CHAPTER IX.

THE SUN'S LIGHT AND HEAT: COMPARISON OF SUNLIGHT WITH ARTIFICIAL LIGHTS.—MEASUREMENT OF THE SUN'S HEAT, AND DETERMINATION OF THE "SOLAR CONSTANT."—PYRHELIOMETER, ACTINOMETER, AND BOLOMETER.—THE SUN'S TEMPERATURE.—THEORIES AS TO THE MAINTENANCE OF THE SUN'S RADIATION, AND CONCLUSIONS AS TO THE SUN'S POSSIBLE AGE AND FUTURE DURATION.

332. The Sun's Light.—*The Quantity of Sunlight.* It is very easy to compare (approximately) sunlight with the light of a standard[1] candle; and the result is, that when the sun is in the zenith, it illuminates a white surface about 60,000 times as strongly as a standard candle at a distance of one metre. If we allow for the atmospheric absorption, the number would he fully 70,000. If we then multiply 70,000 by the square of 150,000 million (roughly the number of metres in the sun's distance from the earth), we shall get what a gas engineer would call the sun's "*candle power.*" The number comes out 1575 billions of billions (English); *i.e.*, 1575 with twenty-four ciphers following.

333. One way of making the comparison is the following: Arrange matters as in Fig. 118. The sunlight is brought into a darkened room by a mirror M, which reflects the rays through a lens L of perhaps half an inch in diameter. After the rays pass the focus they diverge and form on the screen S a disc of light, the size of which may be varied by changing the distance of the screen. Suppose it so placed that the illuminated circle is just ten feet in diameter; that is, 240 times the diameter of the

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[1] A standard candle is a sperm candle weighing one-sixth of a pound and burning 120 grains an hour. The French "Carcel burner," used as a standard in their photometry, gives just ten times the quantity of light given by this standard candle. An ordinary gas-burner consuming five feet of gas hourly gives a light equivalent to from twelve to fifteen standard candles.

lens. The illumination of the disc will then be less than that of direct sunlight in the ratio of 240^2 (or 57,600) to 1 (neglecting the loss of light produced by the mirror and the lens, a loss which of course must he allowed for). Now place a little rod like a pencil near the screen, as at P, light a standard candle, and move the candle back and forth until the two shadows of the pencil, one formed by the candle, and the other by the light from the lens, are equally dark. It will be found that the candle has to be put at a distance of about one metre from the screen; though the results would vary a good deal from day to day with the clearness of the air.

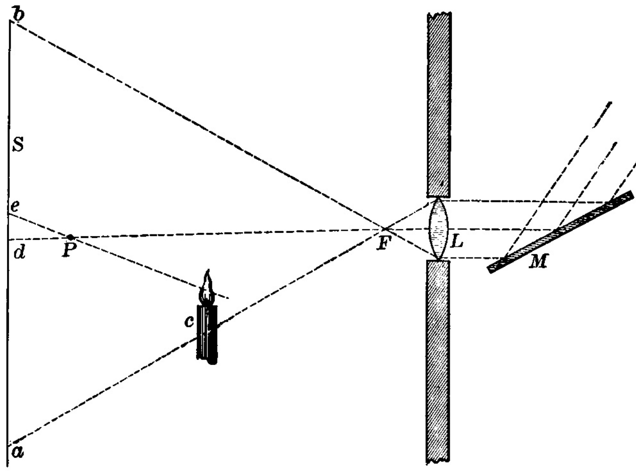

FIG. 118.—Comparison of Sunlight with a Standard Candle.

334. When the sun's light is compared with that of the full moon and of various stars, we find, as stated (Art. 259), that it is about 600,000 times that of the full moon. It is 7,000,000000 times as great as the light received from Sirius, and about 40,000,000000 times that from Vega or Arcturus.

335. The Intensity of the Sun's Luminosity.—This is a very different thing from the total quantity of its light, as expressed by its "candle power" (a surface of comparatively feeble luminosity can give a great quantity of light if large enough). It is the *amount of light per square inch of luminous surface* which determines the intensity. Making the necessary computations from the best data obtainable (only roughish approximations being possible), it appears that the sun's surface is about 190,000 times as bright as that of a candle flame, and about 150 times as bright as the lime of the calcium light. *Even the darkest part of a solar spot outshines* *the lime.* The intensely brilliant spot in the so-called "crater" of an electric arc comes nearer sunlight than anything else known, being from one-half to one-fourth as bright as the surface of the sun itself. But either the electric arc or the calcium light, when interposed between the eye and the sun looks like a dark spot on the disc.

336. Comparative Brightness of Different Portions of the Sun's Surface.—By forming a large image of the sun, say a foot in diameter, upon a screen, we can compare with each other the rays coming from different parts of the sun's disc. It thus appears that there is a great diminution of light at the edge, the light there, according to Professor Pickering's experiments, being just about one-third as strong as at the centre. There is also an obvious difference of color, the light from the edge of the disc being brownish red as compared with that from the centre. The reason is, that the red and yellow rays of the spectrum lose much less of their brightness at the limb than do the blue and violet. According to Vogel, the latter rays are affected nearly twice as much as the former. For this reason, photographs of the sun exhibit the darkening of the limb much more strongly than one usually sees it in the telescope.

337. Cause of the Darkening of the Limb.—It is due unquestionably to the general absorption of the sun's rays by the lower portion of the overlying atmosphere. The reason is obvious from the figure (Fig. 119). The *thinner* this atmosphere, other things being equal, the *greater the* ratio *between the percentage of absorption at the centre and edge of the disc, and the more obvious the darkening of the limb.*

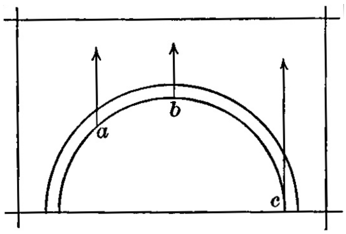

FIG. 119.
Cause of the Darkening of the Sun's Limb.

Attempts have been made to determine from the observed differences between the brightness of centre and limb the total percentage of the sun's light thus absorbed. Unfortunately we have to supplement the observed data with some very uncertain assumptions in order to solve the problem; and it can only be said that it is *probable* that the amount of light, absorbed by the sun's atmosphere lies between fifty and eighty per cent; *i.e.*, the sun deprived of its gaseous envelope would probably shine from two to five times as brightly as now. It is noticeable also, as Langley long ago pointed out, that thus stripped, the "complexion" of the sun would be markedly changed from yellowish white to a good full *blue*, since the blue and violet rays are much more powerfully absorbed than these at the lower end of the spectrum.

THE SUN'S HEAT.

338. Its Quantity; the "Solar Constant." By the "*quantity of heat*" received by the earth from the sun we mean the number of heat-units received in each unit of time by a square unit of surface when the sun is in the zenith. The heat-unit most employed by engineers is the *calorie*, which is the quantity of heat required to raise the temperature of one kilogram of water one degree centigrade. It is found by observation that each square metre of surface exposed perpendicularly to the sun's rays receives from the sun each minute from twenty-five to thirty of these calories; or rather it *would do so* if a considerable portion of the sun's heat were not stopped by the earth's atmosphere, which absorbs some thirty per cent of the whole, even when the sun is vertical, and a much larger proportion when the sun is near the horizon. This quantity, *twenty-five calories*[1] *per square metre per minute* (using the smaller of the values mentioned, which *certainly* is not too large), is known as the "*Solar Constant.*"

339. Method of determining the "Solar Constant."—The method by which the solar constant is determined is simple enough in principle, though complicated with serious practical difficulties which affect its accuracy. It is done by allowing *a beam of sunlight of known cross-section to shine upon a known weight of water* (*or other substance of known specific heat*) *for a known length of time, and measuring the rise of temperature.* It is necessary, however, to determine and allow for the heat received from

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[1]For many scientific purposes the engineering calorie is inconveniently large, and a smaller one is employed, which replaces the kilogram of water by the *gram* heated one degree—the smaller calorie being thus only $\frac{1}{1000}$ of the engineering unit. As stated by many writers (Langley, for instance), the solar constant is the number of these *small* calories received per square *centimetre* of surface in a minute. This would make the number 2.5 instead of 25. It would perhaps be better to bring the whole down to the "c.g.s. system" by substituting the *second* for the minute; and this would give us for the solar constant, on the "c.g.s. system," 0.0417 (*small*) *calories per square centimetre per second.*

other sources during the experiment, and for that lost by radiation. Above all, the absorbing effect of our own atmosphere is to be taken into account, and this is the most difficult and uncertain part of the work, since the atmospheric absorption is continually changing with every change of the transparency of the air, or of the sun's altitude.

340. Pyrheliometers and Actinometers.—The instruments with which these measurements are made, are known as "pyrheliometers" and "actinometers." Fig. 120 represents the pyrheliometer of Pouillet, with which in 1838 he made his determination of the solar constant, at the same time that Sir John Herschel was experimenting at the Cape of Good Hope in practically the same way. They were the first apparently to understand and attack the problem in a reasonable manner. The pyrheliometer consists essentially of a little cylindrical box *ab*, like a snuff-box, made of thin silver plate, with a diameter of one decimetre and such a thickness that it holds 100 grams of water. The upper surface is carefully blackened, while the rest is polished as brilliantly as possible. In the water is inserted the bulb of a delicate thermometer, and the whole is so mounted that it can be turned in any direction so as to point it directly towards the sun. It is used by first holding a screen between it and the sun for (say) five minutes, and watching the rise or fall of the mercury in the thermometer at *m*. There will usually be some slight change due to the radiation of surrounding bodies. The screen is then removed, and the sun is allowed to shine upon the blackened surface for five minutes, the instrument being continually turned upon the thermometer as an axis, in order to keep the water in the calorimeter box well stirred. At the end of the five minutes the screen is replaced and the rise of the temperature noted. The difference between this and the change of the thermometer during the first five minutes will give us the amount by which a beam of sunlight one decimetre in diameter has raised the temperature of 100 grams of water in five minutes, and were it not for the troublesome corrections which must be made, would furnish directly the value of the solar constant.

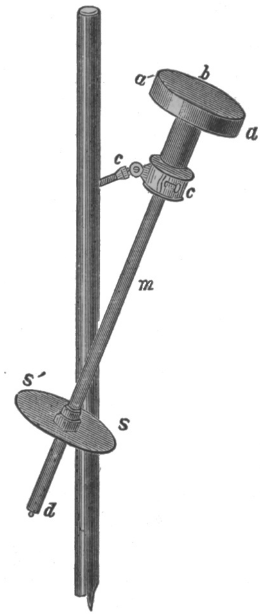

FIG. 120.—Pouillet's Pyrheliometer.

341. The second apparatus, Fig. 121, is the actinometer of Violle, which consists of two concentric metal spheres, the inner of which is blackened on the inside, while the outer one is brightly polished, the space between the two being filled with water at a known temperature, kept circulating by a pump of some kind. The thermoscopic body in this case, instead of being a box filled with water, is the blackened bulb of the thermometer T; and the observations may be made either in the same way as with the pyrheliometer, or simply by noting the difference between the temperature finally attained by the thermometer T after it has ceased to rise in the sun's rays, and the temperature of the water circulating in the shell.

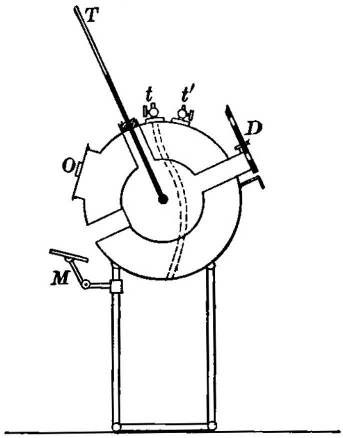

FIG. 121.—Violle's Actinometer.

342. Correction for Atmospheric Absorption.—The correction for atmospheric absorption is determined by making observations at various altitudes of the sun between zenith and horizon. If the rays were *homogeneous* (that is, all of one wave-length), it would be comparatively easy to deduce the true correction and the true value of the solar constant. In fact, however, the *visible* solar spectrum is but a small portion of the whole spectrum of the sun's radiance, and, as Langley has shown, it is necessary to determine the coefficient of absorption separately for all the rays of different wave-length.

343. The Bolometer.—This he has done by means of his "Bolometer," an instrument which is capable of indicating exceedingly minute changes in the amount of radiation received by an extremely thin strip of metal. This strip is so arranged that the least change in its electrical resistance due to any change of temperature will disturb a delicate galvanometer. The instrument is far more sensitive than any thermometer or even thermopile, and has the especial advantage of being extremely quick in its response to any change of radiation. Fig. 122 shows it so connected with a spectroscope that the observer can bring to the bolometer, B, rays of any wave-length he chooses. The rays enter through the collimator lens L, and are then refracted by the prism P to the reflector M, whence they are sent back to B.

Langley has shown that the corrections for atmospheric absorption deduced by earlier observers are all considerably too small, and has raised the received value of the solar constant, from 20 or 25, which was the value accepted a few years ago, to 30. We have, however, provisionally retained the 25, as his new results, though almost certainly correct, have not yet been universally accepted, and perhaps need verification.

344. A less technical statement of the solar radiation may be made in terms of thickness of the quantity of *ice* which would be melted by it in a given time. Since it requires about eighty calories of heat to melt a kilogram of ice, it follows that twenty-five calories per minute per square metre would liquefy in an *hour* a sheet of ice *one metre square and about nineteen millimetres thick.* According to this the sun's heat would melt about 174 feet of ice annually on the earth's equator; or $136\frac{1}{2}$ feet yearly all over the surface of the earth, if the heat annually received were equally distributed in all latitudes. (See note at end of the chapter, page 232.)

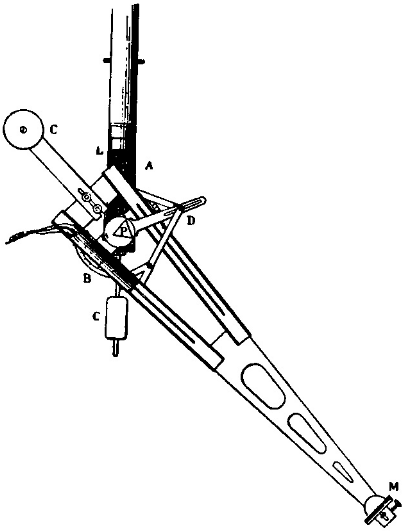

FIG. 122.
Langley's Spectro-Bolometer, as used for Mapping the Energy of the Prismatic Spectrum.

345. Solar Heat expressed as Energy.—Since according to the known value of the "mechanical equivalent of heat" (Physics, p. 159) a horse-power corresponds to about $10\frac{7}{10}$ calories per minute, it follows that *each square metre of surface* (neglecting the air-absorption) *would receive, when the sun is overhead*, about *two and one-third horse-power continuously.* Atmospheric absorption cuts this down to about one and one-half horse-power, of which about one-eighth can be actually utilized by properly constructed machinery, as, for instance, the solar engines of Ericsson and Mouchot (see Langley's "New Astronomy"). In Ericsson's apparatus the reflector, about 11 feet by 16 feet, collected heat enough to work a three-horse-power engine very well. Taking the earth's surface as a whole, the energy received during a year aggregates about sixty mile-tons for every square foot. That is to say, the *heat annually received on each square foot of the earth's surface, if employed in a perfect heat engine, would be able to hoist sixty tons to the height of a mile.*

346. Solar Radiation at the Sun's Surface.—If, now, we estimate the amount of radiation at the sun's surface itself, we come to results which are simply amazing and beyond comprehension. It is necessary to multiply the solar constant observed at the earth (which is at a distance of 93,000000 miles from the sun) by the square of the ratio between 93,000000 and 433,250, the radius of the sun. This square is about 46,000; in other words, the amount of heat emitted in a minute by a square metre of the sun's surface is about 46,000 times as great as that received by a square metre at the earth. Carrying out the calculations, we find that this heat radiation at the surface of the sun amounts to *over a million calories per square metre per minute*; that it is over 100,000 horse-power per square metre continuously acting; that *if the sun were frozen over completely to a depth of fifty feet, the heat emitted is sufficient to melt this whole shell in one minute of time*; that if an ice bridge could be formed from the earth to the sun by a column of ice two and one-fourth miles square at the base and extending across the whole 93,000000 of miles, and if by some means the whole of the solar radiation could be concentrated upon this column, it would be melted in one second of time, and in between seven and eight seconds more would be dissipated in vapor. To maintain such a development of heat *by combustion* would require the *hourly burning of a layer of the best anthracite coal from sixteen to twenty feet thick* over the sun's entire surface,—a ton for every square foot of surface,—at least nine times as much as the consumption of the most powerful blast furnace in existence. At that rate the sun, if made of solid coal, would not last 6000 years.

347. Waste Of Solar Heat.—Those estimates are of course based on the assumption that the sun radiates heat equally in all directions, and there is no assignable reason why it should not do so. On this assumption, however, *so far as we can see*, only a minute fraction of the whole radiation ever reaches a resting-place. The earth receives about $\frac{1}{2200,000000}$ of the whole, and the other planets of the solar system, with the comets and the meteors, get also their shares; all of them together, perhaps ten or twenty times as much as the earth. Something like $\frac{1}{100,000000}$ of the whole seems to be utilized within the limits of the solar system. As for the rest, science cannot yet tell what becomes of it. A part, of course, reaches distant stars and other objects in interstellar space; but by far the larger portion seems to be "wasted," according to our human ideas of waste.

348. Experiments with the thermopile, first conducted by Henry at Princeton in 1845, show that the heat from the edges of the sun's disc, like the light, is less than that from the centre—according to Langley's measurements about half as much. The explanation evidently lies in its absorption by the solar atmosphere.

349. The Sun's Temperature.—While we can measure with some accuracy the *quantity* of heat sent us by the sun, it is different with its *temperature* in respect to which we can only say that it must be very high—much higher than any temperature attainable by known methods on the surface of the earth.

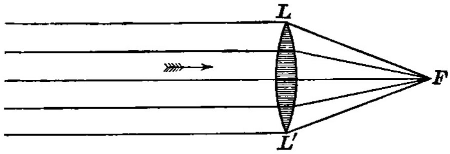

FIG. 123.

This is shown by a number of facts, for instance, by the great *abundance of the violet and ultra-violet rays* in the sunlight.

Again, by the *penetrating* power of sunlight; a large percentage of the heat from a common fire, for instance, being stopped by a plate of glass, while nearly the whole of the solar radiation passes through.

The most impressive demonstration, however, follows from this fact; viz., that at the focus of a powerful burning-lens all known substances melt and vaporize, as in an electric arc. Now at the focus of the lens the *limit* of the temperature is that which would be produced by the sun's direct radiation at a point where the sun's angular diameter equals that of the burning-lens itself seen from the focus, as represented in Fig. 123. An object at F would theoretically (that is, if there was no loss of heat conducted away by surrounding bodies and by the atmosphere) reach the same temperature as if carried to a point where the sun's angular diameter equals the angle LFL'. In the most powerful burning-lenses yet constructed a body at the focus is thus virtually carried up to within about 240,000 miles of the sun's surface, where its apparent diameter would be about 80°. Here, as has been said, the most refractory substances are immediately subdued. If the earth were to approach the sun as near as the moon is to us, she would melt and be vaporized.

350. Ericsson in 1872 made an exceedingly ingenious and interesting experiment illustrating the intensity of the solar heat. He floated a calorimeter, containing about ten pounds of water, upon the surface of a large mass of molten iron by means of a raft of fire-brick, and found that the radiation of the metal was a trifle over 250 calories per minute for each square foot of surface; which is only $\frac{1}{400}$ part of the amount emitted by the same area of the sun's surface. He estimated the temperature of the metal at 3000° F. or 1649° C.

351. Effective Temperature.—The question of the sun's temperature is embarrassed by the fact that it has no *one* temperature; the temperature at different parts of the solar photosphere and chromosphere must be very different. We evade this difficulty to some extent by substituting for the *actual* temperature, as the object of inquiry, what has been called the sun's "*effective temperature*"; that is, the temperature which a sheet of *lampblack* must have in order to radiate the amount of heat actually thrown off by the sun. (Physicists have taken the radiating power of lampblack as *unity.*) If we could depend upon the laws[1] deduced from laboratory experiments, by which it has been sought to connect the temperature of the body with its rate of radiation, the matter would then be comparatively simple: from the known radiated *quantity of heat* (in calories) we could compute the *effective temperature* in degrees. But at present it is only by a very unsatisfactory process of extrapolation that we can reach conclusions. The sun's temperature is so much higher than any which we can manage in our laboratories, that there is not yet much certainty to be obtained in the matter. Rosetti, the most recent investigator, whose results seem to be on the whole the most probable, obtains 10,000° C. or 18,000° F. for the effective temperature.

352. Constancy of the Sun's Heat.—It is an interesting and thus far unsolved problem, whether the total amount of the sun's radiation varies perceptibly at different times. It is only certain that the variations, if real, are too small to be detected by our present means of observation. Possibly, at some time in the future,

[1] A number of such laws have been formulated; for instance, the well-known law of Dulong and Petit (Physics, p. 470). The French physicists Pouillet and Vicaire, using this formula, have deduced values for the sun's effective temperature running from 1500° to 2500° C. Ericsson and Secchi, using Newton's law of radiation (which, however, is certainly inapplicable under the circumstances), put the figure among the millions. Zöllner, Spörer, and Lane give values ranging from 25,000° to 50,000° C.

observations on a mountain summit above the main body of our atmosphere may decide the question.

It is not unlikely that changes in the earth's climate such as have given rise to glacial and carboniferous periods may ultimately be traced to the condition of the sun itself, especially to changes in the thickness of the absorbing atmosphere, which, as Langley has pointed out, must have a great influence in the matter. Since the Christian era, however, it is certain that the amount of heat annually received from the sun has remained practically unchanged. This is inferred from the distribution of plants and animals, which is still substantially the same as in the days of Pliny.

353. Maintenance of the Solar Heat.—The question at once arises, if the sun is sending off such an enormous quantity of heat annually, how is it that it does not grow cold?

(a) The sun's heat cannot be kept up by *combustion.* As has been said before, it would have burned out long ago, even if made of solid coal burning in oxygen.

(b) Nor can it be simply a *heated body cooling down.* Huge as it is, an easy calculation shows that its temperature must have fallen greatly within the last 2000 years by such a loss of heat, even if it had a specific heat higher than that of any known substance.

As matters stand at present, the available theories seem to be reduced to two,—that of Mayer, which ascribes the solar heat to the energy of meteoric matter falling on the sun; and that of Helmholtz, who finds the cause in a slow contraction of the sun's diameter.

354. Meteoric Theory of Sun's Heat.—The first is based on the fact that when a moving body is stopped, its mass-energy becomes molecular energy, and appears mainly as heat. The amount of heat developed in such a case is given by the formula

$$Q = \frac{MV^2}{8339},$$

in which Q is the number of calories of heat produced, M the mass of the moving body in kilograms, and V its velocity in metres per second; the denominator is the "mechanical equivalent of heat" (Physics, p. 159) multiplied by $2g$ expressed in metres; *i.e.*, $425 \times 2 \times 9.81$.

Now, the velocity of a body coming from any considerable distance and falling into the sun can be shown to be about 380 miles per second, or more than 610 kilometres. A body weighing one kilogram would therefore, on striking the sun with this velocity, produce about 45,000000 calories of heat,

$$\left[\frac{(610000)^2}{8339}\right].$$

This is 6000 times more than could be produced by *burning* it, even if it were coal or solidified hydrogen burning in pure oxygen.

Now, as meteoric matter is continually falling upon the earth, it must be also falling upon the sun, and in vastly greater quantities, and an easy calculation shows that a quantity of meteoric matter equal to $\frac{1}{100}$ of the earth's mass striking the sun's surface annually with the velocity of 600 kilometres per second would account for its whole radiation.

355. Objections to Meteoric Theory of Sun's Heat.—There can be no question that a certain fraction of the sun's heat is obtained in this way, but it is very improbable that this fraction is a large one; indeed, it is hardly possible that it can be as much as *one per cent* of the whole.

(1) The annual fall on the sun's surface of such a quantity of meteoric matter implies the presence *near* the sun of a vastly greater mass; for, as we shall see hereafter, only a few of the meteors that approach the sun from outer space would strike the surface: most of them would act like the comets and swing around it without touching. Now, if there were any considerable quantity of such matter near the sun, there would result disturbances in the motions of the planets Mercury and Venus, such as observation does not reveal.

(2) Professor Peirce has shown further that if the heat of the sun were produced in this way, the earth ought to receive from the meteors that strike her surface about half as much heat as she gets from the sun. Now the quantity of meteoric matter which would have to fall upon the earth to furnish us daily half as much heat as we receive from the sun, would amount to nearly fifty tons for each square mile. It is not likely that we actually get $\frac{1}{10,000000}$ of that amount. It is difficult to determine the amount of heat which the earth actually does receive from meteors, but all observations indicate that the quantity is extremely small. The writer has estimated it, from the best data attainable, as less in a *year* than we get from the sun in a *second*.

356. Helmholtz's Theory of Solar Contraction.—We seem to be shut up to the theory of Helmholtz, now almost universally accepted: namely, that the heat necessary to maintain the sun's radiation is principally supplied *by the slow contraction of its bulk*, aided, however, by the accompanying liquefaction and solidification of portions of its gaseous mass. When a body falls through a certain distance, *gradually*, against resistance, and then comes to rest, the same total amount of heat is produced as if it had fallen *freely, and been stopped instantly.* If, then, the sun does contract, heat is necessarily produced by the process, and that in enormous quantity, since the attracting force at the solar surface is more than twenty-seven times as great as terrestrial gravity, and the contracting mass is immense. In this process of contraction each particle at the surface moves inward by an amount equal to the diminution of the sun's radius: a particle below the surface moves less and under a diminished gravitating force; but every particle in the whole mass, excepting only that at the exact centre of the globe, contributes something to the evolution of heat. In order to calculate the precise amount of heat evolved by a given shrinkage it would be necessary to know the law of increase of the sun's density from the surface to the centre; but Helmholtz has shown that under the most unfavorable conditions *a contraction in the sun's diameter of about two hundred and fifty feet a year* (125 feet in the sun's *radius*) *would account for the whole annual output of heat.* This contraction is so slow that it would be quite imperceptible to observation. It would require more than 9000 years to reduce the sun's diameter by a single second of arc; and nothing much less would be certainly detectible by our measurements. *If the contraction is more rapid than this*, the mean temperature of the sun must be actually *rising*, notwithstanding the amount of heat it is losing. Long observation alone can determine whether this is really the case or not.

357. Lane's Law.—It is a remarkable fact, first demonstrated by Lane of Washington, in 1870, that a gaseous sphere, losing heat by radiation and contracting under its own gravity, *must rise in temperature and actually grow hotter*, until it ceases to be a "perfect gas," either by beginning to liquefy, or by reaching a density at which the laws of perfect gases no longer hold. The kinetic energy developed by the shrinkage of a gaseous mass is more than sufficient to replace the loss of heat which caused the shrinkage. In the case of a *solid or liquid* mass this is not so. The shrinkage of such a mass contracting under its own gravity on account of the loss of heat is never sufficient to make good the loss; but the temperature falls and the body cools. At present it appears that in the sun the relative proportions of true gases and liquids are such as to keep the temperature nearly stationary, the liquid portions of the sun being of course the little drops which are supposed to constitute the clouds of the photosphere.

358. Future Duration of the Sun.—If this shrinkage theory of the solar heat is correct (and there is every reason to accept it), it follows that in time the sun's heat must come to an end, and, looking backwards, we see that there must have been a beginning.

We have not sufficient data to enable us to calculate the future duration of the sun with exactness, though an approximate estimate can he made. According to Newcomb, if the sun maintains its present radiation, it will have shrunk to half its present diameter in about 5,000000 years at the longest. Since when reduced to this size it must be about eight times as dense as now, it can hardly then continue to be mainly gaseous, and its temperature must begin to fall. Newcomb's conclusion, therefore, is that it is not likely that the sun can continue to give sufficient heat to support such life on the earth as we are now acquainted with, for 10,000000 years from the present time.

359. Age of the Sun.—As to the past of the solar history on this hypothesis, we can be a little more definite. It is only necessary to know the present amount of radiation, and the mass of the sun, to compute how long the solar fire can have been maintained at its present intensity by the processes of condensation. No conclusion of geometry is more certain than this,—that the contraction of the sun to its present size, from a diameter even many times greater than Neptune's orbit, would have furnished about 18,000000 times as much heat as the sun now supplies in a year, and therefore that the sun cannot have been emitting heat *at the present rate* for more than 18,000000 years, *if its heat has really been generated in this manner.*

But of course this conclusion as to the possible past duration of the solar system rests upon the assumption that the sun has derived its heat *solely in this way*; and moreover, that it radiates heat equally in all directions in space,—assumptions which possibly further investigations may not confirm.

360. Constitution of the Sun.—(a) As to the nature of the main body or nucleus of the sun, we cannot be said to have certain knowledge. It is probably *gaseous*, this being indicated by its low mean density and its high temperature—enormously high even at the surface, where it is coolest. At the same time the gaseous matter at the nucleus must be in a very different state from gases as we commonly know them in our laboratories, on account of the intense heat and the extreme condensation by the enormous force of solar gravity. The central mass, while still strictly gaseous, because observing the three physical laws of Boyle, Dalton, and Gay Lussac, which characterize gases, would be denser than water, and viscous; probably something like tar or pitch in consistency.[1]

While this doctrine of the gaseous constitution of the sun is generally assented to, there are still some who are disposed to consider the great mass of the sun as liquid.

361. (*b*) The *photosphere* is probably a shell of *incandescent clouds*, formed by the condensation of the vapors which are exposed to the cold of space.

362. (*c*) The photospheric clouds float in an atmosphere containing, still uncondensed, a considerable quantity *of the same vapors out of which they themselves have been formed*, just as in our own atmosphere the air around a cloud is still saturated with water vapor. This vapor-laden atmosphere, probably comparatively shallow, constitutes the *reversing layer*, and by its selective absorption produces the dark lines of the solar spectrum, while by its general absorption it probably produces the darkening at the limb of the sun.

But it will be remembered that Mr. Lockyer and others are disposed to question the existence of any such shallow absorbing stratum, considering that the absorption takes place in all regions of the solar atmosphere even to a great elevation.

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[1]The law of Dalton (Physics, p. 181) is, that any number of different gases and vapors tend to *distribute themselves throughout the space which they occupy in common, each as if the others were absent*. The law of Boyle or Mariotte (Physics, p. 110) is, *that at any given temperature the volume of any given amount of gas varies inversely with the pressure: i.e.*, $pv = p'v'$. The law of Gay Lussac (Physics, p. 185) is, that a gas *under constant pressure expands in volume uniformly under uniform increment of temperature*, so that $V_t = V_0(1 + at)$. This is not true of *vapors* in presence of the liquids from which they have been evaporated; for instance, of steam in a boiler.

363. (*d*) The *chromosphere and prominences* are composed of the *permanent gases*, mainly hydrogen and helium, which are mingled with the vapors of the reversing stratum in the region near the photosphere, but usually rise to far greater elevations than do the vapors. The appearances are for the most part as if the chromosphere was formed of jets of heated hydrogen ascending through the interspaces between the photospheric clouds, like flames playing over a coal fire.

364. (*e*) The *corona* also rests on the photosphere, and the peculiar green line of its spectrum (Art. 329) is brightest just at the surface of the photosphere, in the reversing stratum and in the chromosphere itself; but the corona extends to a far greater elevation than even the prominences ever reach, and seems to be not wholly gaseous, but to contain, besides the hydrogen and the mysterious "coronium," dust and fog of some sort, perhaps meteoric. Many of its phenomena are as yet unexplained, and since it can only be observed during the brief moments of total solar eclipses, progress in its study is necessarily slow.

364*. *Note to Article* 344. The total heat received by the earth from the sun in any given time is that intercepted by its diametrical cross-section, *i.e.*, by the area of one of its great circles kept always perpendicular to the sun's rays. The quantity of ice which would be melted annually on this circular plane by the solar rays would be a sheet having a thickness of 166.5 metres or 546 feet ($19^{\mathrm{mm}} \times 24 \times 365\frac{1}{4} = 166.5^{\mathrm{met}}$).

The thickness of the ice which could be melted in a year on a narrow equatorial belt would be $\frac{546^{\mathrm{ft}}}{\pi}$, or 174^{ft}, since such a belt intercepts the rays that would otherwise fall on a diametrical strip of the same width upon the circular plane.

If the sun's heat were *uniformly* distributed over the earth's whole surface, which equals four great circles, $(4\pi R^2)$, it could melt a shell having a thickness of $\frac{546^{\mathrm{ft}}}{4}$, or $136\frac{1}{2}^{\mathrm{ft}}$.

It is true that at the sea-level the solar-constant is much diminished by atmospheric absorption; and probably does not exceed fifteen calories per minute *directly* received from the sun's rays. But a large part of the solar heat absorbed by the atmosphere reaches the earth's surface *indirectly*, so that it must not be considered as lost to the earth, because not directly measurable by the actinometer.