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SUNSPOTTERY:

Or, What do we Owe to the Sun?

A POPULAR ACCOUNT

OF THE

SPOTS ON THE SUN,

Their Phenomena, Nature, and Cause:

WITH AN INQUIRY

INTO THEIR ALLEGED INFLUENCE UPON

THE WEATHER, FAMINES, PESTILENCES

COMMERCIAL PANICS, &C.,

BY

J. A. WESTWOOD OLIVER.

LONDON:

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With the Author's
Compliments.

July 13 83

Argyll Lodge, Kensington.

My dear Ian

The accompanying
Pamphlet has
been sent to me
by the Author.

I have told
him that I have ... reply
sent it on to

You–

I dont know
whether you will
think them
orthodox or
Heterodox.

[illegible]

With the Author's
Compliments.

Read Some date.
The writer has read
a lot of books but
has done nothing
himself so far as
appears. I dont think
much of his "speech"
to the Jury. He is no
judge. I dont see
the reason of publishing
unless it be to
advertise books
"Sunspottery"

G

rapely

indicates Vulgarity
and selfsufficient
contempt for
wiser men.
This is one of the
public to whom
I am about to
issue Thermography.
and for so doing
I suppose that
I must write me
down an ass

With the Author's
Compliments.

With the readers
compliments. Jaques
with this authors
Verdict on himself
Page 56

SUNSPOTTERY:

OR, WHAT DO WE OWE TO THE SUN?

"Sunspottery" is for
"the most part
"humbug"

Sept 14. 1883.
Author of Phenomography

SUNSPOTTERY:

OR, WHAT DO WE OWE TO THE SUN?

A POPULAR EXAMINATION

OF THE

CYCLE THEORY OF THE WEATHER, FAMINES, PESTILENCES, COMMERCIAL PANICS, &c.

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PREFACE.

The following pages are intended to convey to the public a general notion of the new science of Sunspottery. By some its importance has been unduly exaggerated; by others its value has been unreasonably depreciated; and much squabbling has resulted. The writer being of neither party, he hopes to give the reader an impartial view of the subject.

J. A. W. O.

London, May, 1883.

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"The sun's rays are the ultimate source of almost every motion which takes place on the surface of the earth. By their heat are produced all winds, and those disturbances in the electric equilibrium of the atmosphere which give rise to the phenomena of lightning, and probably also to those of terrestrial magnetism and the aurora. By their vivifying action vegetables are enabled to draw support from inorganic matter, and become, in their turn, the support of animals and of man, and the sources of those great deposits of dynamical efficiency which are laid up for human use in our coal strata. By them the waters of the sea are made to circulate in vapour through the air, and irrigate the land, producing springs and rivers. By them are produced all disturbances of the chemical equilibrium of the elements of nature, which, by a series of compositions and decompositions, give rise to new products, and originate a transfer of materials. Even the slow degradation of the solid constituents of the surface, in which its chief geological changes consist, is almost entirely due on the one hand to the abrasion of wind and rain, and the alternation of heat and frost; on the other, to the continual beats of the sea waves, agitated by winds, the results of solar radiation. Tidal action (itself partly due to the sun's agency) exercises here a comparatively slight influence. The effect of oceanic currents (mainly originating in that influence), though slight in abrasion, is powerful in diffusing and transporting the matter abraded; and when we consider the immense transfer of matter so produced, the increase of pressure over large spaces in the bed of the ocean, and diminution over corresponding portions of the land, we are not at a loss to perceive how the elastic power of subterranean fires, thus repressed on the one hand and relieved on the other, may break forth in points where the resistance is barely adequate to their retention, and thus bring the phenomena of even volcanic activity under the general law of solar influence."
—*Sir John Herschel.*

SUNSPOTTERY.

"Sunspottery" is a word of doubtful etymology, and of recent origin. It is not respectable enough to find a place in the most comprehensive dictionary. But it aptly designates a very modern development of a very ancient science, and so I have used it to head this little exposition at the risk of being thought vulgar.

It may be necessary to explain what the term means. Simply, then, it denotes that branch of investigation whose province it is to determine the relation between solar events and terrestrial events—between the occurrence of a tremendous disturbance in the gaseous envelope of the sun and the melancholy suicide of Mr. Smith through commercial depression—and to find out, if possible, the cause of a connection so singular.

Unlike all the other sciences, sunspottery cannot lay any claim at all to hoar antiquity. It did not, like astronomy, originate in the "earliest times"; it was not, like meteorology, coeval with the human race. We do not learn that the Chaldeans, who were such patient astronomical observers, ever dreamed of a "solar physical observatory"; nor does it appear that the sun-spot cycle was in any form known to the Egyptians. As a matter of fact, the science has only unfolded itself in the latter part of this nineteenth century—astronomy, meteorology, physics, statistics, some ingenuity, and not a little credulity, all contributing to its development. And the result, notwithstanding its newness, has become popular. Many people know something about sunspottery who have only heard that there is such a thing as astronomy, and who could not tell what the photosphere is to save their lives.

It is not our business at present to inquire into the causes of this popularity. To do so would inevitably lead us to the contemplation of a phase of character in the man of science, of recent development, but of unhappy prevalence, which we would rather shut our eyes to.[1] Our immediate purpose is to endeavour to find out how far the popular favour is justified.

The subject may be conveniently dealt with in four divisions: (1) we shall briefly notice the solar furnace, its distance, its size, its physical nature, the heat it radiates, and how it is supplied with fuel; (2) then we have to consider the solar spots, their phenomena, their periodical variation, and—what is the root of the whole science of sunspottery—their relation to solar activity; (3) in the third place we must examine the question of an eleven-year period in meteorological phenomena; (4) and fourthly, we shall discuss the alleged connection between the occurrence of famines, &c., and the number of spots.

I shall try to write impartially and plainly. To assist those who want to follow up any of the subjects incidentally touched upon, references to a few popular and easily accessible authorities are given.

[1] What I here refer to is the practice, which I may as well take this opportunity of entering my earnest protest against, of gulling the public from the lecture platform. The popular lecture is becoming more and more powerful as a means of spreading a knowledge of scientific truth among the unscientific masses; and yet—would it be believed?—the lecturer and public teacher is so little conscious of the weighty responsibility resting upon him, that he very often only takes advantage of the opportunity thus afforded him to give his pet theory an airing. Prof. Robinson Jones refers in flattering terms to the ingenious hypothesis of his valued friend Prof. Jones Robinson; Prof. Jones Robinson carefully expounds the latest intellectual flight of his valuable friend Prof. Robinson Jones; and mutual glorification results. Now, I would submit that this practice is to be condemned; first, because an audience composed of the general public is not qualified to sit in judgment upon a scientific theory, and is quite incapable of discriminating between truth and error in the matter; secondly, because abstract theories, be they plausible or otherwise, are far less interesting and instructive than the simple truths of science; and lastly, because the exposition of individual views is foreign to the purpose of the lecture, and so the lecturer has no *right* to introduce such matter. I grant that it is a little difficult for a man who believes that he has found a crumb of truth to refrain from sharing it with his fellows (such is his generous nature); but it is certainly his duty to keep that crumb to himself until his confreres adjudge it to be really a crumb of truth and not one of vanity. The province of the lecture is to instruct ordinary people in matters which they have not time to give much attention to; what such people want to know is the broad outline—the general principles—of the subject dealt with; and when the lecturer does not give that, he fails to discharge his duty.

THE PROBLEM.

The sun is the principal source of heat in the solar system. The earth derives nearly all its heat from solar radiation. The meteorological phenomena of our globe are primarily due to local variations in temperature, and are thus directly dependent upon the heat of the sun. Famines and pestilences are more or less induced by the meteorological conditions that prevail. Many human circumstances are influenced by abnormal mortality in the race. Those circumstances are therefore an effect of solar radiation.

All these phenomena depending upon the solar radiation, any change in that radiation must be followed by corresponding changes in the phenomena.

Does the heat radiated by the sun, then, undergo any variation, periodical or otherwise? Do the meteorological phenomena exhibit any corresponding variation? Do the famines and pestilences follow a like law? And, lastly, do the human experiences referred to coincide with the general variation?

I.—SOLAR PHYSICS.

1. The Sun.—To most observers the sun is simply the thing that makes the day different from the night, and summer more comfortable than winter. It generally gets up at an absurd hour in the morning, and goes to bed at an equally unreasonable hour in the evening. Its rays are bad for the complexion, and to be avoided; but they are invariably absent when most wanted. That is all that many of us know about it.

Astronomers, however, have learned a little more. They have found out, for one thing, that poets are about as wide of the truth as usual when they describe the "orb of day" as the perfection of immaculate brightness. But before we can attempt to give an account of his appearance and constitution as the telescope and the spectroscope have revealed them to us, we must find out his dimensions, and in order to do that it is necessary that we should first know his distance.

2. Distance.—The determination of this point is perhaps the most difficult, as it is certainly the most important, problem in the whole range of astronomy. Its great difficulty lies chiefly in the unsuitableness of the methods at our disposal. We all know that a problem which arithmetic enables us to work out only in the most clumsy and unsatisfactory manner may be solved with ease and precision by means of algebra. The sun's distance is like such a problem in the hands of one to whom the clumsy method only is available. Transits of Venus across the solar disc afford the best opportunity of arriving at an approximate determination. The importance of the problem is due to the fact that the value, whatever it be, is the foundation of dimensional astronomy—the standard measure by which we gauge the size, distance, and motions of the planets, and the entire extent of the visible universe.

The result of many investigations is that, when our earth is at the part of her orbit farthest from the sun, his distance is nearly 94 million miles; when at her nearest point it is a little under 91 million miles; and his mean distance is about $92\frac{1}{3}$ millions of miles. These numbers are, of course, inconceivable; but it may convey some idea of their meaning to mention that a railway train, running day and night at a uniform speed of 60 miles an hour, would require about 176 years to traverse the distance.[1]

3. Apparent Size.—The sun's disc fills a space in the celestial vault of a little more than half a degree. A circle, it will be remembered, is divided into 360 degrees. From one point of the horizon, therefore, to the opposite point, is about 180 degrees, and of this space the sun fills a three-hundred-and-sixtieth part.[2] The apparent size of the moon is very nearly the same, as may be seen during a solar eclipse.

4. Actual Magnitude.—Were we ignorant of the relative distances of the sun and the moon from our earth, we might infer them to be of the same magnitude. But having found, as we have done, that the sun is distant about 92,300,000 miles, and knowing, as we do, that the distance of the moon is only about 238,500 miles, we are led to conclude that the real diameter of the sun is at least 390 times that of the moon. And so it is.

The sun's diameter is about 860,000 miles; whence it follows that his surface is more than 2,323,500,000,000 square miles in extent, and his volume not less than 334,588,000,000,000,000 cubic miles. Of these three dimensions, that of the surface is the most important to us, for it is the radiation from the surface of the sun that supplies us with our light and heat.

Compared with the earth in bulk or volume, the sun is about 1,300,000 times the size of our globe.

5. Mass.—By the mass of a body is meant the quantity of matter in it. This explanation is not unnecessary, for some people will confuse mass and bulk or volume. The adjectives "massive" and "bulky" have reference, as everybody knows, to the relative proportions of size and weight in a body. We speak of a massive iron casting, because it is heavy for its size; or of a bulky bale of cork, because it is large in proportion to its weight.

[1] It is impossible, in the limited space at command, to give much more than bare results. The explanation of scientific methods, however, is no less instructive than the statement of the results arrived at by them, and I need make no apology for referring the reader to books where such explanations are to be found. It is difficult to give an intelligible description, for instance, of the way in which a transit of Venus is utilised by astronomers, without calling in the aid of numerous diagrams, and devoting many pages of letterpress to their elucidation. Those who are curious about the matter had better consult books specially devoted to it. Such are Mr. R. A. Proctor's *Transits of Venus; a Popular Account of Past and Coming Transits:* the same author's *Studies of Venus' Transits; an Investigation of the Circumstances of the Transit of Venus in* 1874 *and* 1882: and Prof. George Forbes's *The Transit of Venus*, in Macmillan's "Nature Series." A brief account of the phenomenon will be found in any book on elementary astronomy.

[2] The sun's distance varying from day to day—and from moment to moment, for that matter—the apparent size of his disc undergoes a corresponding variation. The measurement of the solar disc is consequently an operation of extreme delicacy. The instruments used are called *micrometers* and *heliometers*. For a description of the various kinds that have been invented see Arago's *Popular Astronomy*, book xiv., chap. 2 (vol. i., pp. 382-404 of Smyth and Grant's Translation).

In the one, weight predominates, and it is called massive; in the other, size is the chief feature, and it is called bulky. So, we may easily remember that *mass* is the weight of a body, taking weight to represent *quantity of matter*, and *bulk* is the size of a body, or the space in which the matter composing it is distributed.[1] We have determined the bulk of the sun; we now want to know his mass; and when we have got both his bulk and his mass, we can easily find out his *density*.

When Newton saw that immortal apple fall to the ground, he only saw what everybody had seen a dozen times before. But that particular incident has led to our being able to weigh the sun. Galileo had investigated the laws of falling bodies; but the conclusions he arrived at were so startlingly true, that he only got himself imprisoned for his trouble. Nevertheless, Sir Isaac Newton took up the matter where he left it off, and between them they managed to give us the key to the motions of the solar system.

Gravity is the attractive force which every particle of matter in the universe exerts upon every other particle in it. Now, consider the consequences of this. Suppose we take away two bits of matter exactly the same size to some out of the way corner of the universe where there is no other matter near, and place them, say six feet apart. On being released from restraint, they will at once run together, each moving through three feet in doing so. Leaving this double piece, we bring a third bit of the same size as the first two, and place it six feet off. The bodies run together as before; but instead of each of them moving through three feet, the smaller piece moves four feet, and the double one only two. The greater the disparity of size in the bodies, the greater the disparity of motion (or space moved through). In the case of the earth and the apple, the apple attracts the earth as well as *vice versâ;* and, what is more, the earth tends to move towards the apple as well as the apple towards the earth; but the difference in size being enormous, the difference of motion is proportionately enormous, and quite imperceptible to our senses. (The earth, not being a rigid body, does not really *move* towards the apple. It only undergoes distortion.) We learn from this that gravity is proportioned to the quantity of matter, and consequently that the

[1] It is not uncommon for scientific writers to affect a literal precision in their statements which often enough borders upon the ridiculous. These hyper-accurate gentlemen look quite scandalised if you speak of the sun "rising." They seemingly feel all their notions of cosmical order upset by the very mention of the sun doing such a thing. Should any of them chance to read the above paragraph, I do hope that they may not be overcome by the shock of finding weight treated as the measure of mass. To ordinary people, who have not acquired the habit of regarding things as they really are, but who only know them as they find them, it is by no means an easy thing to conceive matter as an inert, powerless, tangible entity, and gravity as an attractive force inherent in matter, when in nature they only find that all matter somehow is heavy. It might, perhaps, be better if people looked at things in the proper way; but it is quite outside my present purpose to teach them how to do so.

force of gravity is a direct measure of quantity of matter, or *mass.*

The nature of gravity we do not know; but we do know that this attractive force, in common with the radiant forces of light and heat, is diminished by distance. What we call the *weight* of 1 lb. of matter at the earth's surface is the attraction of the earth for that mass. If we lift it about 4000 miles above the earth, it then weighs $\frac{1}{4}$ lb.; if 8000 miles, $\frac{1}{9}$ lb.; or if 12,000 miles $\frac{1}{16}$ lb. As 4000 miles is about the distance of the earth's surface from its centre, we may express these results thus:—

$$\begin{aligned} 4000 \times 1 &= 1 \text{ lb.} \\ 4000 \times 2 &= \tfrac{1}{4} \text{ ,,} \\ 4000 \times 3 &= \tfrac{1}{9} \text{ ,,} \\ 4000 \times 4 &= \tfrac{1}{16} \text{ ,,} \end{aligned}$$

Hence the attraction between the bodies *varies inversely as the square of their distance apart.*

It will now be understood, from what has been said, how the sun's mass is determined. He pulls the earth with a force directly proportioned to his mass, but inversely proportional to the square of the distance between the two bodies. We know this distance; we can find what his actual pull is; and from these data we calculate his mass to be about 326,800 times that of the earth.

6. Density.—But his bulk, as we have seen, is 1,300,000 times that of the earth. Consequently his mean density must be little more than a fourth of the density of our globe.

7. Physical Constitution.—Having got an idea of the distance, magnitude, and density of the great luminary, we may now pass on to the consideration of his physical constitution, which has a more direct bearing upon our present subject. The instrument to which we are chiefly indebted for our knowledge on this point is the spectroscope.[1] Before the method called spectroscopic analysis was discovered, astronomers could only advance the wildest speculations regarding the sun's nature. Sir William Herschel held that it might be inhabited; and less eminent men contended for theories even more extravagant. We now know a good many *facts* about the solar constitution, but the theories are about as conflicting as ever. It is with the facts only that we mean to deal.

8. The Corona.—In all photographs of the sun, it will be observed that the edges of the disc are slightly darker than the

[1] It might have been desirable to give here a short account of the spectroscope and its mode of application to celestial problems, but to do so properly would require more space than can be spared. Very popular expositions of the subject by Roscoe, Huggins, and others, will be found in the various series of the "Manchester Science Lectures," published at one penny each, by Mr. John Heywood. *The Spectroscope and its Applications*, by J. Norman Lockyer (Macmillan's "Nature Series"), and *The Spectroscope and its Work*, by R. A. Proctor (Society for Promoting Christian Knowledge), are excellent introductions, while the more advanced student will find Schellen's *Spectrum Analysis*, Roscoe's *Spectrum Analysis*, and Lockyer's *Studies in Spectrum Analysis*, very useful and interesting.

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[illegible]

centre. The same effect may be noted when the sun's image, magnified and suitably darkened, is thrown upon a sheet of white paper. The appearance is explained by the existence of an *absorptive atmosphere*, which, surrounding the body of the sun, intercepts some of his rays. It is evident that, the sun being a sphere, rays approaching us from the border of his disc would have a greater extent of such an absorbing medium to pass through than those emanating from the centre of his disc, and would probably be absorbed in greater numbers accordingly. As we actually find the border region less luminous than the centre, we are justified in concluding that a light-absorbing envelope of the kind does exist.

This conclusion is confirmed by a phenomenon observed during solar eclipses. In a total eclipse, the dark body of the moon entirely covers the sun's disc, and we might naturally expect the latter orb to be blotted out of the sky for the time being. The sun, as we know it, is wholly concealed; but all round the dark moon is visible a "glory" of light, extending far out into space. This glory is the solar atmosphere, or *corona*. It is bright; but its brightness is vastly inferior to that of the sun himself, and so it only becomes visible when the superior light is obscured.[1]

So far as can be determined at present, the corona is composed of hydrogen gas and a material which has no known counterpart in our earth, called "1474 stuff." It seems to shine chiefly by its own light, but also in part by reflecting sunlight. It emits heat as well as light, as Edison proved in 1878. The precise height to which this solar atmosphere extends above the sun's surface cannot be stated, its outer limit being very irregular. Perhaps its average height is about 1,000,000 miles, while the coronal "streamers" sometimes extend 5,000,000 miles. Our own atmosphere is only about 100 miles in height.[2]

9. Prominences.—Immediately below the corona is a region called by some the *chromosphere*, and by others the *sierra*. During

[1] The results of the eclipse of May 6 are being looked forward to with interest, on account of the unusually long duration of totality. On ordinary occasions totality lasts only for one or two minutes, but this time its duration was no less than six minutes. Such a protracted view of the corona has never before been obtained. Dr. William Huggins in the meantime, however, has made a discovery which promises to render astronomers quite independent of eclipses for studying the corona. The violet rays of the spectrum are relatively stronger in the light of the corona than in that of the sun, and as the violet rays are most effective in photography, by sifting the light of the sun and a portion of the sky in its vicinity of all but these rays, a photographic picture of the corona is obtained. When fully worked out, this discovery may be expected to yield most valuable results.

[2] It is not very long since the real nature of the corona, as a solar appendage, became generally recognized. Some maintained it to be an effect produced in our atmosphere; others thought it was the moon's atmosphere strongly illuminated by the sun behind. Neither positions are now tenable, recent eclipse observations having proved conclusively that the "glory" belongs to the sun. If any doubt remained, the discovery of Dr. Huggins, referred to in the preceding note, must have dispelled it, as the corona has now photographed itself for us.

total solar eclipses, red objects are seen close round the edges of the black moon. At first it was thought that they belonged to the moon; but the eclipse of 1851 proved them to be solar appendages. These objects are commonly known as "prominences," and the region where they abound we shall call the *sierra.*

Although as a rule this red matter is only seen in isolated masses where it projects from the solar disc, there is reason to believe that it forms a continuous layer around the sun's globe. The depth of the layer may be from 7000 to 10,000 miles.[1]

It is impossible to give an idea of the appearance of the sierra without the aid of pictures. The reader is therefore referred to any of the treatises on the sun mentioned at the end of this section. All that we can attempt here is to give a brief summary of what is known about it.

A distinction is made between cloud prominences and eruptive prominences. The former are masses of glowing vapour (hydrogen and an unknown element called *helium*) floating in the solar atmosphere at an enormous height (sometimes about 80,000 miles) above the sun's surface. They chiefly prevail over the equatorial and polar regions of the sun. The latter are more intensely heated vapours (of hydrogen and some metallic elements) which burst up from the sun's surface with tremendous velocity to a height of 20,000, 50,000, and even 100,000 miles, spread out in a cloud-like form, and gradually settle down to the surface again. These gigantic outbursts are almost confined to the regions midway betwen the poles and the equator.

A description of the remarkable outburst witnessed by Professor Young, of America, on September 7, 1881, will serve to give some notion of the vast nature of the solar operations. On September 6, Professor Young noticed a large, quiet-looking cloud of glowing hydrogen floating about 15,000 miles above the sierra. It was not remarkable for anything but its size (being some 100,000 miles in length). Several vertical columns, not unlike waterspouts in shape, connected it with the sierra. The cloud remained the same until shortly after noon on the 7th, when the southernmost column became exceedingly bright, and at the same time a brilliant lump "like a summer thunder-head" appeared immediately under the northern end of the cloud. At this point Professor Young was called away for 25 minutes. On returning (at 12.55) he found the cloud blown to shreds. Vast masses of glowing gas, some of them exceeding in size the continent of Europe, were flying upwards with a velocity of 160 miles per second. Many of them had already reached a height of 100,000 miles, and 10 minutes later some were 200,000 miles above the sun's surface. At that height, or in some cases under

[1] By a special arrangement of the spectroscope, the prominences can be studied in full sunshine. This important discovery was made about fifteen years ago, and to it may be ascribed all our present knowledge of the sierra and its phenomena.

it, the filaments faded away. In the meantime the little thunder-head became violently agitated, and rose like a pyramid to a height of 50,000 miles. Its summit was drawn out into long thin filaments, which were curled backwards as if met by a strong wind. About half-past two it also vanished, so that in less than two hours the whole thing was completely dissipated.

It is found that outbursts of this kind are most frequent and of greater violence about the times of maximum spots.

10. The Reversing Layer.—Between the sierra and the photosphere (which is the actual light-giving body of the sun) is a thin layer—a mere film in comparison with the whole bulk of the orb—of relatively cool matter. In passing through this layer a number of the rays of light emitted by the photosphere are absorbed; whence the spectrum of the sun, instead of being continuous, is crossed by numberless dark bands, which are the blank spaces corresponding to the particular rays so intercepted. The rays that are wanting have been identified with those emitted by certain substances when heated to incandescence, and in that way it has been found out that the absorbing layer is composed of iron, nickel, copper, zinc, lead, and many other terrestrial elements.

11. The Photosphere.—The photosphere is really the surface of the sun; for the reversing layer, sierra, and corona are only different sections of the solar atmosphere. Respecting the nature of the *actual* sun, then, we have very little knowledge. It is probably gaseous at the surface, merging into its atmosphere by insensible gradations. But we have seen (p. 15) that the mean density of the whole globe is about one-fourth that of the whole earth, or one and a half times that of water. So much of the outside, therefore, being of very small density, it follows that the internal parts must be of greater density than the mean; and it is supposed by some that the nucleus is very dense indeed. In chemical composition, we may perhaps suppose the internal matter to consist of the metals of greatest density—mercury, platinum, &c.—or else of elements (of still greater density) unknown to us.

12. Radiant Energy of the Sun.—It is as our great source of light and heat that the sun is most familiar to us. Respecting his physical constitution the general public knows little, and seemingly cares less; because, after all, of what use is such knowledge? But as our common light and fire he appeals directly to all, for, were he to go out some day, it would be decidedly awkward.

Besides rays of light and heat, the sun emits *chemical* rays, which are better understood in their effects than in their nature. A certain *magnetic* action is also induced by the sun, as we shall have occasion to explain by-and-bye.

13. The Light of the Sun.—The light of the sun is the brightest radiance we have any experience of. Its intensity is so much in excess of the very brightest of our terrestrial lights that it is

difficult to form an estimate of it by any comparison. Perhaps the following experiment, made by Professor Langley some years ago, gives the best idea of it. Everybody knows how dazzling the surface of molten iron is. The metal in a Bessemer "converter," then, is so intensely luminous that when a stream of molten iron flows into it, the latter looks dark brown by comparison. Professor Langley compared the solar beams, after they had struggled through the smoky air of Pittsburg, with this incandescent metal in the converter, and found the sunlight to be five thousand three hundred times brighter than its blinding surface! When we reflect that a considerable portion of the sun's light is absorbed by his own atmosphere, and that a still greater portion (more than two-thirds) is stopped by our atmosphere, the brilliance of his actual surface may be imagined.

The total light emitted by the sun is estimated to equal that of 6,300,000,000,000,000,000,000,000,000 candles, equivalent to 400,000,000,000,000,000,000,000,000 ordinary gas-jets, neither of which numbers, however, convey a very definite impression to the mind.

14. The Sun's Heat.—But more immediately connected with our subject is the radiation of heat by the sun. Heat is one of the most active agents in the production of terrestrial phenomena. The earth derives its supply from two sources.[1] First, its own proper heat, evidence of which we find in the gradual rise of temperature observable when we descend towards the centre. This heat is constantly diminishing, for it is conveyed by conduction from the internal regions of the earth to the surface of its crust, whence it is radiated into space. The second, and by far the most important source, is the heat of the sun. Without it we could not, of course, exist. But, even if we could, we would have no phenomena to enliven our dreary pilgrimage—nothing but the frozen materials of nature around us.[2]

[1] The heat imparted to space by the stars, the impact of meteors, &c., is sometimes mentioned as a third source. The influence of such heat must, of course, be purely negative, for, even at the highest estimate, the temperature of space is always assumed to be far below the lowest polar temperature. Its action is simply to modify radiation, and so prevent the earth from parting with its store of heat so readily as it otherwise would do. Fourier ascribed great importance to this, asserting that the comparative warmth of the interplanetary regions (— 60° C.) may be the means of preserving our globe from abrupt fluctuations of temperature which no form of life could withstand. Other philosophers have suggested that epochs of exceptional heat and cold may be due to the passage of the solar system through comparatively warm and cold regions of space. It is now believed that the stellar heat received by the earth is quite insignificant; perhaps not equalling the stellar light in quantity. A fourth source of terrestrial heat is the constant conversion, by natural and artificial processes, of other varieties of energy into that form. The tendency of nature is for all energy to assume the form of heat, and the human race has found it convenient to help in the same direction. The effects of this may be trifling, but they are certainly as worthy of consideration as those arising from stellar radiation.

[2] Something of what we owe to heat may be learned from Tyndall's delightful work, *Heat a Mode of Motion.*

15. Its Measurement.—Heat is motion in the molecules or particles of bodies. When a piece of iron is red hot its particles are moving about far more rapidly than when it is cold. When the particles are thus agitated they require rather more room than when they are in their normal state; consequently, bodies expand when heated. We take the expansion of mercury in the bulb of a thermometer as a measure of the heat imparted to the mercury, and degrees of that expansion we call temperature. Now, if we can measure the degree of expansion caused by the sun's rays falling upon one square inch of surface for, say, five minutes, we can calculate the total amount of heat received by the earth from the sun in that time, and thence deduce the whole quantity radiated by the sun within the same period.

Sir John Herschel, while at the Cape of Good Hope, applied himself to this problem; and, later, M. Pouillet, of Paris, re-investigated it. We cannot take time to describe the methods of instruments employed, but must content ourselves with the results.

16. Its Quantity.—Both Herschel and Pouillet expressed their result by stating the quantity of ice melted per minute by a vertical sun. Herschel found 0·00754 of an inch; Pouillet, 0·00703 of an inch. The mean ·00728 of an inch, or about half an inch per hour, may be taken as pretty nearly accurate. Now, let us see what this means.

The heat received by one square mile of the earth's surface from the sun when overhead is sufficient to melt 26,000 tons of ice in an hour. The amount received by the whole earth in the course of a year would liquefy a layer of ice 100 feet covering the entire globe, or about 5,700,000,000,000,000 tons. But the earth intercepts only about the 2250 millionth part of the total heat emitted by the sun. And further, the aqueous vapour in our atmosphere absorbs a considerable proportion of the rays intercepted, so that not much more than sixty per cent. of them ever reach the surface. Calculating from these data, we find that the sun's heat would suffice to melt a layer of ice at its surface at the rate of 2,400 feet, or about 2,600,000,000,000,000,000,000 tons per hour. Herschel puts it another way. Suppose a cylinder of ice, 2¼ miles in diameter, to span the distance of over 90,000,000 miles between the earth and the sun. If the sun concentrated its heating power upon it, the whole cylinder would be liquefied in the space of one second. Expressed by the combustion of coal, the solar emission corresponds to the burning of 11,750,000,000,000,000 tons per second.

17. Its Maintenance.—The enormous radiation we have just been considering does not seemingly tend to exhaust the sun. How, then, is the supply kept up? Many answers have been given to this question; but as I am not writing a treatise on solar physics, I can do no more than mention that Mayer suggested a constant rain of meteors into the sun, the motion of which, by

impact, would be converted into heat and light; that Helmholtz maintained a gradual contraction of the sun's mass to be the prime cause; and that Dr. C. W. Siemens lately proposed a theory made up of his own dark imaginings in physics and chemistry.[1] The speculations of both Meyer and Helmholtz are open to serious objections; but until our knowledge of solar phenomena has become more definite, it is hardly safe to pronounce for or against any one theory.[2]

18. SUMMARY.—We have now got some general notions about the sun—that orb which is our light, our fire, our very life. We have learned that his distance is about $92\frac{1}{3}$ millions of miles, more or less; that his diameter is about 860,000 miles, and his surface more than 2,323,500,000,000 square miles; that his bulk is about 1,260,000 times that of our earth; that his mass is only 326,800 times that of our globe; that his density is consequently little more than a fourth of the earth's density, or slightly denser than water; that he is enveloped in a gaseous atmosphere, 1,000,000 miles or so in height, called the corona; that below the corona is a layer of coloured, flame-like matter, from 7,000 to 10,000 miles in thickness, called the sierra; that this sierra is the region of tremendous outbursts of solar energy; that beneath the sierra rests a comparatively thin layer of gaseous, but relatively cool matter, the existence of which is the chief cause of the absorption bands in the solar spectrum; that under this "reversing layer" is the light-giving surface of the sun, or the photosphere; that the total light emitted is equal to 400 quadrillions of ordinary gas-jets; that the heat radiated is equivalent to that produced by the combustion

[1] Dr. Siemens's action with reference to this theory is hardly to be commended. His first step, that of communicating it to the Royal Society, was right enough; but, when it failed to meet with much encouragement there—the place of all places in the country where it could be understood, appreciated, and applauded if worthy—why did he lay it before the general public in the pages of the *Nineteenth Century*, and (still worse) make it a principal feature of his own presidential address to the British Association? From these two sources, it naturally found its way into many of the newspapers and periodicals of the world, and, as the adverse criticisms of the various eminent astronomers and physicists who took the trouble to examine it have *not* been so widely circulated, I verily believe that at the present moment many people regard Dr. Siemens's fantastic speculation as an accepted truth of science. I think it is not too much to say that a man who thus deliberately lends his influence and reputation (in Dr. Siemens's case admittedly great) to the propagation of error, does his fellow men and the age in which he lives a positive injury. Even admitting that the theory *may* be right, it is the unanimous verdict of the scientific world that all natural principles, as at present understood, are opposed to it; and so, until we find a reason to throw over those principles the theory must not be accepted; for assuredly we cannot overturn two sciences to make way for a theory.

Just as this goes to press I see that Dr. Siemens is about to publish his papers on the subject in volume form, together with the discussions they have given rise to.

[2] The maintenance of solar energy is discussed in Mr. W. Mattieu Williams's *Fuel of the Sun*.

of 11,750 billions of tons of coal per second; and that the source of this supply is not rightly understood.[1]

We have now to notice some of the phenomena exhibited by the spots on the sun, and try to find out if the spots have anything to do with the quantity of heat radiated by him.

II.—THE SPOT PERIOD.

19. Telescopic Appearance of the Sun.—To the naked eye the sun's surface appears to be of uniform brightness, except for the slight darkening round the edge of the disc; but when viewed through a good telescope, details come out which were before quite invisible, and it is found that, far from being uniform, the whole photosphere is made up of flecks of intense brilliance upon a (relatively) dark background, giving the solar surface a curdled appearance. When the conditions of observation are unusually favourable, and it becomes possible to use a high magnifying power, these flecks are seen to be composed of "granules" or luminous points. Here and there may generally be perceived streaks of greater brilliance, shining even against the intensely luminous background of the surface (hence called *faculæ*, from the Latin, "a little torch"). They are irregular in shape, and measure from 5,000 to 20,000 miles in length. Then, lastly, there are the dark patches, known as "spots."

So far as can be conjectured at present, the flecks and granules are masses of intensely luminous matter floating upon or about the sun's surface; the faculæ are vast ridges of this luminous matter which protrude through that absorbing film called the reversing layer, and so appear brighter because less of their light is absorbed by it; and the spots are simply holes in the floating matter, which permit us to see the cooler and darker matter beneath.

20. The Spots.—Galileo is very often credited with the discovery of the solar spots; but Arago, in his biographical notice of that

[1] The reader is referred to the following popular works for further details: *The Sun*, by A. Guillemin, translated by Dr. T. L. Phipson; *The Sun*, by Prof. C. A. Young (International Scientific Series); *The Sun; Ruler, Light, Fire, and Life of the Planetary System*, by R. A. Proctor; and *Contributions to Solar Physics*, by J. Norman Lockyer. These works contain some very fine illustrations of the corona, prominences, spots, &c., which will give one a far truer idea of the real phenomena than any verbal description can possibly do.

philosopher,[1] has shown that the honour is unmerited. We need not trouble ourselves about the historical point here; the fact remains that the spots were under observation very early in the seventeenth century, or about 1610-11.[2]

Careful watching soon resulted in the discovery that the spots move. They gradually came into view at one limb of the sun and passed over to the opposite one, occupying a little over twelve days in doing so. Some philosophers thought that they might be planets circulating very close to the orb, but both Fabricius and Galileo maintained them to be marks on his surface, their motion indicating his rotation (a fact hitherto unsuspected), and they were right. The change of aspect exhibited by the spots as they pass over the solar disc, due to foreshortening when near either limb, proves conclusively that they belong to the sun, and are not extraneous to him.

21. The Parts of a Spot.—A spot when perfect is composed of two well-defined portions. The central or nuclear portion (called the *umbra*) is irregular in shape, and of a deep purplish colour. It looks exactly like a hole, which in all probability it really is. Surrounding the umbra is a fringe of radial filaments (called the *penumbra*), the brightness of which is less than that of the sun's general surface. The boundaries between the umbra and the penumbra, and between the penumbra and the photosphere, are clearly marked, not shaded into one another as might be imagined. In general contour, the average spot, when at its fullest development, is nearly round. While forming, and also while undergoing dissipation, it is often quite irregular in form.

22. Dimensions of Spots.—To those who take the term "spot" in its literal and usual sense, the actual size of the solar spots must be a little startling. Many have been seen which measured from 30,000 to 50,000 miles in diameter. Very ordinary ones are sufficiently large to receive two or three of our earths into them without their edges being grazed! The biggest spot ever observed appeared in 1858. It measured more than 143,000 miles across; so that many globes the size of the earth would be required to cover it. No spot of less than 24,000 miles in diameter is visible to the naked eye.

[1] *Notices Biographiques*, tom. iii.

[2] Kepler fancied that sunspots are referred to by Virgil (See *Georgics*, Book i., lines 441 and 454). The Chinese are said to have recorded the appearance of spots visible to the naked eye in A.D. 321. The Peruvians, according to Acosta, were found to have a knowledge of them when their country was conquered by the Spaniards. Several historians of Charlemagne relate that in 807 a large black spot was seen on the sun for eight consecutive days. Kepler saw one in 1609, but supposed it to be the planet Mercury. From 1610 to 1612 the spots seem to have been discovered and studied by several astronomers independently, as a result of the invention of the telescope a few years before. Fabricius, Scheiner, Galileo, and Hariot, all wrote on the subject, priority of publication belonging to Fabricius.

23. Duration.—The length of time during which a spot remains visible is very variable; sometimes hours, sometimes days, but generally two or three months. The most enduring spot on record lasted for eighteen months.

24. Changes.—We have already referred to the change of appearance which a spot undergoes in its passage across the sun's disc, and the cause of the change. But, besides this, the spot itself generally suffers alteration, not apparent, but real. The following quotation from Professor Young's recent work gives a good idea of the life-history of an average spot:—"Generally, for some time before the appearance of the spot, there is an evident disturbance of the solar surface, manifested especially by the presence of numerous and brilliant faculæ, among which 'pores' or minute black dots are scattered. These enlarge, and between them grayish patches, in which the photospheric structure is unusually evident, as if they were caused by a dark mass lying veiled below a thin layer of luminous filaments. The veil grows gradually thinner, apparently, and breaks open, giving us at last the completed spot with its perfect penumbra. . . . When the spot is once completely formed, it usually assumes an approximately circular form, and remains without striking change until the time of its dissolution. As its end approaches, the surrounding photosphere seems to crowd in upon and cover and overwhelm the penumbra. Bridges of light, often many times brighter than the average of the solar surface, push across the umbra, the arrangement of the penumbra filaments becomes confused, and, as Secchi expresses it, the luminous matter of the photospherie seems to tumble pell-mell into the chasm, which disappears, and leaves a disturbed surface marked with faculæ, which in their turn subside after a time."

It must not be supposed that this description applies to the history of all, or even to that of the majority of spots. Endless variety characterises the solar phenomena, as it does the phenomena of our earth, and it is as difficult to find generalities in the one case as in the other.

25. Rotation.—It has occasionally been observed that the filaments which constitute the penumbra are curved, and that when this is the case, the spot has a slow gyratory motion. M. Faye, seizing upon this curious fact, has suggested that all the spots are merely whirls or eddies in the photosphere. A good deal can be said in favour of this explanation, as it satisfactorily accounts for not a few of the observed phenomena; but unfortunately for the theory, only about two or three per cent. of the whole spots observed exhibit a cyclonic motion, while of those that do gyrate, some go one way, some another, and many turn in opposite directions alternately. Everything considered, the phenomenon of rotation is probably purely accidental.

26. Disruption.—Large spots frequently divide into several parts, which all fly asunder like repellant bodies. The fragments

move apart with great velocity, sometimes at the rate of one thousand miles an hour.

27. Proper Motion—Galileo and the early observers rightly inferred that the movement of the spots from east to west over the sun's disc implies the rotation of the orb on its axis. Careful study of this movement, however, has disclosed a very remarkable fact. It is that the equatorial region of the solar surface completes a revolution in a shorter time than the polar regions. Spots, consequently, move with a greater or less velocity according to their position relative to the equator. The explanation of this surface drift, as it is called, is entirely a matter of conjecture, so we need not dwell on the point. But besides the motion just referred to, many spots have a motion of their own, quite independent seemingly of that of the solar surface. When undergoing any change, they usually advance (westward) at a perceptibly increased rate. Then, according to M. Faye, some describe small ellipses as they are carried along, taking a day or two to complete each revolution. And, finally, Carrington detected a slight equatorial tendency in the motion of spots within 20° of the equator, and a polar tendency in the motion of those beyond that limit.

28. Distribution.—It is more usual for spots to appear in groups than single and isolated. Very often a big spot is attended by a train of little ones. Their appearance in any form, large or small, is confined to the region of the solar sphere which answers to our temperate zones, so that their distribution is neither uniform nor erratic.

29. Number.—It was early recognised that the number of spots visible on the sun's surface from year to year is variable. At the time of their discovery, as it happened, they were very numerous. Scheiner saw more than fifty at one time. Hevelius also makes mention of large groups from 1660 to 1671. From 1676 to 1684, and from 1695 to 1700, none were visible; but between 1700 and 1710 they appeared in great numbers. In the latter year only one was seen, and during the two years following (1711 and 1712) the sun's disc was spotless. Again, in 1713, one made its appearance, and from 1716 to 1720 they greatly increased, being so large and numerous in 1719 that they formed dark belts round the sun. The years 1758, 1759, 1764, 1769, 1779, and 1780, were marked by the appearance of very large spots. Schrœter says that on one occasion he counted sixty-eight, and on another, eighty-one. On some days in 1801 and 1802, Herschel counted fifty. But soon after this more systematic observations began to be made. Pastorff and Schmidt started the investigation, and in 1826 Schwabe, of Dessau, set about that series of daily observations which has made his name immortal as an example of diligence and perseverance, and which resulted in the discovery of the law that lies at the foundation of the sunspottery of to-day.

30. Schwabe's Researches.—For upwards of forty years Schwabe carefully chronicled the groups of spots visible on the

sun's disc. He made more than ten thousand observations. Here is part of the result :—

Year.	Number of Days of Observation in the Year.	Number of Groups of Spots observed in the Year.	Epochs of Maximum and Minimum.	Number of Days in the Year during which no Spots were visible.
1826	277	118		22
1827	273	161		2
1828	282	225	Maximum.	0
1829	244	199		0
1830	217	190		1
1831	239	149		3
1832	270	84		49
1833	267	33	Minimum.	139
1834	273	51		120
1835	244	173		18
1836	200	272		0
1837	168	333	Maximum.	0
1838	202	282		0
1839	205	162		0
1840	263	152		3
1841	283	102		15
1842	307	68		64
1843	324	34	Minimum.	149
1844	320	52		111
1845	332	114		29
1846	314	157		1
1847	276	257		0
1848	278	330	Maximum.	0
1849	285	238		0
1850	308	186		2
1851	308	151		0

A glance at this table shows that the spots increase and decrease with marked regularity, the maxima and minima occurring alternately. Further, both the maxima and minima apparently occur at intervals of ten years, more or less. And, lastly, the minima do not fall exactly midway between the maxima, but nearer the maximum following than that preceding. Schwabe thus discovered that the sun-spots vary in number *periodically*, and roughly in accordance with fixed laws.[1]

[1] It is instructive to note that Schwabe began this tedious investigation without the slightest notion of the result. "Like Saul," he says, "I went to seek my father's asses, and found a kingdom." It is to be feared that very few of Schwabe's successors could truthfully say the same of themselves. Figures and tables have never undergone such systematic torturing as since they fell into the hands of sun-spot theorists.

31. Wolf's Work.—The next man to take up this subject was Professor Wolf, of Berne; but instead of devoting his time, like Schwabe, to actual sun-watching, he ransacked the old records with a view to the disentombment of past observations. After the examination of many hundred volumes he succeeded in carrying Schwabe's list back to 1610; so that, instead of about fifty years' variations to deduce the period from, he had two hundred and fifty. Of course, the earlier observations, being drawn from so many different sources, are not nearly so reliable as the invaluable series of Schwabe.

We have not space to give any of Wolf's tables, so must content ourselves with his conclusions. He found that the period between recurrent maxima is very far from a fixed one. A maximum occurred towards the close of 1829, and another about the beginning of 1837, the interval in this instance being little over seven years. In 1788 there was a maximum, but another did not occur until 1804, or until after a lapse of 16 years. 8, 9, 10, 11, and 12 years are the commonest intervals. The minimum period is equally variable. Finally, a maximum follows a minimum, on the average, in $4\frac{1}{2}$ years, while the minimum generally follows the maximum in $6\frac{1}{2}$ years. Thus, "the disturbance which produces the sun-spots springs up suddenly, but dies away gradually."

32. The Sun-Spot Period.—It is very justly doubted by some astronomers whether the variation in the number of sun-spots is truly periodical at all. There is certainly the rough semblance of a period; but such a semblance might well arise through the operation of causes other than those which produce periodic effects. It requires, indeed, no small degree of faith to see even this semblance; for, by assuming a cycle of 11 years, and giving it a latitude of more than 8 years to go and come on, it were hard to find any series of events *not* bearing out such a cycle.

The mean period deducible from Wolf's observations is 11·111 years. Hence, about 11 years is known as the sun-spot cycle. This number is constantly referred to by writers on sunspottery as if it were a fixed and invariable quantity about which there can be no doubt whatever. We should be careful, however, to remember what it really is, and that, while the number may represent a true period, variation from which is caused by accidental influences, it is also possible that it expresses nothing at all, but is merely the mean of several unequal and quite erratic intervals. When we refer in what follows to the sun-spot period, we assume that this correction is borne in mind. We are dealing, as the reader will now begin to see, with a vast speculative structure, the very lowest foundation of which is an unwarranted assumption.[1]

[1] As an example of the way in which the true nature of the sun-spot cycle has been misrepresented by would-be interpreters of science to the public, I make a quotation or two from a paper on "Sun Spots and Rainfall," by a Mr. Norman J. Ross, which appeared in the *Sunday Magazine* for August, 1878. The italics are mine. "While interest is awake over the troubles of the Indian famine, astronomers come forward to deliver the message of their visions, and announce

33. The Cause of Sun-Spots.—The cause of solar spots, as well as of their assumed periodic variation, is a most interesting question, and has naturally exercised a good many minds. It does not concern us much what this philosopher holds and that astronomer is prepared to maintain, seeing that we do not *know* what the cause is; but we may just mention that Galileo, and many after him, thought the spots were clouds floating above the photosphere; that Lalande fancied them to be the peaks of solar mountains projecting through the fiery envelope; that Sir William Herschel imagined them to be holes in the same, permitting the dark body of the sun to be seen; that Sir John Herschel suggested whirling storms, boring like eddies through the photosphere; that Zöllner more recently proposed that they might be masses of scoria floating on a molten surface; that Secchi maintained them to be clouds produced by solar eruptions; and that Faye at present contends that they are rotating storms in the photosphere, just like the cyclones in our own atmosphere.

None of these theories take particular cognisance of the "cycle," however. Accordingly, we have two supplementary ones specially designed to account for that all-important phenomenon.

34. The Planetary Theory.—After a very careful examination of very carefully preserved sun-spot records, the Kew observers (Messrs. De La Rue, Stewart, and Loewy) found reason to believe that the positions of the planets relative to the sun may have something to do with his degree of spottedness. It was discovered that maxima and minima in the number of solar spots correspond approximately with the conjunction and opposition of certain of the planets. The idea thus suggested has been enthusiastically taken up by Professor Balfour Stewart, whose researches promise to result in the discovery of an infinite number of minor periods in the sun-spot variation, for he has already traced the influence of three intra-Mercurial planets.[1] Jupiter, whose period of revolution is about 11 years and 10 months, was at one time thought to be the prime agent in producing spots, partly because of his pre-eminent

that in the condition of the sun's surface they have found an index to the recurrence of these calamities, and that after continued observation it will be possible to *forecast with certainty* the time of their return." "Hitherto the observations have been quietly (!) made by a few men. Now that their achievements are so surprising, increased activity may be looked for, and instructive results expected." "The results [of sun-spot observations] have been registered, compared, and discussed, till *the subject is now very fully known.*" "The spots and the uprushes vary together, and all these phenomena ebb and flow once in eleven years. So that *every eleven years* we have the greatest activity, &c., &c. . . . . This is the sun-spot cycle." The public is hardly to be blamed for ignorance of scientific truth when its teaching is such.

[1] The existence of planets within the orbit of Mercury is a controversial point of much importance. Adams inferred the presence of such from observed inequalities in the motions of Mercury, and quite recently two astronomers averred that they saw an intra-Mercurial planet during an eclipse of the sun. Not a little wrangling resulted, and some severe things were said of the two lynx-eyed observers. For the present the matter rests until some reasonably conclusive evidence can be adduced.

influence, being the giant member of the solar system, and partly on account of the superficial agreement between his time of revolution and the sun-spot period; but upon closer examination it was found that, while about 1870 the spot maximum occurred when the planet was nearest the sun, early in the century the minima invariably occurred then, so that the proximity of the planet could not possibly be the cause of the spots. Many eminent astronomers are disposed to regard the agreement between planetary positions and the state of the sun's surface as purely fortuitous, and the instance just quoted certainly goes to support that conclusion.

But the chief objection urged against this planetary theory is that the greatest possible influence (measured by the usual standards of mass and distance) which the planets could exert upon the sun would be utterly inadequate to produce the vast disturbances that actually occur. Professor Young takes the trouble to show that the tide-raising power of Jupiter upon the sun's surface can only be about $\frac{1}{1000}$th that of the sun upon the earth's surface. The objection is hardly valid, however, seeing that the theory expressly assumes a different sort of influence altogether. To let Professor Stewart speak for himself:—"The chief difficulty in attributing solar outbreaks to configurations of the planets is the comparative smallness and great distance of these bodies, so that when we reflect on the enormous amount of energy displayed in a sun spot we cannot but have great difficulty in supposing that such vast phenomena can be caused by a planet like Venus, for instance, that is never as near to the sun as she is to the earth. But this difficulty depends very much on what we mean by the word 'cause.' If we mean that the planets cause sun spots in the way in which the blow of a cannon ball or the explosion of a shell causes a rent in a fortification, the hypothesis is certainly absurd. But if we only mean that the planets act the part of the man who pulls the trigger of the gun, the hypothesis may be unproved, but it is no longer absurd. For we have reason to believe that there may be great delicacy of construction in the sun's atmosphere, in virtue of which a small cause of this kind may produce a very great effect."[1] From this it will be seen that the assumption upon which the theory rests is not an exaggerated planetary influence of the ordinary kind, but a subtile influence, which acts by releasing the sun's own potential energy. The real objection, therefore, is that we have no physical evidence in favour of an influence of the kind assumed.[2]

[1] Lecture in the course on Solar Physics at South Kensington, delivered April 27, 1881. See *Nature*, vol. xxiv., p. 150.

[2] It is curious that Young, whose work on the sun is so thoroughly up to date that I have been able to do little more than follow him in making statements of fact, should fall into the error of supposing the planetary theory of sun-spots to be based upon tide-lifting power. After proving—what is obvious enough—the absurdity of assuming such action on the part of the planets, he continues: —"If the sun spots are due in any way to planetary action, this action must be that of some different and far more subtile influence,"—which is precisely what Professor Balfour Stewart contends.

35. The Meteoric Theory.—Mayer and Waterston having suggested the impact of meteoric matter as the probable source of the sun's supply of light and heat, and Sir John Herschel having attributed the equatorial surface drift (already referred to[1]) to a like cause—the matter being supposed to strike the orb obliquely and so continually accelerate its rotation—some few astronomers are inclined to look upon this same matter as directly concerned in the production of spots. They imagine the meteors to revolve in an elongated orbit around the sun, having a period of 11 years or so; and further, they suppose them to be gathered into a dense cluster in one part of the train, and thinly scattered elsewhere. Thus the cluster comes round to the sun every eleven years, and produces the marked outburst of spots. Like all other theories, there is much to be said for this one, and much to be said against it. It is only a theory.[2]

36. Does the Solar Radiation Vary?—We have found that the variation in the number of sun spots is roughly periodical. The question now arises—Do the spots influence the solar radiation in any way? For if they do, the radiation must vary; and, further, it must vary in accordance with the sun-spot period. Now—it may seem ridiculous to say so, but it is the fact,—this question, which (together with the question of a true sun-spot period) lies at the root of sunspottery, *is purely a matter of opinion.* Direct observation throws little, if any, light on it; *à priori* reasoning throws less; and investigators, left to the guidance of their own sweet wills, have assumed whatever conclusion suited their purpose best. The point being of fundamental importance, we must discuss it somewhat in detail.

37. Observational Evidence.—Undoubtedly the only satisfactory way in which the question can be settled is for the solar

[1] See p. 25.

[2] It is not at all unlikely that some modification of this idea may yet prove to be the true explanation of many solar phenomena, and of their variation in frequency. One system of meteors with an eleven years' period of revolution obviously will not do, for the sun-spots exhibit no such strict periodicity in their variation as this would imply. But we may assume several systems, each composed of one or more clusters, and each having a different period of revolution. And then the anomalous irregularities in the sun-spot cycle become of simple explanation, for the maxima, being due to the accidental proximity of several clusters to the sun at the same time, will follow a law truly periodic, but so involved as hardly to be recognisable. The meteors, in order to produce the surface drift, would require to have a *direct* motion—that is, the same way as the planets—and in order to form the spot zones would need to have their orbits very slightly "inclined;" and, so far as we are entitled to infer the elements of unknown meteoric systems from known ones, and the elements of meteor systems from those of comets, there is certainly strong evidence in favour of such being actually the case, nearly all comets of short period having direct motion and slight inclination. The important part played by meteoric matter in the solar system is only now beginning to be understood. The mysterious connection between comets and meteors, and the no less surprising relation of meteoric flights to the fluctuations of terrestrial temperature, already point to the conclusion that those little bodies have an important bearing both upon the great problems of the cosmos and upon the comparatively small ones of our earth.

radiation to be directly measured. Such measurement, however, has never been properly made. According to Professor Balfour Stewart, the needful instruments are ready to hand, and the reason why nothing has been done is to be found in the indolence and indifference of astronomers, "one of the strangest points in the history of scientific progress." According to Professor Young, the variation is "too small for measurement with our present instruments, and science waits anxiously for apparatus and methods of delicacy adequate to deal with the problem." In the absence of systematic observations (nobody denies the absence, although the cause of it is a matter of dispute) we must be content with such crumbs of information as casual observations afford.

About 1875, Professors Roscoe and Stewart found the direct heat of sunshine near London to be greater in years of maximum than in years of minimum solar disturbance.[1] Somewhat later, Mr. J. B. N. Hennessey made actinometrical observations at Mussooree and Dehra, in India, the result of which went to support the same conclusion. Attempts made at various places to measure and record the sun's chemical action have proved nothing at all as yet; but the Kew observers have noticed that the number of fine days in the year which permitted of solar pictures being taken is slightly greater in years of maximum than in years of minimum spot frequency. That is about all the direct evidence we have in favour of an increased radiation during spot maxima. Emphatic assertions cannot be taken as evidence.[2]

On the other hand, Secchi long ago found that spots produce a diminution of the temperature of the sun at its surface. By means of the thermopile it has since been ascertained that the umbra of a spot emits only about fifty-four per cent. as much heat as a similar area of the photosphere. Hence, when the sun is very much spotted, the direct result must be a decrease in our heat supply. Faculæ, however, emit *more* heat than the photosphere, and as they always make their appearance in abundance when the spots abound, it is possible that their heat-increasing influence may counteract the heat-decreasing influence of the spots. Finally, Mr. S. A. Hill some time since discussed the variation of solar radiation, as deduced from observations of the black bulb in vacuo radiation thermometer, made in the north-west provinces of India, and found that a slight *decrease* coincides with the occurrence of spot maxima, and *vice versâ*. Thus the observational evidence, such as it is, favours one view quite as much as the other.

38. Theoretical Evidence.—*A priori* considerations lead to three different conclusions as to the effect of spots upon solar radiation :

[1] See *Proceedings* of the Royal Society, vol. xxiii., p. 580.

[2] In much of the popular writing and lecturing on this subject it is tacitly assumed, and asserted as matter of fact, that many spots indicate much activity in the sun, and increased radiation in consequence. Until decisive evidence be forthcoming, it is premature to assume or assert anything of the kind. As I said before, the point must in the meantime be regarded as one of individual opinion.

(*a*) that spots indicate great activity in the sun, and increased heat-emitting power; (*b*) that spots, being a manifestation of solar energy, decrease the amount of that energy available for radiation, and so produce a diminution of the heat rays; and (*c*) that spots mark a state of great disturbance in the solar surface, and, while tending to decrease radiation themselves, have their influence counteracted by concomitant circumstances, the effect being nil, or at most very slight. We shall let a representative of each of these views speak for himself.

(*a*.) "At first sight, we might be tempted to suppose that we must have less heat from the sun when there are most spots, since the centre of a sun-spot gives out unmistakably less light and heat than the same extent of ordinary solar surface. A little reflection will, however, I think, serve to convince us that the very opposite of this is more probably the correct hypothesis. Something of this kind occurred, no doubt, to the mind of the late Sir John Herschel when he made the remark that at times of maximum sun spots the solar pot is perhaps boiling most furiously.

Let us now inquire a little into the nature of the scientific machinery by which the sun is able to give out from day to day, from year to year, and from millenium to millenium, that wonderful light and heat without which we should all be dead men. Quite apart from observation we may be certain that the surface of the sun cannot possibly be a solid surface like that of our earth. If I am not mistaken, Sir William Thomson has made the remark that in such a case the sun would cool in a few minutes. The outer row of particles would soon give out their light and heat, and having done so, and being bound together in a solid framework, they must remain where they are, and wait until, by the comparatively slow process of conduction, more heat is supplied to them from the inside. To illustrate this let me take a somewhat long tube containing water, at the bottom of which there is a small cake of ice. Now it is easy to cause the water at the top of this tube to boil, without sensibly affecting the ice in the bottom. The reason is that the heat is only supplied to the ice through the very slow process of conduction. Even if we take a good conductor, such as a metal, you are aware that in a pot of hot metal the surface may be crusted over while the interior is in a fluid state. It is not thus that the sun will conquer in its battle against the cold of space. The foremost files, when they have once fired off their heat-shot must at once retreat, not merely to recruit themselves, but to give place to a fresh and unexhausted battalion from within. The rule in these celestial quarters is very similar to that of ordinary mundane warfare. A position is defended against the enemy, not so much in virtue of the number of men which it contains as by the number of shots that can be fired in one second. Everything, then, so far as the sun is concerned, will depend upon the power of that machinery in virtue of which the battalions of particles which have done their work are hurried within and replaced by a fresh and unexhausted levy. Now this implies a powerful system of convection or carriage of particles. I have shown you that if the top of a tube of water be made to boil, ice in the bottom will hardly be heated. But if the ice be all at the top, and the heat be applied at the bottom, we shall have a very different result. Then the ice will speedily melt. In the former case there was no carriage of particles, but in the latter, the heated particles, becoming specifically lighter, ascend, and their place is supplied by colder particles from above. It is this unceasing carriage of particles that distributes the heat, and, in fact, enables us to boil with ease the kettle on our kitchen fire.

But convection is still more manifest when we go from liquids to gases. We are all familiar with the roar of air as it rushes into a furnace fire that is connected with a tall chimney. The vigour of the furnace depends unquestionably upon the velocity of the rush of air. Let us examine what causes this rush. The air being heated becomes specifically lighter and ascends. Now the perfection of this process depends on four things. It depends—

1. On the fact that air and all gases are things which expand greatly when heated.
2. On the strength of the fire.
3. On the attraction of the earth, for it is on account of this attraction that the air becomes specifically lighter, and therefore mounts upwards.
4. On the scale of the arrangement, the rush will be more powerful in a large furnace attached to a tall chimney.

Having thus analysed the conditions which go together to form a perfect convection system, let us now turn to the sun and inquire what we find there. In the first place we find *gas*—that is to say, a body that expands greatly when heated. Secondly, the *fire* is very strong, or, in other words, the inequalities of temperature are very great. Thirdly, the *attraction* of the sun is much more powerful than that of the earth. Fourthly, the *scale of the arrangement* is enormously large. You thus see that we are entitled to expect very powerful convection currents upon the surface of the sun, and without supposing that the remarks now made offer a complete explanation of everything that there takes place, we are yet, I think, entitled to assume that the extremely powerful carriage or convection system there exhibited is intimately connected with the sun's heat-giving power. Whenever, therefore, we find this convection system to be exceptionally strong—as, for instance, at the time of maximum sun-spots—we may perhaps conclude that the solar furnace is in most active operation, and therefore giving us out most light and heat. There is, in fine, a greater stirring up."[1]

(*b.*) "Starting with the preliminary assumption that the total available amount of solar energy at any given time is *constant*, we find at least two ways in which this energy manifests itself in the sun: (1) in the movements and disturbances of the solar gases exhibited primarily in the prominences and secondarily in the spots; (2) in the maintenance of a high temperature. Now, if a variation occurs in either of these forms of energy, it may be reasonably inferred (remembering our assumption) that a corresponding inverse variation occurs in the other. So that the period of maximum disturbance in the solar currents—in other words, the epoch of maximum sun spot—ought to be that of minimum solar temperature. Conversely, at the epoch of minimum sun spot, less energy being spent in the motion of convection currents, more should remain in the form of sensible heat, and therefore solar temperature be at a maximum. Since, *ceteris paribus*, radiation varies directly with the temperature of the radiating body, the minimum

[1] Prof. Balfour Stewart, in a lecture on "Suspected Relations between the Sun and Planets," delivered at Glasgow, January 30, 1878. The source from which the above quotation is drawn accounts for its diffuse style. A more condensed passage would have been preferable, but I could not find one.

epoch of the sun spots should be the maximum epoch of solar radiation, and *vice versâ*."[1]

(*c*.) "We get our light and heat from the photosphere which is covered by an atmosphere of gases, and in this atmosphere a considerable absorption occurs. Now, if the level of the photospheric surface be disturbed, so that it is covered with waves and elevations of any considerable height, as compared with the thickness of the overlying atmosphere, then, as Langley has shown, the radiation will at once be increased ; since, while the absorption is increased by a certain percentage for those portions of the photosphere which are depressed below their ordinary level, it is *much more decreased* for those that are raised.

The reason of this is that, when a luminous object is immersed in an absorbing medium, it loses much more light for the first foot of submergence than for the second, and more for the second than for the third ; so that when it has reached a considerable depth it requires an additional submergence of many feet to diminish its radiation as much as the first foot did. If, therefore, sun spots are accompanied by considerable vertical disturbance of the photosphere, as is almost certain, we must have as a result an increased radiation on account of the disturbance, offsetting, more or less entirely, the opposite effect which is at first view most obvious [*i.e.* the reduced radiation due to the low temperature of the spots].

Then, again, it is altogether probable that spots are either due to, or accompanied by, an eruptive action—the internal, and hotter, gases bursting through the photosphere in unusual abundance during seasons of spot maximum. This must necessarily tend to increase the emission of heat from the sun, and possibly by a considerable amount. But, on the other hand, any considerable increase in the thickness of the chromosphere [or sierra], such as might result from abundant and long-continued eruption, would work in the opposite direction.

It is impossible, therefore, to predict *à priori* which effect will predominate."[2]

39. We have devoted so much space to the quotation of evidence that we have very little left for its discussion. What has to be said may be said very briefly, however. So far as direct observation enlightens us, the sun may be either hotter or colder when his surface is excessively spotted. So far as *à priori* reasoning from facts can teach us, he may be either one thing or another, or neither of them. And the conclusion we are forced to draw is that, until suitable instruments and methods of observation put us in possession of knowledge at present unattainable, *we have not the slightest ground* for assuming an appreciable variation in the temperature and radiation of the sun.

40. Summary.—We have now learned that, viewed through a good telescope, the surface of the sun is far from uniform, presenting a mottled appearance, and being diversified frequently by bright patches (faculæ) and dark patches (spots) ; that those patches move across the solar disc, indicating the rotation of the orb; that spots

[1] Prof. E. Douglas Archibald, *The Rainfall of the World in connection with the Eleven-year Period of Sunspots.* Calcutta: 1878. Introd. p. v.

[2] Prof. C. A. Young, *The Sun*, pp. 160-1.

are generally composed of two well-defined portions—the dark nucleus or *umbra*, and the less dark fringe surrounding the umbra or *penumbra* ; that they are of enormous dimensions, varying from a few thousand to more than one hundred thousand miles in diameter ; that they are of very variable stability, sometimes lasting many months, but just as often vanishing in a few hours ; that they undergo marked changes of form and construction during development, and while undergoing dissipation; that they are sometimes observed to rotate, and occasionally to break up into fragments ; that they exhibit a motion of their own upon the sun's surface ; that they are almost exclusively confined to the "temperate zones" of the solar sphere, forming two bands on either side of the equator ; that they vary in number in a marked degree; that this variation is roughly periodical, the mean interval between epochs of maximum spots being about eleven years ; that the cause of solar spots has afforded the theme of much speculation ; that the cause of their periodical variation has been made the subject of more speculation; that the question whether the spots and the solar radiation vary together in any way has exercised many minds ; and that the result is that we really cannot answer the question in the meantime.[1]

The next part of our problem is : Taking it for granted that the sun-spots vary in number periodically (which they do not), and that the intensity of solar radiation undergoes a corresponding variation (which we have no ground for supposing to be the case), do those terrestrial phenomena which immediately depend upon solar radiation show any trace of like periodicity ?

[1] There are no *popular* works on the sun-spot period, for it is an eminently dry subject. The curious reader should consult the works of Carrington and Wolf. He will also find much information scattered through the Journals of the Royal and the Royal Astronomical Societies. But the chief *repertoire* of sun-spot literature is *Nature*. The columns of that otherwise excellent periodical abound in papers, memoirs, letters, and paragraphs illustrative of the many phases of sunspottery. The "intelligent foreigner" must almost fancy the pursuit of cycles to be the chief occupation of the British man of science. God forbid !

III.—SUN-SPOT METEOROLOGY.

41. The Old Meteorology and the New.—The science of meteorology, if we may so designate rough weather-records and the forecasting rules formulated from them, has a very long and a singularly unprogressive history. The Greeks and Romans observed the weather changes with a view to the determination, if possible, of constant relations among them; of late years we have been studying the same phenomena for the purpose of tracing the operation of celestial influences. The ancient weather-watchers aimed at obtaining a foreknowledge of to-morrow's weather; our modern meteorologists (some of them, that is) are desirous of knowing the character of next year's seasons. But the works of Virgil and Aratus bear testimony to a degree of success in the one case that those of the cycle-hunters fail to do in the other, and the farmer of to-day is guided more by the empirical rules, or "superstitions," handed down to him by tradition, than by calculations based upon numerical cycles. Tested by practical results, then, the new meteorology does not seem to be much of an improvement upon the old. Nevertheless, if the search for a cycle has not resulted in any practical benefit as yet, it has at least had the effect of stimulating research, and has given a fresh impulse—though, it is to be feared, a false one—to a branch of science that was in a very backward state. Twenty years ago the most desponding views were held regarding the future of meteorology. "In spite of all the millions of meteorological observations which have been accumulated up to the present time," says a writer in *Macmillan's Magazine* (August, 1866), "it must be confessed that very little good has been got out of them." Even more gloomy is the utterance of a life-long weather student. "With all my practice and experience in observing atmospheric changes, and recording hour by hour, and day by day, thermometrical and meteorological observations, and in connection with simultaneous observations made and recorded elsewhere, I feel more and more convinced that it is not in the power of any human being to determine, even a single day in advance, what change will take place in the atmosphere." The necessity being felt for a new departure, and general disgust having been created by the failure of the observational method to yield anything but vast collections of tables, it is not wonderful that, the line of departure once indicated, it should have been followed, in the eagerness natural to a novel pursuit, to an altogether unwarrantable extent, leading in many cases to the most absurd results. And so we find those dry bones, the "millions of meteorological observations," suddenly inspired, and bearing witness, or being made to bear witness, to all manner of cycles.

Who first originated the cycle investigation cannot now be very easily determined. Before the publication of Wolf's extensive researches, the way was gradually being prepared for the reception of some revolutionising discovery. Thus we find Sir John Leslie saying, "Although two or more years of remarkable heat or cold often follow consecutively, yet there can be no doubt that atmospheric changes, however complicated and perplexing, are determinate in their nature, as the revolutions of the heavenly bodies. When the science of meteorology is more advanced, we shall, perhaps, by discovering a glimpse of those vast cycles which result from the various aspects of the sun, combined with the feeble influences of the moon, be at length able to predict, with some degree of probability, the conditions of future seasons." Leslie, it will be remarked, did not forget the moon. He was quite right. Were an amount of labour, ingenuity, and enthusiasm equal to that which has been bestowed upon the sun-spot cycle, now given to the discovery of a lunar one, the result would perhaps astonish some people.[1]

42. Sun-Spots and the Weather.—The idea that the weather is influenced by the number of spots on the sun's surface was entertained early in the seventeenth century. In 1614, according to Schyrle, an unusual crowd of spots caused frightful winds, rain,

[1] At a recent meeting of the British Association, Sir William Thomson made the statement, that careful observation had established the fact that the moon does not exert any influence whatever upon the weather. So far from this being the case, the most carefully determined results point to precisely the opposite conclusion. The existence of atmospheric tides due to the moon's attraction can hardly be doubted. But the lunar heat produces a more marked effect. Melloni's attempt to determine the heating power of the moon was not very successful, owing to the method he employed; but Lord Rosse has since succeeded better, and found that lunar heat rays do reach the earth's surface. The greater number of them, however, are absorbed by aqueous vapour in the higher regions of the atmosphere, for we have reason to suppose that they are dark rays, and Tyndall has shown how readily such undergo absorption. The direct result of this, as Mr. Park Harrison and others have pointed out, must be to raise the temperature of the air above the clouds, cause increased evaporation from their surface, and so effect in a certain measure their dispersion. Now, it is a matter of the commonest observation that the sky is clearer, generally speaking, about the time of full moon, than when she is in her other phases. Sir John Herschel remarked this without "any knowledge of such a tendency having been observed by others." Humboldt also speaks of it as a fact well known to the pilots and seamen of Spanish America. I have seen the circumstance ascribed to the greater *conspicuousness* of clear nights when the moon is full than when there are only the stars to shed their feeble glimmer, but an observer like Sir J. Herschel was hardly likely to be misled by a mere illusion of the memory. He says emphatically that the tendency to disappearance of clouds under the full moon is a meteorological *fact*. A necessary consequence of the dispersion of the clouds is increased radiation from the ground, producing a slight reduction of temperature in the air near the ground. Mr. Harrison discussed temperature observations made at Oxford, Greenwich, and Berlin, and found a mean decrease of more than 2 deg. Fahr. about the time of full moon. To confirm all, Arago ascertained that the rainfall is slightly less about full than about new moon. In face of these observations, which point to a slight but quite appreciable influence of the moon upon our weather conditions, it is difficult to imagine where Sir William Thomson can have found the ground for his statement. This subject is an interesting one, and I hope to deal with it fully in a little work already announced, "Facts and Fallacies about Weather Forecasting."

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and a quite extraordinary degree of cold in the month of June. Sometime earlier in the year, Battista Baliana had written to Galileo to say that he feared, should the spots become numerous, the cold would be severely felt. How far this prediction may have influenced the chronicle I cannot say. The opinion that many spots induce cold and wet weather was current during the whole of the seventeenth and eighteenth centuries. Even after Sir William Herschel had combated this view, and endeavoured to establish the opposite one, it numbered many adherents. In 1825, the German newspapers announced that Dr. Fischer, of Konenburg, had predicted a very hot and dry summer and autumn, owing to the sun being free from spots and thus giving more light and heat to the earth than usual; and later, Dr. Thomas Dick, the author of several widely-read books on popular astronomy, contended for the same notion.

It seems to have occurred to Sir William Herschel to put the prevailing ideas regarding the influence of sun-spots upon the weather to the test of actual observation and comparison; but as no weather records of anything like precision could be found extending far enough back, he took the price of wheat as a fair index of the seasons, and by comparing the average price of the cereal during a certain period with the number of spots visible on the sun's surface during the same period, endeavoured to settle the point. Here is his table:—

From 1650 to 1670—one or two spots,	-	Wheat—50s.	per qr.
,, 1676 to 1684—no spots,	- - -	,, 48s.	,,
,, 1685 to 1691—spots,	- - -	,, 37s.	,,
,, 1691 to 1694—spots,	- - -	,, 32s.	,,
,, 1695 to 1700—no spots,	- - -	,, 63s.	,,
,, 1710 to 1713—two spots,	- - -	,, 57s.	,,
,, 1714 to 1717—spots,	- - -	,, 47s.	,,

These statistics favour the notion that numerous spots are accompanied by good seasons. Subsequent years, however, failed to confirm the conclusion. In 1826 the spots were extremely numerous, but the harvest so late and poor that the prices of all kinds of grain became more than doubled. In 1836 and 1837 again the spots were plentiful, but the seasons cold and the harvests wretched. I mention these facts because I think that they indicate a reason why Herschel's investigation was not more ardently followed up by other philosophers, nor similar researches instituted. The comparison and its results are frequently quoted, but the table seems generally to be regarded rather as an example of an odd coincidence than as affording proof of the terrestrial influence of sun-spots.

Whatever Herschel may have thought of his curious table, he was fully convinced of the intimate relation between the state of the sun and the weather. "We are not only in possession of photometers and thermometers," he says, "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 might not exceed that 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."[1]

43. THE CYCLE.—A connection between sun-spots and the weather being supposed to exist, it was only natural, upon the periodical variation of the former being discovered, that an attempt should be made to trace a corresponding variation in the weather. The sun-spot cycle being eleven years, the cycle to be sought in the atmospheric phenomena must be eleven years also. And thus arose that extraordinary branch of investigation called physical, or solar, or sun-spot meteorology.

One of the earliest to take up the inquiry was Professor Wolf, whose researches regarding the sun-spot period we have already had occasion to mention. That indefatigable man compiled a record of the state of the weather since the year 1000, and deduced from it a general confirmation of Herschel's opinion—that the years of many sun-spots are drier and more fruitful than those of few sun-spots. It does not appear that Wolf was very enthusiastic over the result of his investigation. Some of his successors, however, have fully made up for his want of ardour.

Several years ago the columns of *Nature* contained a very remarkable article on "The Meteorology of the Future." The author was Mr. J. Norman Lockyer. That paper has since been incorporated in Mr. Lockyer's work on "Solar Physics," and also referred to in an article in the *Nineteenth Century* (by Mr. Lockyer himself) as having contributed very materially to the progress of sunspottery; from which circumstances we are led to infer that the views put forward in it are the author's matured convictions, and not merely words penned in the heat of momentary enthusiasm. This explanation is necessary, the article is so remarkable. Here are the opening sentences:—"It would be a curious inquiry, which we commend to those learned in statistics, to determine how many millions of observations have been made in the British Isle on dry and wet bulb thermometers, on barometers, and on other meteorological instruments. It would be a still more curious inquiry, and seeing that the infinite industry displayed in these observations shows that the importance of the study of meteorology is universally

[1] *Philosophical Transactions*, 1801.

conceded, to determine why it is that meteorologists, State-endowed and otherwise, have as a rule been content to grope their way in the dark, and not only not seek to find, but persistently refuse the clue which, if followed, would bring them into the light of day." In the ensuing paragraph the clue which is to lead benighted meteorologists to the broad light of truth—which is to do for meteorology what gravity has done for astronomy, and evolution for biology—is generously offered for acceptance—it is a cycle! "Surely in meteorology, as in astronomy, the thing to hunt down is a cycle, and if that is not to be found in the temperate zone then go to the frigid zone or the torrid zone to look for it, and if found, then above all things, and in whatever manner, lay hold of it, study it, record it, and see what it means." Now, these words are at once historical and prophetic. The unfortunate thing to which they refer has been hunted over the wide face of the globe. Mr. Lockyer has himself joined in the chase. It has been caught; it has been laid hold of; it has been studied; it has been examined; it has undergone all manner of rough usage; but alas! the obstinate creature refuses to tell us "what it means." So meteorologists are still in the dark. Could not Mr. Lockyer use his persuasive powers to induce this thing to enlighten us?

44. Phases of the Cycle.—The phases assumed by the cycle in order to elude man's search are very numerous. The persevering hunt just alluded to has discovered it lurking in the following phenomena, together with others to be mentioned later:—Magnetic storms and disturbances; auroræ; hot and cold seasons; storms and gales; wet and dry seasons; thunder and hail storms; the volume of rivers; and the depth of lakes. The two last are, of course, merely effects of the rainfall cycle. We shall now briefly notice each of these in turn.[1]

45. Magnetic Declination.—It is very commonly supposed that the compass needle points due north and south. In reality it does not do so. In one part of the earth it points many degrees west of north, and in another part as many degrees east of north. Further, its direction is ever changing.[2] Even in the course of a

[1] An exhaustive treatment of this part of our subject is quite impossible, both on account of the space it would require, and because it would not be suitable for the general reader. But the foundations of sunspottery are so wretchedly shaky that we can afford to leave the superstructure to its inevitable fate.

[2] In London just now the needle points about 16 degrees west of north, but in 1580, it is found, it was pointing east of north. About 80 years after that it indicated the true north, and 150 years later still it had worked round to nearly 25 degrees west of north. Since then it has been gradually drawing towards the north again. This variation, termed the *secular* variation, is doubtless periodic, but the exact length of the period cannot yet be determined. There is another variation. The needle approaches the north from the time of the spring equinox, when it is farthest from it, until the summer solstice, when it reaches its nearest point to it, and then steadily recedes again. This is the *annual* variation. The diurnal movement referred to in the text also shows an annual change, the range in middle latitudes being greater in summer than in winter. Besides all these, there are the erratic oscillations which occasionally take place, called magnetic storms. We shall have something to say about these later on.

day it moves appreciably. About sunrise the north end of the needle moves slowly westward; shortly after noon it turns and begins to go back; and by ten o'clock at night it has regained its original position, in which it remains until sunrise next morning. This movement is known as the *diurnal declination* of the needle. The *amount* of it varies, however. Sometimes the needle makes much longer excursions than usual, and sometimes shorter ones. The extent of its movement then is called its *range*, and the phenomenon is generally referred to as the "diurnal declination range."

Now, so long ago as 1850, Lamont, of Munich, pointed out the fact that the average extent of this diurnal range undergoes a regular increase and decrease every $10\frac{1}{3}$ years. The observations at his disposal were not very complete, but such as they were they indicated some period of about that length. Two years later, immediately upon the publication of Schwabe's discovery of a sun-spot period, Sir Edward Sabine in England, Professor Wolf in Switzerland, and M. Gautier in France, independently announced that they had found a coincidence between the variation in the daily magnetic range and the number of sun-spots. Since then observers too numerous to mention have added their testimony to the truth of the discovery.

There are a few sceptics (M. Faye for one) who contend that, the mean period traceable in the magnetic ranges not agreeing *exactly* with the mean sun-spot period, the conclusion that there is a connection between them cannot hold, for in the course of time the relation in which they now stand to one another must be precisely reversed. It is perhaps premature to deduce any mean period at all, since the really reliable observations do not extend very far back. The method of plotting out the numbers in the form of curves, and comparing them, is much more satisfactory. And the results of this, in the case we are dealing with, show pretty conclusively that the alleged connection does exist. The curve representing the magnetic declination range coincides very closely with that representing the number of sun-spots, the maximum range occurring about the time of maximum spots. Mark the *about*, for Professor Balfour Stewart has detected a lagging behind of the magnetic maxima, the important significance of which will be seen directly.

46. Magnetic Storms.—The simultaneous agitation of needles in widely separated regions of the globe is called a magnetic storm. Sometimes the disturbance is violent and widespread; at other times it is slight and local. Sabine noticed that these disturbances are most numerous when the solar surface is much spotted, and Wolf deduced a period of maximum magnetic disturbance (11·11 years) corresponding exactly with his sun-spot period. Since then Professor Loomis, of America, has discussed 135 cases of magnetic disturbance, and his results confirm the connection thus indicated.

47. Auroræ.—But, as magnetic storms are nearly always accompanied by displays of the aurora in both the northern and southern hemispheres, it follows that the record of such displays should

bear evidence of a periodical variation like the "storms." It does so, as numerous investigations prove. And thus the influence of the sun's condition upon our magnetic phenomena must be regarded as an indisputable fact.[1]

48. MAGNETIC WEATHER.—Though not directly connected with the question under discussion, the new subject of "magnetic weather" must be briefly referred to here. Since we find that solar disturbances almost instantaneously produce magnetic disturbances in the earth, we might reasonably infer that the magnetic action of the sun, whatever its nature, is of very rapid transmission, and must invariably produce its effect very nearly simultaneously with the occurrence of the exciting cause. For a long time this was supposed to be actually the case; but Professor Balfour Stewart has lately brought to light an instance of the contrary. We have already explained what the "diurnal declination range" is. Well, Dr. Stewart has found reason to believe that variations in the extent of the range dependent, he supposes, upon the variations in the power of the sun, do not occur simultaneously over the earth's entire surface, but travel, like weather, from west to east. This magnetic weather, he finds, takes about two days to cross the Atlantic. The inference is obvious. Either the variation in the range is not due to the sun's direct action at all, or that action does not invariably produce an immediate effect, as hitherto supposed. We are thus led to the consideration of a very important point, namely, the *nature* of the sun's magnetic action.

49. NATURE OF THE SUN'S MAGNETIC INFLUENCE.—Unluckily, as is too often the case when we reach a point of real importance, there is not much to be said under this head. Whether the magnetic radiation of the sun (so to call it) is essentially different and distinct from his radiant light and heat, we do not exactly know. The presumption is that his action upon the earth is somewhat akin to the ordinary magnetic induction which takes place between

[1] If more convincing evidence than that afforded by the comparison of sun-spot and magnetic records be wanted, it is to be found, I think, in the simultaneous occurrence of solar outbursts and magnetic disturbances. Events of the kind have been repeatedly observed; but the most striking, and consequently the most frequently quoted, instance was witnessed and described by Messrs. Carrington and Hodgson in 1859. On September 1 both these gentlemen, many miles apart from each other, were making their usual examination of the spots visible on the sun's surface. Suddenly two intensely luminous objects, far brighter than the photosphere, appeared on the edge of a large spot, and began to move over it. They rapidly diminished, and disappeared after being visible for about five minutes. The shape of the objects was something like a crescent moon. They were each about 8000 miles in length, and 2000 miles wide. The distance between them was about 12,000 miles, and they traversed 36,000 miles before disappearing. At the very time this was occurring, a violent magnetic storm took place, and when night closed in one of the most remarkable auroras on record was witnessed. It was seen in southern Europe, the West Indies, South America, Australia, and even in regions situated within 18 degrees of the equator. The disturbance underground was no less remarkable, for Sir John Herschel tells us that the telegraphic apparatus was set fire to. The simultaneous occurrence of two such extraordinary phenomena could not by any possibility be accidental. The reader will find a detailed narrative of this event, chiefly in the words of the observers, in Mr. Proctor's work, *The Sun*, &c.

magnetic bodies when brought into proximity. Leaving that point, however, it cannot be denied that our knowledge of the sun as a great magnet is much more precise than our knowledge of him as our great furnace. As we have already seen, it is not only a matter of dispute whether his heat-giving power is greater or less during the time of many spots, but it is far from certain that his power in this respect undergoes any variation whatever. In the case of his magnetic power, on the contrary, we do know that it varies considerably from time to time, and further, we know that it is greatest when his surface is disturbed.

In favour of this conclusion, we have—

(1) The marked agreement between the sun-spot curve,[1] on the one hand, and the curves of magnetic variation and auroral displays, on the other, the maxima in all three cases very nearly coinciding.

(2) The simultaneous occurrence of magnetic fluctuations and auroral displays with sudden disturbances in the solar envelope.

(3) The prevalence of *metallic* prominences about the times of sun-spot maxima.

Professor Stewart, however, having especial reference to his interesting discovery of travelling magnetic fluctuations, or magnetic weather, contends that the sun does not *directly* influence the earth's magnetism at all. He gets over the second argument quoted above by supposing the earth to be in a magnetically critical state at the time the solar disturbance takes place, that disturbance serving to upset the deranged magnetic system altogether. This, it will be observed, is merely the idea underlying his planetary theory of sun-spots over again. We cannot pause to enter into the arguments for and against the direct magnetic action of the sun, but must be satisfied with the safe conclusion, that the sun for the most part controls (directly or indirectly) the variations in the magnetic elements of the earth, and that disturbances indicated by spots, &c., on his surface, produce corresponding disturbances in the earth's magnetic state. So much, at least, is certain.[2]

Before passing on to notice the attempts that have been made to trace the effects of varying solar radiation in atmospheric

[1] See p. 41.

[2] Sabine fancied a sympathetic magnetic action to exist throughout the whole solar system, so that when the sun becomes magnetically disturbed all his family of planets follow suit. In accordance with this view, it was suggested that the coloured prominences which are known to surround the sun's disc, and which are most numerous when spots are plentiful, might be simply solar auroras, the result of great magnetic disturbance. Recent discoveries regarding the nature of the prominences show this opinion to be untenable; but Mr. Procter has proposed a similar explanation of the corona and zodiacal light. Hitherto it has not been possible to study the corona except during the few moments of totality in a solar eclipse, and so we do not know positively whether it undergoes any changes in extent and brilliance corresponding to the state of the sun's surface. But the discovery of Dr. Huggins, before referred to, may be expected to throw important light upon the point. In connection with the subject of solar-planetary sympathy, it is noteworthy that Dr. Lohse has found the curious red spot on Jupiter to make its appearance regularly about the time that the sun becomes spotty.

phenomena, we would here point out how essentially different magnetic and atmospheric disturbances really are, and how unreasonable it has been to expect (as many of our cyclical meteorologists have done) that because the eleven-year cycle proved traceable in the one, it ought to be traceable in the other also. Everybody is familiar with the extreme sensitiveness of the compass needle. Everybody knows how that needle, in some form or another, is now used for many of the most delicate purposes, for making the most minute measurements, for detecting the most imperceptible variations. And yet, merely because *it* shows signs of being influenced by the state of the sun, meteorologists, who ought of all men to have known better, have perseveringly and hopefully sought to find like indications of solar influence in the ponderous and slowly evolved phenomena of our atmosphere! As well expect a beam of light, sensible only to the eye, to communicate its ethereal vibrations to the air, and so become perceptible to the ear, as think that a solar disturbance, detectable by the magnetic needle, should affect the thermometer and barometer. Had this distinction been fully borne in mind, we would have been spared the science of sunspottery.

50. Temperature.—The idea of a connection between the number of sun-spots and temperature was very early held, as we have seen.[1] Previous to the time of Sir William Herschel, it was supposed that the spots tended to diminish the sun's heating power, and that years of many spots were cold years on the earth. After the publication of Herschel's curious table, already quoted, the opposite opinion came to be held. At the present day, since more precise methods of investigation have been applied, it is found that the variation either way, if it exist at all, is hardly appreciable. Sunspotters are not pleased with this branch of their subject, for it has sadly disappointed their expectations. In one or two popular expositions of the science, which were otherwise fairly exhaustive, I have found this little point passed over in silence. Let us see what the evidence in the matter is like.

Herschel found wheat to be cheaper in years of numerous spots than in those of few, and hence inferred the former years to be warmer.

Wolf, upon examination of the weather records from the year 1000 to 1800, as preserved in the *Zurich Chronicle*, confirmed Herschel's results.

Mr. J. Chambers, of Bombay, has quite lately come to the same conclusion from the study of barometrical observations made in Asia between 1848 and 1876.

General scientific opinion since the beginning of the seventeenth century has favoured the notion of the temperature being highest when the sun is least spotted.

Gautier, of Geneva, found the mean temperature, at Paris, of

[1] See p. 38.

years of few spots to exceed that of years of many spots by 0° 64. The difference at Geneva in the same direction was 0° 33.

Arago compared the price of wheat at Paris with the number of sun-spots, and found it to be dearer in years of maximum spots. His temperature researches confirmed the results previously obtained by Gautier.

Professor Piazzi Smyth, in 1870, discussed 32 years' observations of earth-temperature made by means of four thermometers sunk in the rock at Calton Hill, Edinburgh, and discovered a marked eleven-year periodicity. The temperature maxima occurred about two years behind the sun-spot minima.

Mr. E. J. Stone examined the temperature observations recorded at the Cape of Good Hope, extending over thirty years, and found an agreement with the number of sun-spots "too close to be a matter of chance." The temperature maxima coincided with the spot minima.

Dr. Gould, who carried out his research at Buenos Ayres, arrived at a similar result.

Dr. W. Köppen, who went into this question very thoroughly, concluded that, while in the tropics the temperature maximum precedes the sun-spot maximum by about a year, in the temperate zones the temperature maximum follows the sun-spot minimum by about two years.

Finally, Jelinek, after carefully examining all the temperature observations to be found in Germany, failed to discover any trace of sun-spot influence whatever.

These are not by any means all the witnesses that might be quoted, but only enough to show how hopelessly conflicting their testimony is.[1] The conclusion we are led to by it is obvious, namely, that fluctuations of terrestrial temperature *may* be periodical, and that the period may be somewhere about eleven years; that this cycle may coincide with the sun-spot cycle, or may precede it, or follow it; that the cycle may vary locally, and sometimes even be reversed; but that our present evidence does not warrant any *positive* inference in the matter.

51. Atmospheric Pressure.—The pressure of the atmosphere upon the earth's surface is measured, as we all know, by the barometer. Since the changes in that pressure are assumed by meteorologists to be primarily due to the sun, it follows that any change in the sun himself should become apparent in the fluctuations of atmospheric pressure, and thus influence the barometrical readings.

[1] Mr. E. J. Lowe, an observer of whom better things were to be expected, maintains that great frosts occur at intervals of eleven years. He gives a table of frosts in support of his view, but the figures, so far as I can see, do not bear him out. Professor Piazzi Smyth, again, is convinced that hot summers follow an eleven-year cycle too, and he is also able to quote confirmatory evidence. But he has gone further, for in 1872 he predicted that 1880 would be a hot summer, and lived to see his prediction fulfilled (that is, according to his own idea of fulfilment). Such is the practical stage of development to which sunspottery has already attained.

Hitherto the line of investigation here indicated has not been very ardently followed up; but the results so far obtained are fairly encouraging. For instance, in Western Siberia, where the pressure in the winter months is considerably above the average, Mr. Blanford has found that the barometer is exceptionally high during the years of many sun-spots. In the Indo-Malayan region, on the other hand, where the pressure throughout the year is below the average, the barometer is found to be exceptionally low during the same period. Again, Mr. F. Chambers, of Bombay, has compared barometric observations made at St. Helena, Mauritius, Bombay, Madras, Calcutta, Batavia, and Zi-ka-wei, with the sun-spot numbers, and discovered that "the epochs of maximum and minimum barometric pressure lag behind the corresponding epochs of minimum and maximum solar-spotted area at an interval varying from about six months to nearly two and a half years, or at an average interval of about one year and eight months." Lastly, Professor S. A. Hill, of Allahabad, has shown that the annual *range* of mean monthly barometric pressure at Calcutta is slightly greater than usual in the years of minimum sun-spot. Despite the contradictory nature of these results, I think they afford more *genuine* evidence of a variation in solar influence than the more striking ones obtained too often by the mere manipulation of statistics.

52. Cyclones and Storms.—The honour of starting this inquiry belongs to Mr. Charles Meldrum, the director of the observatory at the Mauritius. In 1872 he published a comparison of the number of cyclones which had occurred in the Indian Ocean since 1847, with the state of the sun's surface. Shortly afterwards he issued a more extended comparison, including storms as well as cyclones proper.

From his table (page 47) he inferred (with what degree of justice the reader is left to judge for himself) that the epochs of maximum sun-spots are the epochs of exceptional disturbance in the atmosphere.

M. Poëy independently worked out this subject in the West Indies, and found that the hurricanes there show a similar agreement with the spot period. The typhoons of the Chinese seas, according to Dr. Hahn, exhibit the eleven-year period also.

53. Rainfall.—We now come to the most important of all the meteorological phenomena in which the sun-spot cycle is alleged to have been traced; but the observations and speculations here are so numerous that we need not attempt to notice a tithe of them.[1] Since cyclones are generally accompanied by heavy rain, it naturally occurred to Mr. Meldrum that the years prolific in cyclones should be the rainiest years also. Accordingly, he "attacked the rainfall of the Mauritius, Queensland, and Adelaide,

[1] I have refrained as far as possible from giving tables, partly because they are not suited for general reading, and partly because those relating to sun-spot questions are often rather difficult to understand.

A Comparison of the Yearly number of Cyclones occurring in the Indian Ocean, with the Yearly number of Spots on the Sun.

Character as regards Sun Spots.	Years.	Total Number of Cyclones.	Number of Cyclones in Maximum Periods.
Maximum.................	1847	5	
	1848	8	23
	1849	10	
	1850	8	
	1851	7	
	1852	8	
	1853	8	
	1854	4	
Minimum..	1855	5	
	1856	4	13
	1857	4	
	1858	9	
Maximum.	1859	15	
	1860	13	39
	1861	11	
	1862	10	
	1863	9	
	1864	5	
	1865	7	
Minimum.................	1866	8	
	1867	6	21
	1868	7	
Maximum...............	1869	9	
	1870	11	31
	1871	11	
	1872	13	
	1873	12	

from the sun-spot period point of view, with results which are simply startling." So says Mr. Lockyer. The mode of attack that was adopted is only too truly described, for it is to be feared that Mr. Meldrum had the eleven-year cycle in his mind's eye throughout the inquiry; and the result must have been startling indeed both to Mr. Meldrum and Mr. Lockyer, seeing that it failed to afford convincing evidence of the eagerly sought period. As it was, however, Mr. Meldrum opened up a discussion which has been fruitful in words and figures, if not in practical results.

Without referring in detail to the various papers of Mr. Meldrum, nor to the independent researches of Mr. Lockyer, Dr. W. W. Hunter, Mr. J. H. Henessey, Dr. J. A. Broun, Professor John Brocklesby, Professor Wolf, Mr. Dawson, Dr. Draper, Mr. Hill, Dr. F. G. Hahn, Professor Douglas Archibald, Mr. Blanford, and others, we shall quote one or two representative pieces of evidence, and let the reader form his own opinion of how much the cycle theory of rainfall is worth.

In 1878, Mr. Meldrum said :—" From an examination of *all* the results, I some time ago came to the conclusion that the evidence of a connection between sun-spots and rainfall was nearly, if not fully, as strong as the evidence of a connection between sun-spots and terrestrial magnetism."[1] After such an assertion, we may fairly take Mr. Meldrum's own statement of the evidence as the most favourable possible. In his " report," then, submitted to the British Association in 1878,[2] he discusses rainfall observations made in Great Britain, Europe, America, India, South Africa, and Australia, and, by a comparison of his rainfall tables with the record of sun-spots, finds, (1) that between 1823 and 1834 (inclusive) " the rainfall reaches its maximum about two years before the year of maximum sun-spots, and its minimum at the time of minimum sun-spots." " There is apparently," he says, " a tendency to a double oscillation in the rainfall ;" (2) that between 1833 and 1844 " the rain increases from the first to the third year of the cycle; but in the fourth decreases, rising again till the eighth year, and then falling to the tenth. This indicates a double oscillation." [As a matter of fact, the maximum rainfall coincides in quite a remarkable manner with the minimum sun-spots in the ninth year, and the minimum rainfall with the maximum sun-spots in the fourth year of the cycle]; (3) that between 1843 and 1857 " The maximum rainfall occurs about one year before the year of maximum sun-spots, and the minimum rainfall in the year of minimum sun-spots at the beginning and end of the cycle;" and (4) that between 1855 and 1867 " the years of maximum and minimum rainfall coincide with the years of maximum and minimum sun-

[1] *Mauritius Mercantile Record*, Feb. 5, 1878.

[2] The paper is printed in full in the Forty-Eighth Annual Report of the British Association, pp. 230-258.

spots, except in the eleventh year of the cycle, and there is little or no appearance of a double oscillation." These results, to the ordinary mind, look somewhat contradictory. But Mr. Meldrum, who is able to read between the lines, is quite satisfied. He admits, in summing up his paper, that there are some discrepancies ; but they are of no moment.

On the other side, we have Dr. Carl Jelinek's elaborate research. He examined the rainfall observations made in Europe, Asia, Africa, and America, from 1833 to 1867, and found fifty-one cases in favour of the hypothesis of sun-spot influence and fifty cases against it.[1]

Mr. Symons has tabulated the British rainfall of the past 140 years, and failed to discover the cycle.[2]

Mr. G. M. Whipple, superintendent of the Kew Observatory, early in 1880, published the results of an exhaustive inquiry into this subject. He obtained rainfall records from Paris for 161 years ; from Padua for 154 years ; England, 140 years ; Milan, 115 ; London, 66 ; Madras, 65 ; Philadelphia, 58 ; Edinburgh, 57 ; New Bedford, 54 ; and Rome, 54. Altogether, he used 978 years' observations. The result is thus stated : "In no one case is there any indication of a period of any integral number of years from 5 to 13 inclusive. Hence, whatever period of variation in rainfall there may be, coincident with fluctuations in the spotted surface of the sun, either of 10, 11, or 12 years, this method of treatment shows it to be completely masked (in a long series of observations) by other variations." [3]

Finally, General Strachey critically examined, not only the results obtained, but the *method* pursued by Mr. Meldrum and others, and found that the observations quoted by them no more indicated an eleven year cycle than a cycle of any other number of years, and that, in fact, he could make the same figures prove the existence of several cycles of different lengths.[4]

The balance of evidence, then, is *not* in favour of the rainfall cycle.

54. Volume of Rivers.—The height of most rivers being directly dependent upon the rainfall, a search for the sun-spot period in their rise and fall necessarily followed Mr. Meldrum's "discovery." So in 1873 Gustav Wex examined the recorded heights of the Elbe, Rhine, Oder, Danube, and Vistula between 1800 and 1867. He arrived at the conclusion that all five rivers are fuller in years of maximum sun-spots. Fritz subsequently submitted the Elbe and Seine to examination, and confirmed Wex's conclusion. Later still, Professor Balfour Stewart has found that the Nile affords similar evidence. The law deduced is a little curious, however, for while a maximum of river height coincides with the maximum

[1] *Zeitschrift für Meteorologie*, March 15, 1873.

[2] *Nature*, vol. vii., pp. 143-145.

[3] *Proceedings* of the Royal Society, vol. xxx., p. 71.

[4] Ibid., vol. xxvi., p. 249.

of sun-spots, another subsidiary *maximum* occurs in the rivers about the time of *minimum* sun-spots. Whence this maximum at a time when the rainfall ought to be at its minimum ?

55. Depth of Lakes.—Mr. G. M. Dawson, geologist to the British North American Boundary Commission, compared the fluctuations of the great North American lakes with the sun-spot records, and discovered a correspondence by no means absolute, but "sufficiently close to open a new field of inquiry." That was in 1874; but, so far as I know, the field has not been entered upon by any one else.

56. Conclusion.—We have now briefly touched upon the chief of those meteorological elements which are supposed to exhibit the sun-spot cycle.[1] The conclusion we are led to may be stated in one or two words. There *may* be an eleven-year period in many meteorological phenomena, and that period *may* be induced by the state of the sun; but, so far, the evidence is utterly unsatisfactory, and it is quite unjustifiable to draw any inferences from, or base any conclusions upon, the existence of such a period.

As we shall see in our next section, this is exactly what statisticians have done.

IV.—THE CYCLE IN CHRONOLOGY.

57. Preliminary Remarks.—Statisticians have undergone not a little ridicule on account of their well-meant attempts to discover the sun-spot cycle in the chronology of human calamities. But, if their inquiries have seemed a little absurd sometimes, it is not really they who are to blame. Agricultural produce is at once the support of existence and the foundation of all human wealth, and that produce being directly dependent upon the character of the seasons, any periodical change in the seasons must affect it,

[1] The unexpected length to which this brochure is running compels me to leave out some of the points which I originally intended to discuss in detail. M. Cruls has very recently announced that the number of thunder storms at Rio de Janeiro shows a marked agreement with the number of solar spots, the storms varying between 49 and 11 in years of maximum and minimum spots respectively. The observations used extend over 25 years. A similar investigation at Toronto is said to confirm the result. Long ago, Wolf fancied that he could trace the eleven-year cycle in the frequency of hailstorms. One of the latest and most curious developments, however, of the sun-spot craze is the attempt, made in sober earnest, I believe, to find the cycle in the recurrence of earthquakes and volcanic eruptions. Perhaps Sir John Herschel's words, which close the quotation prefixed to these remarks, set Mr. A. H. Swinton on the track. If so, Herschel had little idea that his random suggestion would lead to the world's getting a "wrinkle" in the important matter of foreseeing and averting earthquakes. How the thing is to be done has not yet transpired, as Mr. Swinton's book is not, so far as I am aware, published yet. When the next earthquake has been duly foretold, and rendered harmless, we may, perhaps, believe that there is something in this.

and through it mankind. Now, a good many meteorologists have taken upon themselves to assert, positively, that the seasons do undergo a cyclical change corresponding in length to the sun-spot period, and what more natural than that statisticians, who have not, and cannot be expected to have, a critical knowledge of meteorology, should take them at their word, and endeavour to follow up the inquiry in its statistical development? That the assumption is unwarranted does not affect the matter. The persons who lent their authority to it are in fault, not those who unsuspectingly adopted it on what they fancied to be good authority.

It is a little unfortunate in the interests of truth that most of the statistical investigations have been conducted, like Mr. Meldrum's rainfall inquiry, "from the sun-spot-period point of view." One cannot help thinking that in researches of this nature, where the slightest possible balance of evidence one way or another is taken as decisive, the result is apt to be influenced by the investigator's preconceived notions. At all events, it is a remarkable fact that the same sets of figures can be used by different persons to bear out opposite conclusions. This being so, it makes us inclined to be sceptical regarding the results deduced from statistics, even when supported by strong evidence. In no instance can the evidence in favour of the eleven-year cycle in chronology be called strong. On the contrary, it is extremely weak. We have no hesitation, therefore, considering the bias of the inquirers and the equivocal character, at best, of statistical evidence, in setting aside the results obtained as unworthy of a moment's credence. Bearing in mind, further, the more than doubtful nature of the assumption upon which the whole theory rests, we find that there is neither *à priori* nor actual ground for one putting the slightest faith in it.

We shall now notice the principal occurrences in which the cycle has been traced. In no case can we attempt to discuss the points raised, for to do so would require a volume.

58. FAMINES.—The rainfall being assumed to be directly regulated by the intermittent activity of the sun, it was natural to infer that those conditions which arise from a superabundant or scant water supply should exhibit a corresponding periodicity. First among such conditions is famine or scarcity of food, and first among countries to be affected in that way is India: hence the famine records of India were at once searched for traces of the eleven-year cycle; and of course the traces were found. Dr. W. W. Hunter, in 1876, devoted some time to this investigation, and succeeded in convincing himself that the cycle does exist, and that "the subject merits the earnest attention both of men of science and of those who have to deal with the great problem of Indian administration." Dr. Hunter confined his research to Southern India, where, it appears, famines are generally associated with periods of drought. Assuming a scant rainfall to be coincident with a minimum number of sun-spots, he came to the conclusion that famines occur, and may always be expected to occur, about the year of minimum sun-spots. Mr. H. F. Blanford,

of Calcutta, went to the trouble of putting the law thus formulated to the test, and he discovered that, as a matter of fact, not a few of the worst famines on record have occurred about the years of *maximum* sun-spots. He pointed out, further, that scarcity is frequently caused by excess of rain as well as deficiency, so that the law of famine recurrence, if there be any law at all, cannot be the simple one deduced by Dr. Hunter.

In 1880, Mr. F. Chambers, Meteorological Reporter for Western India, discussed the subject, and brought to light something new. We have already referred to his discovery that epochs of unusually high barometric pressure follow the epochs of minimum spots. By comparing the famines with these epochs he detected a correspondence, the famines being "generally accompanied or immediately preceded by waves of high barometric pressure."

Of course, the practical end of all this, and the end doubtless kept in view by the investigators themselves, is to be able to foresee the approach of famine-producing conditions, and take precautions to avert their effects. To judge from what has been written on the subject by Dr. Hunter and others, one might suppose that the end, if not already attained, is quite clearly attainable. It is to be feared, however, that it is nothing of the kind. Even supposing it to be demonstrated that a famine-cycle exists (which has not been done), and that the cycle stands in some simple relation to that of the sun-spots (which of a certainty it does not), we would be no nearer the possession of a useful foreknowledge than ever, for the sun-spots wax and wane in number at most irregular intervals, and it is quite impossible, from the appearance of the sun's disc at any one time, to predict within several years when a maximum or minimum will occur. Then as for Mr. Chambers's discovery, it is quite plain that since (by his own showing) the wave of high barometric pressure follows the critical epoch in solar energy "at an interval varying from above six months to nearly two and a half years," while the famine requires a similarly erratic lapse of time before making its appearance, the knowledge is absolutely useless for predictive purposes, unless, indeed, we are prepared to allow a margin of five years in every case for possible error. Everything considered, we are forced to conclude that the attempt to prove the existence of a famine-cycle has lamentably failed. Mr. Cornelius Walford's inquiry [1] is by far the most exhaustive one ever made, and not the slightest trace of the eleven-year cycle was disclosed by it.

59. Pestilence and Disease.—Famine is so frequently accompanied by the outbreak of epidemic disease that the step from the famine cycle to a pestilential one is very short and very inviting. Who first took it I do not know; nor have I been able to find what sort of arguments are advanced in support of it. But, out of curiosity, I jotted down some of the years in which the most widespread epidemics are recorded to have occurred, and the result is an average period of about eleven years. Here are

[1] *Famines of the World: Past and Present.* London, 1879.

the dates: 1593, 1603, 1613, 1625, 1636, 1646, 1658, 1669, 1679, 1690, 1700, 1710-11, 1722, 1733, 1745, 1756, 1766-7, 1778, 1789, and 1800. To a sunspotter these figures would seem pregnant with truth, and he would at once conclude that pestilences are in some mysterious way associated with sun-spot minima. As it happens, however, the writer looked at the statistics of plagues "from the sun-spot-period point of view," and the result arrived at is only interesting in so far that it shows what a wonderful effect a bias can have upon a statistical investigation of the kind.

The following quotation is taken from a lecture by Prof. Balfour Stewart: "There is a curious point of interest in connection with the disease that took place about three centuries since, of a periodical and very violent character, called the 'sweating sickness.' That disease took place about the end of the fifteenth and the beginning of the sixteenth century. It took place in the following years—1485, 1506, 1517, 1528, and 1551, about a period of eleven years intervening between the outbreaks. Now this is exactly the sun-spot period. Can we tell what the state of the sun was during the outbreaks of this sweating sickness? . . . . Turning to our old records, we find certain displays of the aurora mentioned, and they give a good idea of what must have been the years of maximum sun-spots in those times, and curiously enough these are by no means far from the years of the outbreak of the sweating sickness. There is only a difference of about a year and a half on the whole, and the difference always seems to lie in the same direction. Consequently we are pretty certain that, at any rate, the outbreaks of this sweating sickness took place much nearer the time of maximum than the time of minimum sun-spots."

Asiatic cholera is another example of a sun-spot-induced epidemy. According to a recent medical authority, the disease makes its appearance every fifteen years, this period obviously depending upon that of the sun-spots, being just one and a half times as long![1]

"One of the best known vegetable epidemics is that of the potato disease. The years 1846, 1860, and 1872 were bad years for the potato disease. Now those years are not very far from the years of maximum sun-spots. . . . . . Here, then, we have at any rate a suspicion of some curious connection between these diseases affecting plants and the state of the sun."[2] A "suspicion" truly. If we are to rest scientific principles upon

[1] The periodicity of epidemic visitations is an old idea. Sydenham, for instance, states that the plague visits England every 40 years. According to Jackson, it visits Morocco every 20 years. From other writers we learn that it appears in Egypt at interval of seven years, and at Aleppo every ten years. In Iceland, the small-pox is said to break out every 20 years, and in the north of Persia the same disease appears at intervals of from six to ten years. Finally, Humboldt observed a periodicity of 17 or 18 years in the recurrence of yellow fever in South America, while Howe contends that all epidemic visitations follow a cycle of 18½ years. Thus the sun-spot period is not the *only* pestilential cycle.

[2] Professor Balfour Stewart.

three coincidences—and not by any means close coincidences either—truth will soon become somewhat mixed.

It may just be mentioned here that Dr. T. Moffat, at a meeting of the British Association a few years ago, discussed observations which showed that in years of maximum spots the quantity of ozone present in the atmosphere is greater than usual. The important influence of ozone upon health is sufficiently well known, and a curious inquiry is thus suggested.

60. Locust Visitations.—Plagues of locusts are so often associated in history with drought, famine, and pestilence, that the notion of finding the sun-spot cycle in their recurrence is not so very far-fetched as at first sight may seem. Dr. F. G. Hahn started the investigation, and subsequently Prof. Douglas Archibald, with the assistance of Mr. Walford's table in the *Famines of the World*, showed that there is "an apparent predilection on the part of locusts to swarm during the minimum epoch of sun-spots." Facts give some colour of plausibility to this conclusion, besides which it is advocated by one of the most enlightened, and consequently most moderate of the upholders of sunspottery (I mean Prof. Archibald); but until the circumstance of a rough periodicity can be proved *not* to be due to a mere natural cycle of incubation, it is premature to ascribe it to sun-spot influence.

Mr. A. H. Swinton fancies that the appearance of rare *Lepidoptera* in England is connected with the state of the sun. He has published a table to prove his point, but it is not very convincing.

61. Financial Panics.—When Prof. Roscoe, in a popular lecture at Manchester, enunciated Prof. Stanley Jevons's theory of a commercial panic cycle, the audience received it with "laughter" and "renewed laughter." This expression of amusement was rather hard upon Prof. Jevons, and must have been somewhat trying to his exponent, but it served them both right for introducing such a subject into a course of "Science Lectures for the People." "The people" doubtless know little enough about science, and have great need of science lectures to improve them; yet they are not sufficiently ignorant to mistake a wild hypothesis for sober truth, even when backed up by the authority of so eminent a man as Prof. Roscoe. The theory that struck the Manchester audience as being so funny was simply this: that commercial crises occur periodically, the interval between them being the same as in the case of sun-spot maxima, or 10·46 years. It is not now worth our while to enter into the various arguments advanced by Prof. Jevons, nor to notice in detail the little devices which he resorted to when met by a difficulty. Any one who wants to see the theory taken to bits should read Mr. Proctor's paper in *Scribner's Magazine* for June, 1880 (reprinted, I think, in *Familiar Science Studies*). The following quotation from an article in the *Times*, by the same writer, says all that really needs to be said. (The words in brackets are Mr. Proctor's later emendations.)

"Taking $5\frac{1}{2}$ years as the average interval between the maximum and minimum sun-spot frequency, we should like to find every crisis occurring within a year or so on either side of the minimum; though we should prefer, perhaps, to find the crisis always following the time of fewest sun-spots, as this would more directly show the depressing effect of a spotless sun. No crisis ought to occur within a year or so of maximum solar disturbance; for that, it should seem, would be fatal to the suggested theory. Taking the commercial crises in order, and comparing them with the (approximately) known epochs of maximum and minimum spot frequency, we obtain the following results (we italicize numbers or results unfavourable to the theory):—The doubtful [I ought to have written assumed] crisis of 1701 followed a spot minimum by *three* years; the crisis (imagined) of 1711 preceded a minimum by one year; that of 1721 preceded a minimum by *two* years; 1731-32 ('imagined crisis') preceded a minimum by one year; 1742 ('no crisis known') preceded a minimum by *three* years; 1752 (no crisis) followed a maximum by *two* years; 1763 followed a maximum by *a year and a half;* 1772-73 came *midway* between a maximum and a minimum; 1783 preceded a minimum by *nearly two* years; 1793 came *nearly midway* between a maximum and a minimum; 1804-5 ('no known crisis') *coincided* with a maximum; 1815 preceded a maximum by *two* years; 1825 followed a minimum by *two* years; 1836-39 *included* the year 1837 of maximum solar activity (that being the year, also, when a commercial panic occurred in the United States) [1857 preceded a minimum by one year. This case was, by some inadvertence of mine, omitted from the *Times* article]; 1866 preceded a minimum by one year; and 1878 follows a minimum by a year. Four favourable cases [it should have been five] out of seventeen [it should have been eighteen] can hardly be considered convincing. If we include cases lying within two years of a minimum, the favourable cases mount up to seven [eight], leaving ten unfavourable cases."

62. SHIPWRECKS.—Mr. Henry Jeula, believing in Mr. Meldrum's alleged discovery of a cyclone cycle, set himself to look for a similar period in the occurrence of maritime casualties, which are obviously dependent upon the former. He carefully examined the losses posted on Lloyd's loss-book from 1855 to 1876 inclusive, and found very faint traces of periodicity. Arranging his figures into groups so as to give this bashful cycle every chance of asserting itself, he sent the result to Dr. Hunter. That indefatigable truth-seeker calmly added sun-spot numbers *relating to an altogether different period*, and lo! the connection between sun-spots and shipwrecks was established. We need not trouble ourselves to discuss a relation so clearly manufactured. When an eleven years' cycle is deduced from twenty-two years' observations; when that cycle is so undefined as to be perceptible and no more; when the most elaborate manipulation is required to make it perceptible at all; and lastly, when the contemporaneous record of solar maculation is deliberately set aside, and a more convenient one for comparison

taken instead, we may surely with justice refuse to put faith in the conclusion so arrived at.

We have now noticed, very briefly, the chief directions in which the attempt has been made to trace the sun-spot cycle in history. We might have referred to Dr. Schuster's investigation into the quality of the vintage, rewarded by the inevitable "startling discovery," or to other hare-brained inquiries; but, really, to discuss in a serious way every speculation that any man chooses to indulge in is hardly profitable.

CONCLUSION.

At the outset of this inquiry, I stated the problem, of which sunspottery professes to be the solution. The facts we have just discussed show that sunspottery is not the true solution of it, nor, indeed, any solution at all. That the sun's activity waxes and wanes periodically, that his radiation undergoes a corresponding variation, that our meteorological conditions which depend upon the solar heat fluctuate accordingly, and that those events more or less directly related to the accident of weather exhibit a like change, are each and all assumptions supported only by evidence of the weakest kind; and can we be expected to hang our faith upon a chain of reasoning, every link of which is defective? While refusing, however, to give sunspottery all the credit so loudly claimed for it, I would not contend, as some writers have done, that there is absolutely nothing in it. Could it be proved by direct measurement that the radiant heat of the sun does vary with the degree of spottedness of his surface, then we might reasonably look for some corresponding change in atmospheric phenomena, especially in those localities where disturbing influences of a local character are least potent. But then it cannot be proved that the sun's heat does anything of the kind, and so it is altogether premature to set about tracing the effect of a cause the existence of which is only a hypothesis. In some cases it is safe enough to argue from effect to cause; but hardly so in this case; for experience teaches us that meteorological records, and chronological statistics generally, may be used to prove the existence of numberless cycles varying in length from a few days to many years, and we have nothing whatever to indicate to us the superiority of any one of those cycles over another.

We may say, then, that an impartial examination of the evidence available leads to but one conclusion, which is, that sunspottery is *not* what it is represented to be, but is for the most part humbug.

[*Note.*—It was originally intended to discuss here the question of the State endowment of research, which has been so prominently identified with the subject of sunspottery; but other points have taken up so much space that there is not enough left to do the matter anything like justice. I hope to return to it at some future time.]

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