equal development with the lateral lobes lead to the inference that this central part is present from the earliest period, and that the thyroid isthmus is not formed by a growing together of two distinct sidepieces. In examining the thyroid in fœtal dogs, cats, and hares, I have always found the middle portion equally developed with the side lobes, and bounded by notches which seem to define it from them. With the growth of the fœtus the central part appears to flatten, losing the rounded, lobular condition, and sometimes disappears. The isthmus is formed from the smaller, middle, division uniting the other two; but there may be an absence of isthmus through failure of this union, the middle portion joining the right or left lobe, or a small middle lobe may remain distinct from the other two. The pyramid is very commonly met with in the fœtus, and is clearly an outlying part of the body, sometimes represented by bud-like projections, sometimes consisting of a process which reaches to the hyoid bone. It is probable that these outgrowths from the fœtal thyroid often shrink and disappear with advancing years.

The dissections of the human fœtus lead to the following conclusions:—(1) The thyroid is developed in connexion with the air-tube, and has no relation with the thymus. (2) It does not consist of two separate lateral masses, and the isthmus is present from the first as a distinct central portion. (3) The pyramid is an outlying part of the body, presenting, during fœtal life, all possible variations as to shape and site.

## V. "On the Physical Constitution of the Sun and Stars." By G. Johnstone Stoney, M.A., F.R.S., F.R.A.S., Secretary to the Queen's University in Ireland. Received May 15, 1867.

(Abstract.)

An attempt is made in the memoir of which this is an abstract to take advantage of the insight we have gained within the last few years into the molecular constitution of gases, and the laws which regulate the exchanges of heat that take place between bodies placed in presence of one another, and to apply these new materials to the interpretation of the phenomena of the photosphere of the sun, the appearances presented during total eclipses, and the information about both sun and stars given by the spectroscope.

In an inquiry like this, where we are obliged to put up with such proofs as the materials at our disposal can supply, we must be content to accept results of every variety of probability, from that degree, bordering upon certainty, which commands an unhesitating assent, to that of which the chief scientific value is that it prompts to further investigation and points out a path. Those who read the memoir itself will best judge of the probability of each conclusion from the proofs laid before them; but in this sketch of its contents it may not be useless to indicate what is the value put upon

each result by the author, since the proofs must in many cases be entirely omitted. It will be convenient to do this by numbers.

The probability 4, then, is to be understood to imply that the matter in hand appears to the author to be fully made out. He would, for example, assign this probability to the wave-theory of light, and to the main features of the theory of the molecular constitution of gases which have been worked out by Clausius and others within the last twenty years. The number 1 will be used where an hypothesis agrees so well with such of the phenomena as are known, that it is concluded that it must be either the true account of them, or bear some intimate relation to the true theory; 2 will indicate that we have good ground to conclude our hypothesis to be the true theory, although at the same time the evidence is too scanty or conflicting to free us from hesitation; 3 will indicate a proof so strong that we should be very much surprised if anything were eventually to disturb it; 4, as has been already stated, will mark a conclusion fully made out; and to complete the series, 5 may be used for that demonstrative proof of which few subjects of inquiry are susceptible.

Observations with the spectroscope have made known to us that the sun's outer atmosphere, that is, the part of the atmosphere which extends outside the photosphere, is a mixture of many gases, amongst which hydrogen, sodium, magnesium, calcium, chromium, manganese, iron, nickel, cobalt, copper, zinc, and barium—all of them permanent gases in consequence of the temperature—have been detected. Now it is shown to be a necessary consequence of the molecular constitution of gases that in such an atmosphere, decreasing in temperature from within outwards, the various constituent gases are not everywhere equally mixed, but that in the upper regions those which have the lightest molecules rise the furthest, so that the gases overlap one another in the order of the masses of their molecules (probability 5). It also follows from a consideration of the vapour-densities and atomic weights of the chemical elements, with probabilities which range from 4 to 1, that those which are present in the sun's atmosphere have molecules with masses increasing in the order in which their names have been printed above, the molecules of hydrogen being the lightest. This, then, is the order in which the boundaries of these gases would be met with in descending from the surface of the sun's atmosphere downwards.

This result is abundantly confirmed, and in its main features raised to probability 4, by observations with the spectroscope. Each constituent of the solar atmosphere is opake to those rays which it emits when incandescent, and which constitute its spectrum. In this way all the light of these particular wave-lengths which has been emitted, either by the photosphere, or by the lower and more intensely heated strata of a gas in the solar atmosphere, is stopped in its passage outwards, and the gas substitutes for it the much more subdued light which emanates from its own upper and therefore coolest stratum. Now if the view enunciated in the last paragraph be true, these outer layers of the respective gases, from which the rays as

we see them come, must be at very various temperatures, that of hydrogen being the coldest, and the others in order after it. This is precisely in conformity with the observations. The rays of hydrogen, sodium, and magnesium emanate from a region so cold that the lines of these elements in the sun's spectrum are intensely black in whatever part of the spectrum they may occur; in other words, the light proceeding from the upper layers of these gases is so feeble that it is not in any perceptible degree luminous when placed in contrast with the intense background of light from the photosphere. On the other hand, calcium, iron, and the rest, while they produce only black lines in the violet and indigo, give rise to lines which are sensibly less dark in the blue, and to lines which emit a still more considerable amount of light in the green, yellow, orange, and red, those colours in which a body gradually heated begins to glow.

A detailed scrutiny of the lines emitted by the various gases leads to several interesting results. Hydrogen and iron are the two most abundant constituents of the sun's outer atmosphere, and play in it the same part which nitrogen and oxygen do in the earth's. There is but the merest trace of sodium present. The other gases are met with in intermediate quantities. Again, barium cannot have a vapour-density so high as would appear as first from its atomic weight, and therefore probably belongs to the same class of elements as cadmium and mercury, which have vapour-densities half of what correspond to their atomic weights. To these several results we may attribute the probability 3.

The photosphere consists of two strata which may be distinguished. The outer of these is shown to be cloud in the ordinary sense of the word, that is, solid or liquid matter in a state of minute division, and denser than the part of the atmosphere in which it is dispersed (probability 3). This cloud is precipitated from its vapour by the chill produced by its own abundant radiation towards the sky, a chill which constitutes the shell of clouds a surface of minimum temperature considerably cooler than either the layer above it or the layer beneath (probability 3). The hotter layer, which is outside the luminous clouds, seems to have a depth somewhat greater than the length of the earth's radius (probability 2). Just outside it there is a second layer of luminous clouds, but so excessively thin that they can be seen only during a total eclipse, on which occasions a portion of them has been seen under the form of two arcs of cloud extending for some distance on either side of the points of first and last contact, where alone a sufficiently low part of the sun's atmosphere was disclosed (probability 3). Above these there soar other clouds raised by causes which will be referred to further on.

About the middle of the hot stratum over the photosphere there is a surface of maximum temperature, outside which the temperature decreases almost continuously to the limit of the iron atmosphere. A little outside this there is a second very feeble maximum, the temperature of which falls short of the heat of the flame of a Bunsen's burner; and outside this, through the immense height which is tenanted by sodium, magnesium, and

hydrogen alone, the temperature goes on decreasing till it becomes excessively cold. These results are made out with probabilities 2 and 3.

Within the luminous clouds the temperature very rapidly waxes, and the density, too, appears to receive a nearly sudden increase. All gases with a vapour-density more than about eighty times that of hydrogen are imprisoned within the shell of clouds by the comparative chill which there prevails, cooperating with the intensity of the force of gravity exerted by the sun. Between the film of clouds and the stratum immediately beneath there are violent motions of convection, which both carry up fresh vapour to be condensed into cloud, and carry down the cloud into a region where it becomes mist and rain. It is convenient to restrict the word *cloud* to cloud in that situation in which it can form, giving the names mist or rain to the cloud when carried down, either by currents of convection or by subsidence, into a position from which there is not that abundant radiation towards the sky which is essential to its forming. The clouds, in this restricted sense of the term, are everywhere of a gauze-like transparency to admit of the copious radiation towards the sky which is requisite; and this enables spectators upon the earth to see through them the light emitted by the mist and rain beneath. This mist and rain seem everywhere, except in the solar spots, to be dense enough to be opake, and therefore emit the maximum light corresponding to their temperature. This temperature is higher than that of the clouds, and accordingly the mist and rain constitute a background brighter than the luminous clouds.

Hence the finely-granulated appearance of the surface of the sun, the currents of convection creating a kind of honeycombed structure in the stratum of clouds; the ascending currents carrying up hot vapours in which only excessively thin cloud can form, since under these unfavourable circumstances its lowest parts cannot tolerate even the slight obstruction to their radiating freely which a cloud of the average density would offer; and, on the other hand, the descending currents carrying down those portions which by prolonged radiation have cooled down abnormally, and thus become both more opake by the condensation of more cloud, and less bright. Those portions which by the most persistent radiation cool down the most, seem to furnish the very dark specks which have been taken notice of by observers.

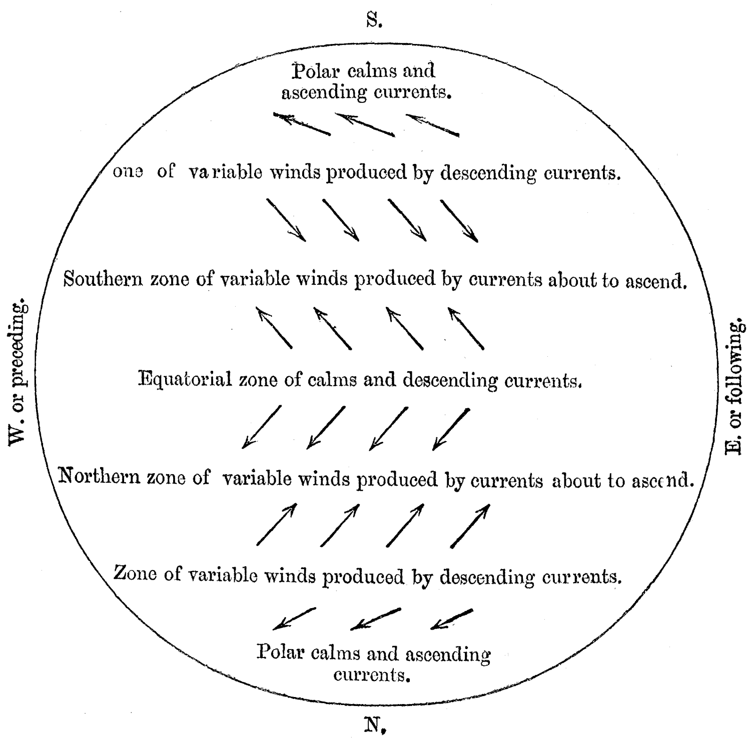
Hence also arises the gradation of light which is observed upon the sun's disk. In the middle of the disk we look vertically through the honeycombed structure which has been described, and see through it the brighter background almost without any intervening obstruction. But as we turn our eyes towards the margin of the disk, we look more and more obliquely across the columns, which progressively intercept increasing quantities of the brighter light from beyond, and substitute for them their own feebler radiations.

If by disturbances in the atmosphere the hotter stratum on either side is made in certain places to encroach upon the luminous clouds, they are unable to maintain in this situation as low a temperature as elsewhere, and

therefore become abnormally thin. If this process is not carried so far as to put a stop to the incessant rain beneath the clouds, their increased transparency will give rise to a facula when the phenomenon takes place on a large scale, and to the coarsely mottled appearance of the photosphere where it presents itself in smaller patches. Hence we see why a facula retains its brightness up to the margin of the sun's disk, a phenomenon which is inconsistent with the usually received hypothesis that the gradation of light on the sun's disk is due to the absorption of the outer atmosphere. If the rain also cease we have the penumbra of a spot; if the cloud itself is dissolved away, we have its umbra.

The dark body which is disclosed in the umbræ and penumbræ of spots must be either an untarnished ocean of some highly reflecting opake substance, or a cloud of some transparent material which scatters light abundantly. Both hypotheses are fully considered.

To most of the foregoing conclusions relating to the photosphere and the adjoining parts we may safely accord the probability 3.




We have strong reasons for suspecting that the luminous clouds consist, like nearly all the sources of artificial light, of minutely divided carbon; and that the clouds themselves lie at a very short distance above the situation

in which the heat is so fierce that carbon, in spite of its want of volatility, and of the enormous pressure to which it is there subjected, boils. The umbra of a spot seems never to form unless when the region in which carbon boils is carried upwards, or the hot region above the clouds is carried downwards, so as to bring them into contact, and thus entirely obliterate the intervening clouds. It is, however, not safe to attribute to the results stated in this paragraph a probability of more than 1.

The trade-winds which blow over the surface of the photosphere are also inquired into. These seem to arise, as Sir John Herschel suspected, from the oblate form of the sun causing a difference in the escape of heat from his poles and equator. There are ascending currents at the poles, descending currents all round the equator. This produces a region of equatorial calms bordered on either side by zones, in the northern of which south-east trades prevail, and in the southern, north-east. These are succeeded by variable winds in the regions of spots, beyond which the polar current blows over the surface of the photosphere in the form of a north-west trade in the northern hemisphere, and a south-west trade in the southern. In the region of spots, both the polar and equatorial currents make their way to a higher level, and in doing so heave up into a colder situation considerable portions of the upper layer of excessively thin cloud, that which is seen only during eclipses. This, though it may at first take place comparatively gently, will be succeeded by a violent upward motion, because the cloud when raised to a cool region will retain a temperature bordering upon that of the photosphere. When this occurs it will both produce the phenomenon of overhanging clouds seen during eclipses, and give rise to a violent cyclone in the regions beneath, immediately over the photosphere. There is no other part of the sun upon which these conditions prevail: hence the limitation of spots to two bands parallel to the equator. To these results we may assign the probability 2.

In the next branch of the inquiry we are obliged to have pretty free recourse to speculation; and the results, though there is much to be said for them, must be received with the caution which becomes us when we are not at liberty to award a probability higher than 1. We are forced to invoke an external agent to account for the periodicity of the spots; and that which is submitted as apparently the most probable, is a swarm of meteors like those which visit the earth in November every thirty-third year, but extended into a much longer stream. These while they pass through the sun's atmosphere would warm the upper regions above his equator, and thus tend to enfeeble the causes which produce the trade-winds. Hence upon each such visit, the trade-winds, the storms which result from them, and the spots which these occasion would all be moderated. It is remarkable that this hypothesis accounts also for the fact that spots prevail more in one hemisphere than the other, inasmuch as the meteors must act more on one hemisphere than the other, and lessen in it the causes that produce spots, unless we make the highly improbable supposition that the axis

major of the orbit of the meteors lies just along the line in which its plane intersects the plane of the sun's equator. It is also very remarkable that the interval of time in which the spots go through their mutations, which we must of course adopt as the periodic time of the meteors in their orbit, assigns to them an aphelion distance outside and close to the orbit of one of the principal planets, Saturn. There is therefore very considerable ground to suspect that there is such a swarm of meteors which was diverted into the solar system by Saturn* at no very remote epoch—just as our November meteors were brought in by the planet Uranus in the year 126 of the Christian era.

Finally, it is shown that an hypothesis which has found much and deserved favour of late years, that the heat expended by the sun is continually restored to him by the falling in of meteors which had been circulating round him, is no longer tenable.

The second part of the memoir treats of other stars. The differences in their appearances are found to depend mainly on differences in the force of gravity exerted at their surfaces. Where gravity on a star is feebler than on the sun, either from the mass of the star being less, or from its being so dilated by heat that its outer parts are further removed from its centre, gases which by reason of the mass of their molecules are imprisoned within the photosphere of the sun, will, when less attracted downwards, be able to stand the coolness of the shell of clouds and pass beyond them. Thus mercury, antimony, tellurium, and bismuth, all of which have too high a vapour-density to exist in the sun's outer atmosphere, show themselves in that of Aldebaran. Again, in these stars all the gases of the outer atmosphere expand until their upper layers, those from which their spectral lines issue, are cooler than on the sun. These spectral lines will accordingly be darker than on the sun, and as this will tell with most effect on the blue end of the spectrum, it will render the light from these stars ruddy.

On the other hand, those stars which, either from being of greater mass than the sun, or from being less hot in their internal parts, attract down the gases of their outer atmospheres with more force, constitute the class of intensely white stars with a somewhat violet tinge, of which Sirius and $\alpha$ Lyræ are examples. Several of the substances which in the sun's spectrum give rise to faint lines, are on such stars confined within the photosphere; and the lowest temperature which others of them can withstand, is by reason of the force with which they are attracted downwards, hotter than the corresponding temperatures of the sun. Hence the substances which on the sun cause his numerous dark lines—sodium, magnesium, calcium, chromium, manganese, iron—produce in the spectrum of the star

* The attraction of Jupiter would also have been competent to divert a cluster of meteors into an orbit of the requisite form and dimensions; but the situation of the orbit would in that case have caused the meteors to cross the path of Jupiter, so that the planet would have acted ever since as a powerful dispersing agent, and it does not seem likely that such an influence has been in operation.

lines equally numerous, but faint. There is but one exception to this. Hydrogen has a molecular mass so amazingly low (one twenty-third part of the mass of molecules of sodium, the nearest to it in this respect of the known constituents of stellar atmospheres), that there is probably no star which can exert a force of gravity so powerful as to compel hydrogen to limit itself to temperatures which show in any part of the spectrum a perceptible degree of brightness when placed upon the background of the photosphere. In all stars accordingly in which hydrogen appears at all, the four hydrogen lines are found intensely black.

We see, then, why solitary stars are found of some particular colours only. Stars which exert upon their outer atmospheres a force of gravity as great or greater than the sun's are white: those on which gravity is a less force are of some ruddy tint,—yellow, orange, or red. The foregoing results are adjudged to be of probability 4, that is, fully made out.

Those stars in which the force of gravity is *very much* less than on the sun appear to form a distinct subclass. The four hydrogen lines are not found in them, and at the same time new spectral lines, arranged in bands each of which is closely ruled and fades off on the less refrangible side, make their appearance. May we not here venture the suspicion that when gravity upon a star is below a certain limit, such conditions prevail as compel the hydrogen which would otherwise be free, to enter into combination with some other element of low vapour-density; and that the resulting compound emits that spectrum of the First Order, as Plücker has called it, which we see?

To account for the colours of the companions of double stars we are again forced to enter upon speculative ground. If the sky be peopled with countless multitudes of dark stars, which as well as the small number that are visible, move only in virtue of their mutual attractions, it cannot be an absolutely unusual occurrence for two stars to come into collision. Whenever this happens, either the two stars emerge from the frightful conflagration which would ensue as one star, or, if they succeed in disengaging themselves, they will be found after the catastrophe moving in new orbits. If their previous courses had been parabolic, it can be shown that the new relative orbit will be elliptic. Hence they will return to the charge again and again, and at each perihelion passage there will be a fresh modification of the orbit. It is shown that these modifications will in some instances be such that the perihelion distance will be constantly on the increase, so that the stars will, in their successive perihelion passages, climb as it were asunder through one another's atmospheres. And the distance to which they will ultimately withdraw before they separate will of necessity be immense, since their atmospheres must have been dilated to a vast size by the friction to which they have been subjected. As the stars recede from one another the amount of heat which they generate at each perihelion passage is progressively less and less, until at length the atmospheres of the stars shrink in the intervals between two perihelion passages more than they ex-

pand when the brush takes place. When this happens the final separation of the two stars is imminent, and a new double star is on the point of being permanently added to the sky.

The astonishing appearances witnessed last year in T Coronæ seem to receive an easy explanation upon this hypothesis. They are exactly what we should expect upon the occurrence of one of the last perihelion passages that take place before two stars which are in the state of transition into a double star finally separate. The outer parts of the atmospheres becoming engaged would raise to incandescence the region in which hydrogen only is found, thus transforming what had previously been its four dark lines into intensely bright lines. At the same time the strata that lie further down would be very sensibly heated, though not to incandescence—quite enough, however, to lessen temporarily in a very material degree the extent to which they at other times subdue the light of the photospheres. This extent would of necessity have been very great, inasmuch as the enormous dilatation of the atmospheres must greatly enfeeble the force of gravity upon the outer strata of both stars.

Again, it follows as a consequence of this hypothesis that the circumstances which most favour the formation of a double star are when the two bodies that come into collision are of nearly equal mass. Such cases must be rare; but when they do occur, there is a very high probability that the issue will be a double star. This appears to accouut for the fact that a very remarkable proportion of double stars have constituents of nearly the same magnitude.

Another consequence is that when the stars are very unequal, the companion will, as it plunges over and over again through the atmosphere of the primary, be gradually deprived of several of its lighter gases; so that when it finally gets clear it will not emit the principal spectral lines of a solitary star, but others which emanate from denser gases. This probably accounts for the blue, violet, and green colours which are found in the minute companions of double stars.

Another consequence is that the orbits of double stars will almost always have a considerable ellipticity.

Another consequence is that the conditions are likely not unfrequently to arise which would separate the companion into two or more fragments; and that when this happens, the separate pieces will pursue paths which are distinct from one another and not far apart. This seems to account for such systems as $\gamma$ Andromedæ.

When the same conditions act with unusual violence they would probably break up the companion into numerous fragments; and it is remarkable that they would at the same time be likely to cause the primary to throw off a number of rings. The fragments and the rings would move all in the same direction and nearly in the same plane, and each fragment would rotate rapidly in the direction in which it revolves in its orbit. When the fragments, as must generally happen, are of inconsiderable mass

their orbits would be almost certain to degrade from ellipses into circles before they got quite clear of the primary. Some would probably be found, when this happens, at the distance of the rings, others within the surface of the primary, none beyond both. Those within the surface of the primary would fall into him and be lost. But one that lay within a ring would gather by its attraction the ring round itself, and so become covered with an immense atmosphere with which it would continue to rotate while advancing in its circular orbit. If this rotation were sufficiently swift, the new planet would throw off rings which might afterwards condense into satellites, with this peculiarity, that they would always keep the same face turned towards the planet, and revolve round it in the same direction and nearly in the same plane in which the planet revolves round its sun.

The speculative element in this hypothesis is so considerable that perhaps we may not prudently yield to it a probability higher than 1. But an hypothesis which carries up so many of the main phenomena of nature to a single source, and which only asks us to admit what is not antecedently improbable, that the number of incandescent stars is but a small proportion of all that exist, seems nevertheless to deserve to be stated.

## VI. "Researches on the Hydrocarbons of the Series $C^n H^{2n+2}$.—No. III." By C. Schorlemmer. Communicated by Prof. G. G. Stokes, Sec. R.S. Received May 15, 1867.

### 1. *Di-Isopropyl*, $C_6 H_{14}$.

Iodide of isopropyl is not perceptibly acted upon by sodium even if the liquid is heated to the boiling-point; but if anhydrous ether perfectly free from alcohol is added, a reaction soon commences without application of external heat; the liquid becomes warm, and the iodide is decomposed with formation of iodide of sodium. The chief products of this reaction are, (1) propylene, from which bromide of propylene was obtained by passing the gases which are evolved through bromine; (2) a gaseous hydrocarbon, which is not absorbed by bromine and which burns with a luminous flame, probably consisting of hydride of propyl; and (3) a liquid hydrocarbon, which, according to its composition and mode of formation, must be considered as di-isopropyl. By the following method I obtained the largest yield of this liquid. A flask holding about 250 cub. centims. was half filled with iodide of isopropyl (which had been prepared by acting with hydroiodic acid upon glycerin); an equivalent quantity of sodium cut into thin pieces was added, upon this a layer of pure ether was poured, and the flask quickly connected with the lower end of a Liebig's condenser. Where the two liquids meet, a brisk reaction soon sets in; the escaping gases carry off a large quantity of the liquid, chiefly of the more volatile ether, and it is therefore necessary to keep the condenser as cold as possible. The reaction goes on generally quietly until the greatest portion of the iodide is decomposed; if it stops after a short time, gentle heat has to be applied as long as gas is evolved. After the reaction is over, the