in the green cells of *Vortex viridis.* I hope, however, shortly to figure these cells and the spectrum of their chlorophyll.

I consider that experiment upon the living organism by exposure to sunlight is not only the best, but the only absolutely safe and certain way of recognising any pigment as chlorophyll. And the entire absence of any evolution of gas from *Bonellia*, *Idotea*, and various other green animals (p. 379), disproves, at any rate, the extreme form in which Pringsheim's "screen" theory is sometimes stated, although, as Lankester points out, and as Pringsheim doubtless intends, it is more probable that it should only be applied to true chlorophyll.

H. I have omitted in the body of the paper to call attention to the great importance of consortism in the economy of nature, for, since the Radiolarians, and doubtless also, at least to a large extent, the Foraminifera, are thus chiefly maintained, and since they serve as nutriment directly or indirectly to most of the higher pelagic animals, the apparently disproportionate abundance of animal life in the open sea becomes no longer enigmatical.

2. On the Thermodynamic Acceleration of the Earth's Rotation. By Sir William Thomson.

It has long been known, having been first, I believe, pointed out by Kant, and more recently brought very near to a practical conclusion by Delaunay, that the earth's rotational velocity is diminished by tidal agency, in virtue of the imperfect fluidity of the ocean. An integral effect of all the consumption of energy by fluid friction (or more properly speaking by continued deformation of fluid matter) in the tidal motions, is to cause the time of high water on an average for the whole earth to be not exactly either transit, or 6 o'clock, as it would be were the ocean a perfect fluid, but to be some time after transit, and before 6 o'clock.* Thus we may

* For brevity, I use the word "transit" to denote a time of transit of the tide-generating body (whether sun or moon), or a time of transit of the point of the heavens opposite to the tide-generating body, across the meridian of the place ; and the word 6 "o'clock," to denote the middle instant of the interval of time between consecutive transits. If, to fix the ideas, we first think of the

imagine the average lunar tide for the whole earth to consist of a displacement of the water, presenting protuberances, not exactly towards moon and anti-moon, but in a line inclined at an angle to the line joining moon and anti-moon, in the direction indicated by

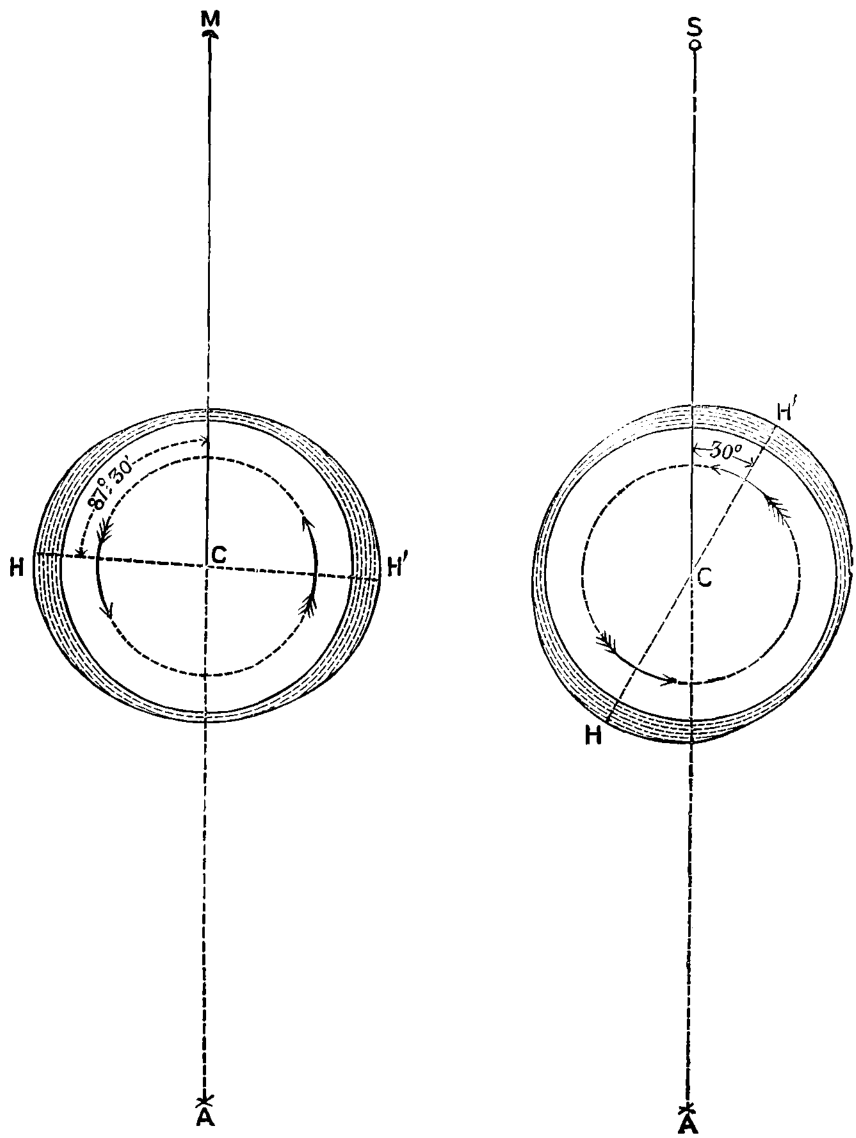

Fig. 1. Fig. 2.

the drawing (fig. 1), in which M, A represent the directions of moon and anti-moon, and H, H′ the crowns of the ideal spheroid, representing the average water-level for the whole earth. The angle HCM is made 87° 30′, which would be actually the case if

lunar tide alone as if there were no solar tide, 6 o'clock will mean 6 lunar hours before or after a lunar transit.

4 o'clock lunar time were the average time of high water for the whole earth. It is obvious that the resultant force of the moon, on the whole mass of the solid and liquid constituting the earth, is not a single force, exerted in the line MC, but that, after the manner of Poinsot, it may be represented by a single force in this line, and a couple in a direction opposite to that of the arrows, indicating in the diagram the direction of the earth's rotation. Thus the lunar attraction produces, as it were, the action of a friction brake resisting the earth's rotation. The same is no doubt also the case in respect to the sun and the water of the ocean.

If HH′ were inclined to the line of the attracting body, on the other side from that shown in the first diagram, the effect of the attraction would be to accelerate the earth's rotation. Now this, which is represented in the second diagram (fig. 2), is found by observation to be actually the case in respect to the sun and (not the waters of the ocean, but) the earth's atmosphere. The accompanying table and formula show the result of the Fourier Harmonic Analysis applied for the diurnal period by Mr. G. H. Simmonds to barometric observations collected from all parts of the world. In the formula, E denotes the excess of the barometric pressure above its mean value for the day, at the time θ reckoned in degrees from midnight, at the rate of 15° per mean solar hour: R_1c_1, R_2c_2, R_3c_3 denote the ranges and angles, corresponding to the times of maximum height, for the first three terms of the Fourier expression which the formula exhibits. The table shows the values of R_1c_1, R_2c_2, R_3c_3, calculated for the different places, from observations at the times stated in column 5.

It is a very remarkable result of this analysis that the amplitude R_2 of the semidiurnal term is for most places, especially those within 40° of the equator, considerably greater than the R_1 of the diurnal term. The cause of the semidiurnal variation of barometric pressure cannot be the gravitational tide-generating influence of the sun, because, if it were, there would be a much larger lunar influence of the same kind, while in reality the lunar barometric tide is insensible or nearly so. It seems therefore certain that the solar diurnal variation of the barometer is due to temperature. Now the *diurnal* term, in the Harmonic Analysis of the variation of

$$E = R_1 . \cos(\theta + c_1) + R_2 . \cos(2\theta + c_2) + R_3 \cos(3\theta + c_3).$$

Extracted from the *Quarterly Journal of the Meteorological Society* for January 1880. "The Diurnal Range of Atmospheric Pressure," by Robert Strachan, F.M.S.

Harmonic Constituents of the Diurnal Variation of Atmospheric Pressure, calculated by G. H. Simmonds, F.M.S.

Name of Place.	Latitude.	Longitude.	Height.	Time of Observation.	Diurnal Constituents.		Semi-diurnal Constituents.		Ter-diurnal Constituents.	
					R_1	c_1	R_2	c_2	R_3	c_3
	° ′	° ′	Feet.		Inches.	°	Inches.	°	Inches.	°
Singapore,	1 27 N	103 49	Small No.	5 Years from 1841 to 1845,	·0210	280·3	·0387	66·0	·0015	333·3
Trevandrum,	8 31 N	77 0	195	5 ,, June 1837 to May 1842,	·0154	290·3	·0424	68·2	·0013	293·1
Madras,	13 4 N	80 14	22	7 ,, 1844 to 1850,	·0234	268·9	·0432	67·6	·0007	270·0
Bombay,	18 53 N	72 48	38	17 ,, 1846 to 1862,	·0198	242·9	·0382	66·4	·0014	286·3
Calcutta,	22 31 N	88 21	18	15 ,, 1855 to 1869,	·0270	250·9	·0394	61·6	·0012	258·5
Simla,	31 6 N	77 12	6953	5·5 ,, June 1841 to December 1846,	·0100	185·7	·0210	48·7	·0015	248·3
Lisbon,	38 43 N	9 8	335	6·9 ,, January 1864 to November 1870,	·0053	246·6	·0176	62·1	·0022	272·4
Pekin,	39 57 N	116 29	101	6 ,, 1850 to 1855,	·0295	270·8	·0217	54·8	·0026	256·0
Washington,	38 54 N	77 3	103	9 ,, 1861 to 1869,	·0168	265·6	·0201	73·8	·0024	172·9
Girard College,	39 58 N	75 11	112	5·1 ,, June 1840 to June 1845,	·0183	266·6	·0179	75·8	·0018	282·1
Toronto,	43 40 N	79 21	342	7 ,, 1841 to 1847,	·0140	242·4	·0127	81·5	·0020	291·7
Tiflis (Awlaba),	41 42 N	44 50	1501	7·3 ,, January 1855 to April 1862,	·0246	288·6	·0142	67·5	·0021	242·3
,, (Kuki),	41 43 N	. .	1343	9·7 ,, May 1862 to December 1871,	·0266	294·3	·0162	70·9	·0018	267·1
Vienna,	48 13 N	16 23	650	7·9 ,, 1849 to 1856 (less one month of April),	·0068	262·4	·0113	59·5	·0012	272·2
Cracow,	50 4 N	19 58	712	7 ,, 1850 to 1856,	·0050	287·5	·0066	42·5	·0016	256·4
Prague,	50 5 N	14 25	351	27 ,, 1842 to 1868,	·0100	271·5	·0086	55·1	·0011	281·8
Brussels,	50 51 N	4 22	190	28 ,, 1842 to 1869,	·0019	268·8	·0095	56·1	·0012	278·7
Greenwich,	51 29 N	. .	159	7 ,, 1841 to 1847,	·0011	133·9	·0104	57·9	·0004	326·6
Oxford,	51 46 N	1 15	212	16 ,, 1855 to 1870,	·0046	312·7	·0096	66·1	·0013	273·3
Nertchinsk,	51 18 N	119 30	2230	19 ,, 1842 to 1845, 1848 to 1855, and 1856 to 1862,	·0126	283·1	·0098	71·1	·0016	236·0
Barnavul,	53 20 N	83 37	400	17 ,, 1842 to 1845, 1850 to 1855, and 1856 to 1862,	·0046	189·2	·0044	72·0	·0011	262·3
Catherinenburg,	56 50 N	60 34	813	18 ,, 1842 to 1845, 1849 to 1855, and 1856 to 1862,	·0036	325·4	·0035	62·8	·0003	212·7
Sitka,	57 9 N	135 18	15	10 ,, 1843 to 1845, 1848, 1850 to 1854, and 1856,	·0028	135·9	·0037	−6·3	·0003	147·3
St Petersburg,	59 57 N	30 28	15	22 ,, 1841 to 1862,	·0014	150·7	·0035	6·2	·0006	206·9
Batavia,	6 11 S	106 50	24	7 ,, 1866 to 1872,	·0239	293·6	·0369	67·3	·0016	281·8
Ascension,	7 55 S	0 58	53	2 ,, September 1863 to August 1865,	·0106	287·4	·0279	66·5	·0004	206·6
St Helena,	15 57 S	5 41	1764	6 ,, 1841 to 1846,	·0071	234·1	·0293	63·4	·0014	348·0
Santiago de Chile,	33 26 S	70 38	1790	2·9 ,, November 1849 to September 1852,	·0065	253·8	·0157	77·2	·0014	105·0
Cape of Good Hope,	33 56 S	18 29	Small No.	5·2 ,, April 1841 to June 1846,	·0047	257·8	·0192	72·0	·0014	281·8
Hobarton,	42 52 S	147 27	105	7 ,, 1841 to 1847,	·0123	317·5	·0197	84·1	·0018	287·6

temperature, is undoubtedly much larger in all, or nearly all, places than the semidiurnal. It is then very remarkable that the *semidiurnal term of the barometric effect of* the variation of temperature should be less, and so much less as it is, than the diurnal. The explanation probably is to be found by considering the oscillations of the atmosphere, as a whole, in the light of the very formulas which Laplace gave in his *Mécanique Céleste* for the ocean, and which he showed to be also applicable to the atmosphere. When thermal influence is substituted for gravitational, in the tide-generating force reckoned for, and when the modes of oscillation corresponding respectively to the diurnal and semidiurnal terms of the thermal influence are investigated, it will probably be found that the period of free oscillation of the former agrees much less nearly with 24 hours than does that of the latter with 12 hours; and that therefore, with comparatively small magnitudes of the tide-generating force, the resulting tide is greater in the semidiurnal term than in the diurnal. Now, if we look to the values of c_2 in the table, we see that, with one exception (Sitka, a place far north, where R_2 is very small), they are all positive acute angles: and we find 61°·3 as the mean of all the 30. If we assign weights to the different values of c_2, according to the corresponding values of R_2, we should find a somewhat larger number for the true mean value of c_2. It is enough for our present purpose to say that the mean is 60° or a little more. Looking now to the formula, we see that the meaning of this is that the times of maximum of the semidiurnal variation R_2 are a little before 10 o'clock in the morning and a little before 10 o'clock at night (exactly at 10 o'clock if c_2 were exactly 60°). Without more of observation, or of observation and theory, than has yet been brought to bear on the subject, we cannot tell the law of variation of R_2 with the latitude. The observations in the table seem to show, what Laplace's Tidal Theory prepares us to expect, that it diminishes more in the Polar regions than it would if it followed the elliptic spheroidal law of proportionality to the square of the cosine of the latitude. We may, however, take by inspection from the table $R_2 = \cos^2 \text{lat} \times {\cdot}032$ inch as a rough estimate of a barometric variation distributed over the whole earth in the form of an elliptic spheroid, which would give the same resisting couple in the calculation of the solar gravitational influence on the disturbed atmosphere; or (getting quit of the intolerable British inch),

$$R_2 = \cos^2 \text{lat} \times {\cdot}08 \text{ cm.}$$

Now the height of the barometer corresponds always to the mass of the air over a given horizontal area of the locality, independently of the temperature of the air; and, in averages for the different places, no doubt independently of the wind also.* Thus for every centimetre of higher or lower mercury in the barometer, there is more or less mass of air over the locality to the extent of 13·596, or say 14 grms. over every square centimetre of horizontal surface. Thus the second diagram with its angle of 30° (corresponding to $c_2 = 60°$) represents the state of things, as regards the quantity of air over different parts in the circle of any parallel of latitude, or at all events of any circle farther from the pole than 60° north or south latitude. It represents the state of things for every parallel of latitude in the imagined elliptic spheroid, constituting the terms we have to deal with in the spherical harmonic expression of the actual effect: and definitively, if we suppose half the excess of the greatest above the least radius of the elliptic spheroid in the diagram to be equal to the square of the sine of the latitude multiplied into ·08 cm., the diagram shows the distribution of a mass of matter of the same density as mercury, over the whole surface of the earth, which would experience the same resultant couple from the sun as does the earth's atmosphere in reality. To evaluate this couple we may use the known formula (*Thomson and Tait's Natural Philosophy*, vol. i. § 539) relative to the mutual attraction between a mass M, not con-

* In strong winds the barometer may stand sensibly above or below the proper value for the weight of the atmosphere over the place, according as the room containing the barometer is more exposed by openings on the windward or on the leeward side of the house in which it is placed. The error due to this cause may be sensible in the diurnal averages for one particular barometer, because of the daily periodic variations in the direction of the wind; but it is not probably large for any well-placed barometer, and, such as it is, it must be fairly well eliminated in the averages for different barometers in variously arranged buildings and in different parts of the world. In passing, it may be remarked, that it is probably not a matter of no importance that the barometer-room of a well-appointed meteorological observatory should be as nearly as may be symmetrically arranged in respect to openings to the external air in different directions, and in respect to shelter against wind from other parts of the building.

centrated in a point, and a portion of matter m, concentrated in a very distant point—

$$L = 3\,m\,\frac{(B-C)\,yz}{(x^2+y^2+z^2)^{\frac{5}{2}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1),$$

where x, y, z denote coordinates of m relatively to rectangular lines OX, OY, OZ coincident with the principal axes of inertia of M through its centre of inertia; B and C the moments of inertia of M round OY and OZ; and L the component round OX, of the couple obtained by transposing, after the manner of Poinsot, the resultant attraction of m, from its actual line through x, y, z, to a parallel line through o, the centre of inertia of M. Suppose now M to be a homogeneous ellipsoid of revolution, having for semi-axes a, b, c, we have

$$B - C = \frac{1}{5}\,M\,(c^2 - b^2)$$
$$= \frac{1}{5}\,M\,(c+b)\,(c-b)\,.$$

Hence for a prolate spheroid of the dimensions stated above, we have

$$B - C = \frac{1}{5}\,Mr\,0{\cdot}32\,. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2),$$

where r denotes the earth's radius in centimetres. To fit the formula (1) to the case represented by the diagram in fig. 2, we have

$$yz = D^2 \sin 30^\circ \cos 30^\circ \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3),$$

where D denotes the sun's distance from the earth. With this and (2), (1) becomes

$$L = \frac{3}{5}\,\frac{mMr\,0{\cdot}32^{\mathrm{cm}} \sin 30^\circ \cos 30^\circ}{D^3} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4),$$

where M denotes the mass of a quantity of mercury equal in bulk to the earth, so that if E denotes the earth's mass $M = 2{\cdot}5$ E. Now $\frac{mE}{D^2}$ is the attraction of the earth on the sun: hence if we call this force F,

$$L = \frac{3}{5} 2{\cdot}5 \frac{r}{D} F . 0{\cdot}32^{cm} . \sin 30^\circ \cos 30^\circ$$

$$= \frac{r}{D} F . \ 0{\cdot}21^{cm} .$$

Now if S denote the number of grammes in the sun's mass, we have

$$F = \frac{r^2}{D^2} S . 980 \text{ dynes} ,$$

since the earth's attraction on a gramme of matter at its surface is about 980 dynes; and so we find

$$L = \frac{r^3}{D^3} S . 980 . 0{\cdot}21 = \frac{r^3}{D^3} S . 207 \quad . \quad . \quad . \quad . \quad (5),$$

Now if $\dot{\omega}$ denote the acceleration of the earth's angular velocity produced by this couple, we have

$$\dot{\omega} = \frac{L}{I} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6),$$

where I denotes the earth's moment of inertia; and, allowing for the increase of the earth's density from the surface inwards, according to Laplace's probable law, we have, approximately,

$$I = \frac{1}{3} r^2 E$$

(instead of $I = \frac{2}{5} r^2 E$, as it would be if the mass were homogeneous), E denoting the earth's mass. Hence

$$\dot{\omega} = 3 \frac{r^3}{D^3} \frac{S}{E} \frac{207}{r^2} .$$

Now $D^3/r^3 = 12{\cdot}3 . 10^{12}$, $S/E = 31{\cdot}9 . 10^4$, $r = 6{\cdot}370 . 10^8$ centimetres which gives $r^2 = 40{\cdot}6 . 10^{16}$. Hence

$$\dot{\omega} = 3 \frac{31{\cdot}9 . 10^4}{11{\cdot}3 . 10^{12}} \frac{207}{40{\cdot}6 . 10^{16}} = 4{\cdot}0 {\cdot} 10^{-23} .$$

This is the rate per second of gain of angular velocity. The earth's angular velocity at present is $\frac{2\pi}{86400}$, or approximately $\frac{1}{13700}$. Calling this ω, we have

$$\frac{\dot{\omega}}{\omega} = 5{\cdot}5 . 10^{-1}$$

for the proportionate gain per second. There are 31·5 million seconds in a year, and 3150 in a century. Hence the ratio to the earth's present angular velocity, of the gain per second, amounts to

$$1{\cdot}73 \times 10^{\;\,9}.$$

To interpret the result, suppose two chronometers, A and B, to be kept going for a century, according to the following conditions :—

Chronometer A to be an absolutely perfect timekeeper, and to be regulated to sidereal time at the beginning of the century, in the usual manner, by astronomical observation.

Chronometer B to be kept constantly regulated to sidereal time by astronomical observations from day to day, and from year to year, during the century.

At the end of the century B will be found to be gaining on A to the amount of $1{\cdot}73 \times 10^{-9}$ of a second per second. This rate of gain has been uniformly acquired ; and, therefore, on the average of the century, B has been going faster than A, at the rate of $\cdot 86 \times 10^{-9}$ of a second per second. Hence, in the whole century (or $3{\cdot}16 \times 10^{9}$ sidereal seconds), B has gained on A to the extent of 2·7 seconds.

In reality a tenfold greater difference, in the opposite direction, would be observed between the two chronometers. Adams, from his correction of Laplace's dynamical investigation of the acceleration of the moon's mean motion, produced by the sun's attraction, found that our supposed chronometer B, regulated to sidereal time, would be 22 seconds behind the perfect chronometer A at the end of a century. (See *Thomson and Tait's Natural Philosophy*, 1st ed., § 830 ; or 2nd ed., vol. i. part 1, § 405.) The retardation of the earth's rotation thus definitively specified, which may be regarded as a well-established result of observation and theory, received from Delaunay what we cannot doubt to be its true explanation,—retardation by tidal friction. The preceding formulas, with the proper change of data, may be readily modified to show the tidal retardation instead of the thermodynamic acceleration. Thus if we go back to fig. 1, and suppose the spheroidal layer to be water, instead of the earth's atmosphere, and take 100 cms. as the excess of the greatest above the least semi-diameter, we have what we may fairly assume to be a not improbable estimate of the equivalent, over the whole earth's surface, to the true tidal deformation of the water of the oceans. If the obliquity HCS were the same in the two cases, and if the sun were the external attracting body in each case, the value of L would be $(50/\cdot08.13\cdot596=)45\cdot9$ times greater in the second case (fig. 1) than in the first case (fig. 2). Suppose now the moon, instead of the sun, to be the influencing body in the second case (fig. 1), other things being the same, the couple will be 91·8 times as great in the second case (fig. 1) as in the first case (fig. 2). (Because the moon's mass, divided by the cube of her distance from the earth, in about double the sun's mass divided by the cube of his distance from the earth.) Now, we must make the couple to be only 10 times as great in the second case (fig. 1) as in the first case (fig. 2) to bring out Adams' result, according to Delaunay's explanation of it. Hence we must suppose, in fig. 1, sin HCM cos HCM to be 1/10 of sin 30° cos 30°; and we may fulfil this condition by taking HCM = 87° 30′.

Thus with the approximate results of observation used above in respect to the earth's atmosphere, and the assumptions we have now made regarding the lunar tide, we have a state of things in which our supposed chronometer B gains on A 2·5 seconds in the course of the century through the thermodynamic acceleration, and loses 25 seconds through the tidal retardation; that is, loses in all 22·5 seconds, or say 22 seconds, which is Adams' result.

3. Notes on a Cist discovered at Parkhill, Dyce, Aberdeenshire, in October 1881. By William Ferguson of Kinmundy. With Notes on the Bones by Dr. Fife Jamieson, M.B.

The station of Parkhill, on the Great North of Scotland Railway, is seven and a half miles from Aberdeen, and the cist which is the subject of these notes was situated in a mound of gravel and sand to the north-east of, and within one or two hundred yards of, the station. This is the second which has been uncovered at the same spot,—a previous one having been disclosed in 1867, the contents of which—a vase and some bones—are preserved in the Anatomical Museum, Marischal College, University of Aberdeen.