 ¾*d.* The difference, which is as full 5 to 4, is well deserving our notice.

A third but very short period, is from the year 1686 to 1688, in which time Cassini could find no spot in the sun. If both years be included, we have the average price of wheat, for those three years, £1. 15*s.* 0 ⅔*d.* the quarter. We ought not to compare this price with that of the three preceding years, as two of them belong to the preceding period of scarcity; but the three following years give the average price for the quarter of wheat £1. 12*s.* 10 ⅔*d.* or, as nearly 11 to 10.

The fourth period on record, is from the year 1695 to 1700, in which time no spot could be found in the sun. This makes a period of 5 years; for, in 1700 the spots were seen again. The average price of wheat, in these years, was £3. 3*s.* 3⅕*d.* the quarter. The 5 preceding years, from 1690 to 1694, give £2. 9*s.* 4⅘*d.* and the 5 following years, from 1700 to 1704, give £1. 17*s.* 11⅕*d.* These differences are both very considerable; the last is not less than 5 to 3.

The fifth period extends from 1710 to 1713; but here there was one spot seen in 1710, none in 1711 and 1712, and again one spot only in 1713. The account of the average price of wheat, for these four years, is £2. 17*s.* 4*d.* the quarter. The preceding four years, from 1706 to 1709, give the price £2. 3*s.* 7½*d.* and the following years, from 1714 to 1717, it was £2. 6*s.* 9*d.* When the astronomical account of the sun for this period, which has been stated above, is considered, these two differences will be found very considerable; the first of them being nearly as 4 to 3.

The result of this review of the foregoing five periods is, that, from the price of wheat, it seems probable that some temporary scarcity or defect of vegetation has generally taken place, when the sun has been without those appearances which we surmise to be symptoms of a copious emission of light and heat. In order, however, to make this an argument in favour of our hypothesis, even if the reality of a defective vegetation of grain were sufficiently established by its enhanced price, it would still be necessary to shew that a deficiency of the solar beams had been the occasion of it. Now, those who are acquainted with agriculture may remark, that wheat is well known to grow in climates much colder than ours; and that a proper distribution of rain and dry weather, with many other circumstances which it will not be necessary to mention, are probably of much greater consequence than the absolute quantity of light and heat derived from the sun. To this I shall only suggest, by way of answer, that those very circumstances of proper alternations of rain, dry weather, winds, or whatever else may contribute to favour vegetation in this climate, may possibly depend on a certain quantity of sun-beams, transmitted to us at proper times; but, this being a point which can only be ascertained by future observations, I forbear entering farther into a discussion of it.

It will be thought remarkable, that no later periods of the disappearance of the solar spots can be found. The reason however is obvious. The perfection of instruments, and the increased number of observers, have produced an account of solar spots, which, from their smallness, or their short appearance, would probably have been overlooked in former times. If we should in future only reckon the years of the total absence of solar spots, even that remarkable period of scarcity which has fallen under my own observation, in which nevertheless I have now and then seen a few spots of short duration, and of no great magnitude, could not be admitted.

For this reason, we ought now to distinguish our solar observations, by reducing them to short periods of symptoms for or against a copious emission of the solar beams, in which, all the phenomena we have pointed out should be noticed. The most striking of them are certainly the number, magnitude, and duration of the openings. The increase and decrease of the luminous appearance of the corrugations is perhaps full as essential; but, as it is probable that their brilliancy may be a consequence of the abundance of the former phenomena, an attention to the latter, which is subject to great difficulties, and requires the very best of telescopes, may not be so necessary.

What remains to be added is but short. In the first of my two series of observations, I have pointed out a deficiency in what appears to be the symptomatic disposition of the sun for emitting light and heat: it has lasted from the year 1795 to 1800.* That we have had a considerable deficiency in the vegetation of grain, will hardly require any proof. The second series, or rather the commencement of it, for I hope it will last long, has pointed out a favourable return of the rich appearance of the sun. This, if I may venture to judge, will probably occasion a return of such seasons as, in the end, will be attended by all their usual fertility.

The subject, however, being so new, it will be proper to

* This period should properly have been divided into two small ones; but, for want of intermediate solar observations, I have joined the visible deficiencies in the illuminating and heating powers of the sun, from the year 1795 to 1796, and again from 1798 to 1800, into one.

conclude, by adding, that this prediction ought not to be relied on by any one, with more confidence than the arguments which have been brought forwards in this Paper may appear to deserve.

EXPLANATION OF THE 1st, 2d, 11th and 12th FIGURES.

SEE PLATES XVIII. and XIX.

Plate XVIII. Fig. 1, represents an opening in the luminous solar clouds, with its surrounding shallow, in a situation much past the centre, towards the preceding limb of the sun. The lines marked with the letters *a, b, c, d, e, f,* answer to those which are marked with the same letters in Fig. 2.

Figure 2, is a section of the same opening. The lines *a, b, c, d, e, f,* are supposed to be drawn from the eye of the observer. *a* and *b* point out the elevation of the corrugations *g, h,* on the preceding side P, above the surface of the shallow *i, k.* *c* and *d* shew the thickness of the shallow; and the line *d* goes through the opening, down into the clear atmospheric space P F, till it meets with the opaque surface of the sun A B. On the following side F, the thickness of the shallow and elevation of the corrugations cannot be seen; since the line *e* goes abruptly into the opening; and *f* goes, as abruptly, from the top of the corrugations, down to the shallow.

Plate XIX. Fig. 11, shews a section of the corrugations, shallow, and opening, of Fig. 10, in the same manner as Fig. 2 represents those of Fig. 1. There is a hanging cloud *a,* in Fig. 11, over the preceding part of the opening; and the same cloud is represented at *b,* in Fig. 12, to which place it was seen to move from its former situation, in 58 minutes of time.

The rest of the figures are sufficiently explained in the places of the text which refer to them.

Fig. 1.

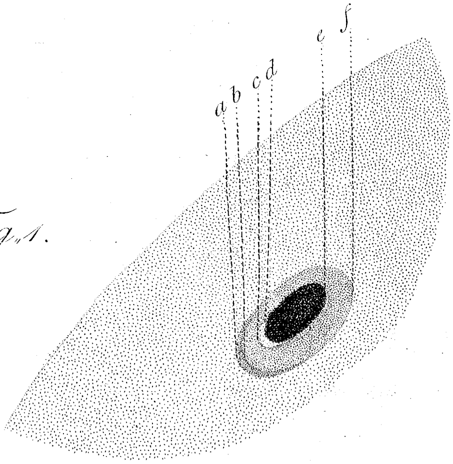


Fig. 2.

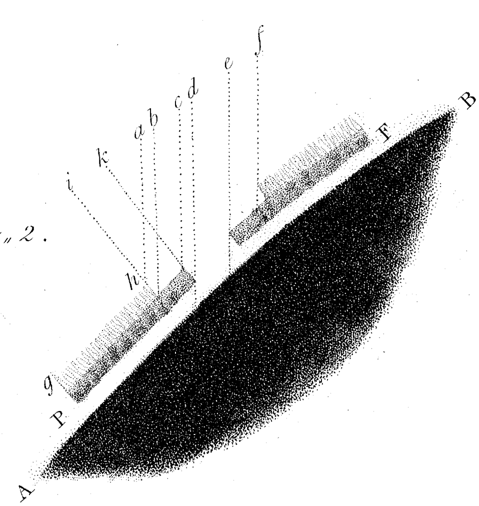


Fig. 3.

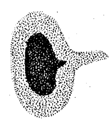


Fig. 4.

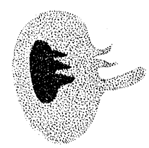


Fig. 5.

Fig. 6.

Fig. 7.

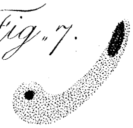


Fig. 8.

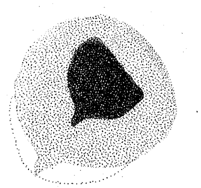
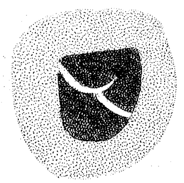


Fig. 9.



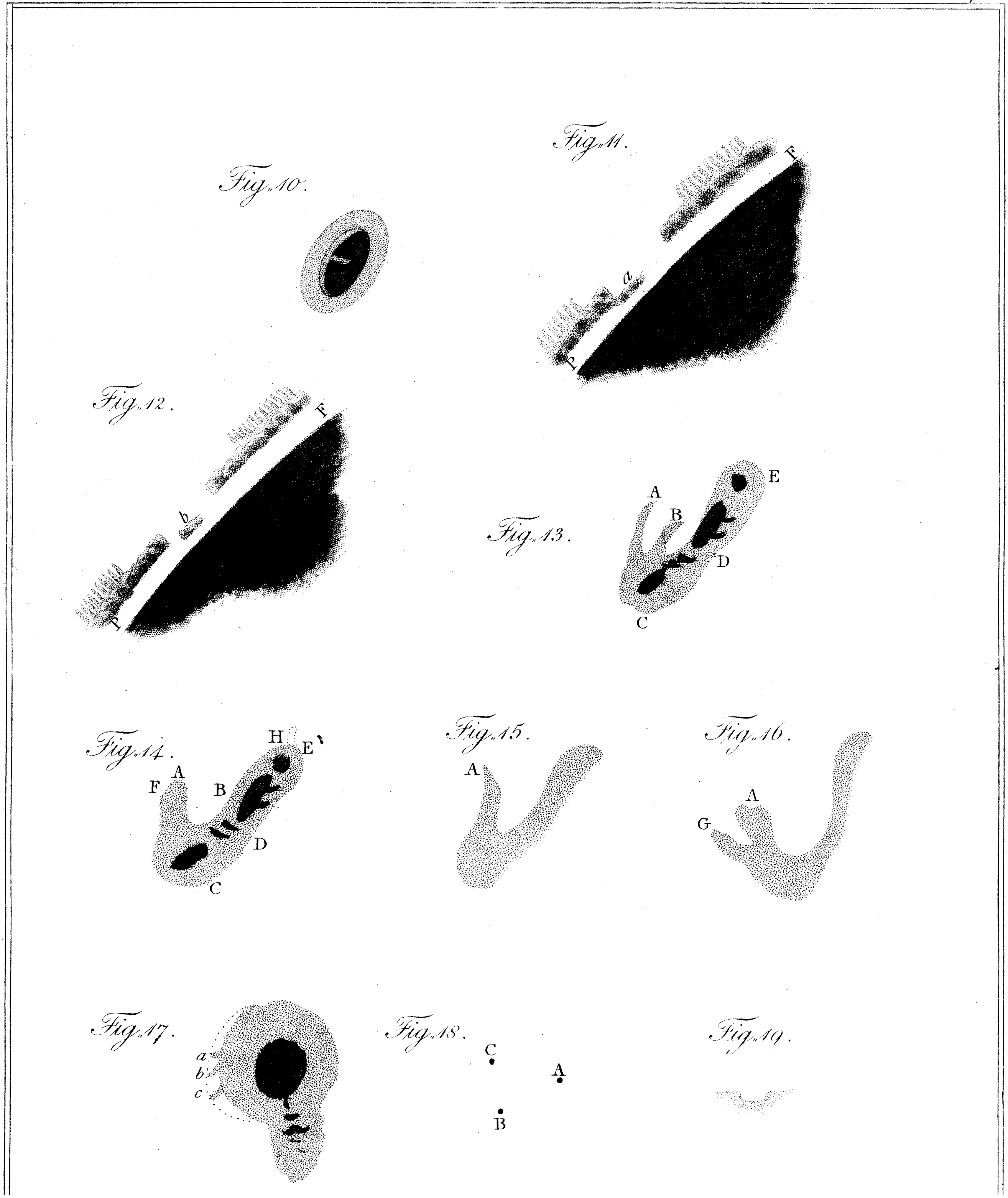


Fig. 10.
Fig. 11.
a
F
P
Fig. 12.
F
b
P
Fig. 13.
A
B
E
D
C
Fig. 14.
H
E
F
A
B
D
C
Fig. 15.
A
Fig. 16.
A
G
Fig. 17.
a
b
c
Fig. 18.
C
A
B
Fig. 19.