smaller number of vibrations per second than a less sensitive one.

The pitch of a sound may be defined as the rate of vibration per second. The absolute number per second being of no moment, a C tuning-fork making 512 vibrations in a second would give the same pitch if it vibrated for only half a second or a less fraction; but, what is the least number of vibrations that will enable an ear to detect pitch?

Theoretically, there can be no rate, and consequently no pitch, to a single vibration. It is essential that there should be two or more to establish a rate, and, to be heard as continuous, must follow each other with an interval not greater than the perception limit, which varies in different individuals, as mentioned above. For the average individual it will probably be not greater than $\frac{1}{10}$ of a second, otherwise they would be heard as distinct pulses without pitch.

With the ordinary apparatus for the study of sound, such as forks, pipes, or siren, it is impossible to determine this low limit experimentally, as they cannot be made to sound for so brief an interval as to make but a few vibrations; but, with the following device, I found no trouble in recognizing pitch with only three or four vibrations. Let the finger nail be drawn across a piece of ribbed paper or cloth such as many books are now bound with, and a whistling sound will be heard, and the pitch may be readily determined. Of course it will vary with the velocity of the hand. The number of ribs passed over in a given interval of time must give the number of vibrations; but, to perceive the pitch, it is necessary to touch but three or four of these, which was determined by using a lead pencil and a light colored piece of ribbed paper. The pencil recorded the number of ribs touched. The rate was such as to be not less than 1,000 per second, and consequently the whole interval was but $\frac{1}{1000}$ or $\frac{1}{100}$ of a second. I was able to touch only two at a trial, else I have no doubt they would have been sufficient to enable me to perceive the pitch; but, as the difficulty seems to be purely a mechanical one, there is no good reason for believing that more than two vibrations are requisite for the recognition of pitch.—*Journal of Otology*.

THE TOUROSCOPE.

THIS instrument is for the purpose of exhibiting plain and colored transparencies and lantern slides, singly, or in combination with each other, and is capable of producing some very rich, beautiful, and even surprising effects.

It consists of a very fine, large lens, similar to those used in the graphoscope, with a dark chamber, in connection with (what is its greatest novelty) a system or series of slots or grooves, for the insertion of the glass or other transparent pictures to be looked upon.

Referring to the drawing: at A are three or more receptacles for the pictures. At B a thin plate of plain or colored ground glass is inserted, in order to soften the effect of the light which is transmitted through the pictures. At C is a

larger receptacle for the same purpose as those at A, only of a size to accommodate such pictures as are mounted in wood, as many lantern slides are.

To produce the intended effects in endless variety, a picture—say of statuary—is inserted in the first slot at A. Now examine its lovely appearance, and then insert in the next slot, behind it, a view of an interior of a cathedral or a picture gallery, and you at once find the statuary piece to have new beauty and interest, for it is located properly in some harmonious interior. The effect of the whole is now heightened by placing a blue, or red, or golden tint in the groove next behind, or at C.

Or the first picture may be a view with splendid foreground and empty sky. Natural clouds may be made to treble the effect by placing a cloud transparency behind the other, and the tinter may then be used or not, as you please. Or it may be you have a beautiful waterfall in first which you can variously tint, and then from its foaming face bring out a splendid statue, with effect almost equal to that of a dissolving lantern. Sunset, sunrise, and moonlight effects may be added to properly chosen landscapes, and day turned into night, and *vice versa*.

The majority of the effects obtainable with a lantern may be secured with the touroscope, and the number of changes possible with it are only limited by the genius of the one working it and the quantity of pictures at hand to work with.

To those who have a variety of transparencies it will be particularly welcome, for by its means they can be used at day or night, and in any light, just as effectively, and as well singly as in combination.

If the portrait photographer would have one on his reception-room table, with a few portrait and other transparencies, he could, by properly pushing the thing, sell many transparencies from his negatives, and tourosopes to exhibit them in. Here is real business for those who want it. Undoubtedly the touroscope, if taken hold of, will open up a new avenue for the growth of photography, and create a demand for a new style of picture. Neither the stereoscope nor the graphoscope was much thought of at first, but see what wonderfully profitable things they have been for our art.—*Phil. Phot.*

PHOTOGRAPHS OF MICROSCOPIC OBJECTS.

THE credit for the excellent article entitled as above, which appeared on page 3404 of SUPPLEMENT, No. 214, was inadvertently omitted. It was written by Carl Meinert for the St. Louis *Practical Photographer*.

[Continued from SUPPLEMENT, No. 217.]

THE SUN'S RADIANT ENERGY.

By S. P. LANGLEY, Allegheny Observatory, Pa.

WHEN the spectrum is allowed to fall on a sensitive plate we can, as has been mentioned, obtain a photograph of it, but, unless special means are used, not of all the lines. The photograph obtained with the salts of silver will fail altogether to reproduce the yellow part; will show something of the green and nearly all of the blue; while up in the violet end the picture is very clear, and beyond the violet, where to all appearance the spectrum has ended, a host of sharply-defined lines comes out on the plate from a region where the keenest eye sees nothing whatever. This is when the instrument is directed full on the sun (not necessarily on its edge, as in a former experiment), and it would appear at first as if there must be in the white sunlight a special kind of rays, which produced not colors or vision, but chemical changes on the plate, printing there images of the slit, which were produced by something quite different from light.

If, on the other hand, we take a delicate thermometer or a radiometer, and move it into successive parts of the spectrum formed by a prism, we find little effect in the blue, more in the yellow, still more in the orange, and as much or more quite beyond the red, where, too, the eye sees nothing. Again, it seems at first that here is another kind still of radiation, causing heat, and which is distinct from that producing light, since one appears where the other does not. In some text books yet in use, diagrams even are given to show the amount of chemical, light, and heat rays in the different parts of the spectrum; but quite recently students of science arrived at a better understanding. The results of old and modern investigations are now seen to point to one conclusion. Given in general terms, this may be said to be that there is, in reality, no such thing as a chemical ray, a light ray, or a heat ray; there is nothing but radiant energy—motion of some kind, causing vibrations across space of something between us and the sun—something which, without understanding fully, we call "ether," and which exists everywhere, even in the "vacuum" of a radiometer. These vibrations are measurable with great accuracy (by processes of which an explanation would be here out of place), and are found to be extremely small in all cases, but to vary among themselves, somewhat as those coarser ones do which have been long known to produce sound. As the high notes of a piano are caused by the rapid vibration of strings, and the low notes by comparatively slow ones, but the sound, whether acute or grave, is due to one thing—motion of the air; so the mis-called "chemical" or "actinic" rays, as well as those which the eye sees as blue, or green, or red, and those which the thermometer feels, are all due to one thing—motion of the ether. Rapid motions exist, which set the molecules of silver vibrating, and are registered by the photograph. These fall also on the eye and on the thermometer bulb or radiometer, and produce some kind of mechanical effect in a minute degree, but not one which those instruments are fitted to register. The longer radiations in turn are not themselves "heat," any more than those which the retina of the eye responds to and calls "light." We have always one and the same cause—radiant energy; and we give this one thing different names: "actinism," "light," or

FIG. 27.—SECTION OF CALORIMETER.

"heat," according as the instrument which reveals its presence to the mind is some chemical substance, the retina of the eye, or a thermometer.

It will appear from what has just been said, that there are substances which respond to some of the ethereal vibrations and not to others. The substance which is most generally useful in receiving and, so to speak, absorbing them, is perhaps that which has been recently put to such remarkable use by Edison—common lampblack. Let us try to measure the sun's radiant energy by measuring all of it we can get in the form of heat, and endeavor in the process to reach some idea of the temperature of its surface. There are many ways of measuring the heat, one of which, convenient for its exposition of principles, we give here, though it is not perhaps the best in practice, returning to other methods later.

Thus, in Fig. 26, let A B D E be a large hollow sphere,

inclosing a small thermometer at its center, *t*. The bulb is carefully covered with lampblack to enable it to absorb as many radiations as possible, and the inside of the sphere is blackened in the same way. Suppose the temperature of the whole at first to be that of absolute cold or at the natural zero, and that the sphere is kept at that, whatever happens. If we remove a given part of the sphere, let us say one-twentieth of the surface area, A B, and fill the aperture with a piece of white-hot iron, this will send heat to *t*, and the thermometer will rise, though not to the temperature of the iron, which, for the sake of illustration, we will call 2,400°. If the whole sphere were at 2,400° the thermometer would also shortly register this (provided we could make one to stand it), but in fact it is receiving such heat from one-twentieth of the sphere only, and giving it

FIG. 28.—CALORIMETER.

out by reradiation from the bulb to the other nineteen-twentieths, that is, to the whole cold surface around it, which returns nothing. In this case, then, the temperature of the thermometer will be found by reflecting that it gives out very nearly twenty times as much heat as it receives, and that it must register nearly $2 \times \frac{1}{20} 2,400^\circ$, or 240°. On the other hand, suppose we, in a new experiment, find the thermometer reads 100°, and want to know the temperature of the iron. We must find what proportion the hole, covered by the hot iron, bears to the whole sphere, and multiply the 100° by this. Were the hole, for instance, in this case but one-thirtieth the size of the sphere, evidently the temperature of the hot iron must have been about 3,000°. If the iron were ever so distant, provided it filled the whole aperture to an eye placed where the bulb is, no external rays could fall on *t* except from it. It is immaterial, then, in this experiment, whether the hot body is near or far, provided the hole is always kept so small that no foreign radiation enters. The reader will see the bearing of this when he reflects that if we turn the opening in the sphere toward the sun, with the above precautions, the result will be just the same as if we had plugged the aperture with a simple piece out of the sun's photosphere and of its actual temperature. We have now only to multiply the thermometer reading by the number of times the surface of the sphere is greater than the hole, and we have apparently found the real temperature there, as exactly as if we had reached across space and dipped our thermometer bulb into the actual surface of the sun.

There are many drawbacks to this plan in practice, and it is only in case radiation and temperature are proportional that it is sound in theory. Various modified, however, it is much relied on by experimenters. Fig. 27 gives an internal, and Fig. 28 an external view of the latest construction adopted by M. Violle, of Grenoble, a distinguished recent investigator. In practice the simplicity of our first illustration is widely departed from, and the use of the instrument is much modified. *T* is the thermometer, whose bulb is at the center of a double sphere maintained at 0° (Centigrade) by a current of ice water circulating through tubes, *t t'*, or by ice put in at *O*. *D* is a diaphragm with various apertures; *M*, a mirror, in which we view the reflected image of *g*; *g* is

ACTION OF LENS.

a piece of ground glass, on which the shadow of the thermometer bulb falls when the instrument is correctly pointed to the sun. This instrument is capable of being used to give us (according to the method just explained) the temperature of the sun, or else the number of units of heat it sends out. The latter result will be presented, however, by another method subsequently, but before we can do either accurately we must find out how much heat is absorbed by our air. To do this, M. Violle has taken his whole apparatus to the summit of Mont Blanc, and finds there the radiant heat from the sun to that below almost exactly as 4 to 3. The total heat at the boundary of our atmosphere is, according to him, something like one-half greater than at the sea level, a rather larger result than one obtained by another means, to be given later.

To find the temperature of the sun from such an apparatus we virtually multiply the thermometer reading by the fraction expressing the ratio of the surface of the sun's disk to that of the celestial sphere, a ratio which is rather less than 1 to 180,000. In the observations of Soret, on Mont Blanc, the inclosed thermometer read nearly 38° Fah. above the temperature of the inclosure, and hence the temperature

of the sun's surface would appear to reach at least the enormous number of $38^\circ \times 180,000 = 6,840,000^\circ$ Fah. The more prolonged and elaborate experiments of Mr. Ericsson give a temperature of about $4,000,000^\circ$ Fah., and indicate that each square foot of the solar surface radiates over 300,000 units of heat per minute; in other words, each foot can furnish heat equal to that required to drive a theoretically perfect heat engine of over 7,000 horse power. There is a very fair agreement among all experimenters as to the amount of heat radiated, but a wide discrepancy as to the temperature, the very same data which above are interpreted as meaning $4,000,000^\circ$ Fah. being asserted by distinguished French physicists to indicate less than $4,000^\circ$ Fah. This monstrous disagreement is not due to any considerable error of measurement—all are pretty well agreed on that—but to our ignorance of the laws connecting temperature and radiation. There are two rules in use, one of which was given by Sir Isaac Newton. It says, in substance, that if a body be raised to double its former temperature, it will radiate double its former heat. The other, given by the French physicists Dulong and Petit, is in the shape of a complex formula, which virtually declares that if a body be raised to double its former temperature it will radiate more than double its former heat; in case both temperatures are high, enormously more. Proving that we get enormous heat from a limited area of the sun's surface, then, does not, in the eyes of some physicists, prove that area to be proportionately hot.

In this there is involved a very practical consideration for us, for this apparently abstruse physical question has a bearing on the duration of the human race, since that duration depends not merely on the present heat of the sun, but largely on the rate at which the sun is spending heat. Suppose some benumbed wanderer to find himself before a fire which seems as if miraculously burning for him, in a cheerless waste, where he would otherwise perish. A fire of straw may be for the moment as hot as a fire of coal; but as the first will spend its stock of heat at once and leave him to die of cold, and the second will spend it slowly and warm him for indefinite time, it is an important thing for him to know the rate at which his fire burns, and this is our own case. The human race—however it came here—finds itself before such a fire, and thus dependent upon it; for it lives on a planet whose proper surface temperature in the absence of solar radiation is variously estimated at from 70° to 273° below zero; and we are all warming ourselves at the sun, without which we should promptly die.

SECTION OF A POLYZONAL BURNING LENS.

Let us come back to the question of the sun's temperature, then, with a sense of its personal interest to us. We should know more about it if we could carry our thermometer nearer to the sun, but we can practically do so by means of a burning lens, Fig. 29, where S F S' is the real angle subtended by the sun, S F S' that which it is made to appear to subtend by the lens, so that the effect is nearly that which would be produced by approaching till the solar diameter filled S S'. The actual construction of the burning glass on a very large scale is not now common, as we have other ways of producing intense heat always at command. When made at present they are built up in sections, as in Fig. 30, so as to avoid the necessity of an enormously thick and expensive lens. Such a one as this, in which the lens subtends an angle of about 30° , as seen from the focus, is capable of melting platinum and the most refractory surfaces; and as a great deal of the heat is absorbed by the glass or otherwise lost, if we could approach the sun till it filled such an angle to the eye, we should find the temperature even higher. It is probable that few of the materials of which the crust of the earth is composed would remain in the solid form if carried very much nearer the sun than the presumed orbit of the hypothetical "Vulcan;" and it may be remarked in passing that it is not unlikely that, in case such an intramercorial planet as Professor Watson is said to have recently discovered had an orbit whose nearest approach carried it within 10,000,000 or 12,000,000 miles of the solar surface, it would prove to be heated to the point where it would be self luminous.

The writer, some time since, made a comparison of the light of the sun with that given from the molten steel in the Bessemer converter. This was chosen as an example of the greatest temperature attained on the large scale in the arts, and it is one which is known to equal that at which platina melts. Looking down the mouth of the converter we see at one stage of the process a stream of molten iron poured into the vessel in which the melted steel is already glowing in the background. Every one knows how bright white hot (and still more melting) iron appears, but in this case the steel is so much brighter, that the fluid iron in front seems like thick chocolate poured into a white cup. The steel, just before it is itself poured, seems of sun-like brilliancy, until we come to compare it with the sun itself, which was done by means of a photometer, so arranged that the steel light shone in at one side and the sunlight on the other. When the angle subtended by each source of light was equal, the image of the molten steel was put out by the presence even of much enfeebled sunshine, and ceased to be visible, as the dull flame of an alcohol lamp would be if it were set beside an electric light. The area of glowing metal exposed was considerably over one square foot, and measures made with

every precaution showed that any single square foot of the solar surface must be giving out much more, at any rate, than one thousand times the light that the melted steel did.

We are not, it is true, entitled to conclude from this that the heat is in exactly the same proportion, but we are justified by inference from this, and by other experiments not here given, in saying not only that the temperature on the sun's surface is far higher than that reached in our furnaces, but that the heat is in fact so enormously greater than any furnace heat here that they can scarcely be made the subjects of comparison. Other considerations, on which we cannot now enter, give the best grounds for belief that this heat is likely to be kept up sensibly at its present rate of emission for a period which, with reference to the brief history of the human race, may be called almost infinite. These are important conclusions, whose practical bearing will be more fully developed in what follows.

When we watch a gentle summer rain, does it ever occur to us that this familiar sight involves the previous expenditure of almost incredible quantities of energy, or do we think of a drizzly day as perhaps calling for a greater exertion of Nature's power than an earthquake? Probably not; but these suppositions are both reasonable.

THE PYRHELIOMETER.

Take Manhattan Island, for instance, which contains 20 square miles, and on which one year with another over 20 inches of rain falls. (To be within the mark we will call the area 20 miles, and the annual rainfall 30 inches.) One square mile contains 640 acres, and each acre 43,560 square feet. Multiplying by 640 and dividing by 12 we have 2,323,200 as the number of cubic feet of water on 1 mile in a rainfall of 1 inch, and as a cubic foot of water weighs $997\frac{1}{16}$ oz. avoirdupois, and there are 35,840 oz. to the ton, this weighs $2,323,200 \times 997\frac{1}{16} \div 35,840$, or, in round numbers, 64,636 tons (to 1 mile and 1 inch of rain). As there are 20 miles and 30 inches, the annual rainfall on this little island is 1,393,920,000 cubic feet, or 38,781,600 tons. The amount of this may be better appreciated by comparison. Thus, the pyramid of Cheops contains less than 100,000,000 cubic feet and weighs less than 7,000,000 tons, and this water, then, in the form of ice, would many times replace the largest pyramids of Egypt. If we had to cart it away, it would require 3,231,800 cars, carrying 12 tons each to remove it, and these, at an average

inch of rain spread over the whole area of the United States is not an extraordinary day's rainfall throughout its territory, but it will be found by any one who wishes to make the computation that such a day's rain represents a good deal over the round sum of ten thousand of millions of tons, and that all the pumping engines which supply Philadelphia, Chicago, and our other large cities, dependent more or less on steam for their water supply, working day and night for a century, would not put it back to the height to which it was raised by the sun before it fell. Every ton was lifted by the silent working solar engine, at the expense of a fixed amount of heat, as clearly as in the case of any steam pump, and this is the result of an almost infinitesimal fraction of the heat daily poured out from the sun! Now heat is something men have only in quite modern times learned to think of as a measurable quantity, and we must remember that we cannot even begin to have accurate knowledge of any form of force till we can answer the question, "how much" about it, not vaguely, but in figures.

When we hold the right hand in warm water, the other in cold, for a few moments, and then plunge both in the same basin of tepid water, the two hands will give different reports; to the right the fluid is cold, to the left it will feel warm, though it is the same really to both, and we might vary the experiment by trying it with shade and sunshine. In either case the experiment would convince us that our sensations were very untrustworthy, and that if we were going to measure the sun's heat we must depend on some sort of instrument and not on anything that can feel. The first things we have to do about the sun's heat is to measure it, not to guess at it—to measure it as accurately as we would anything which we could try with a foot rule or put in a pair

of scales. When we have done this we have a solid foundation to work on, and the doing this has been thought a worthy occupation of a considerable part of their lives by many able men.

One of the first of these was Pouillet; others, such as Saussure and Herschel, had been at the problem before him, but his results were the most accurate until very recently, and even recent work has not materially affected his conclusions.

His instrument is easily understood with a little attention. We have it represented in Fig. 31. Let us first remark, that what we want to get is the sun's direct or radiant heat, quite irrespective of that of the atmosphere around us, and that to get definite results, by our present method, we want to know how much of this radiant heat falls on a given surface of one square foot or yard. We may reckon it by any one of the numerous effects heat produces; practically it is convenient to let it warm water, and to see how much it heats, through how many degrees, and in how many minutes.

Pouillet's pyrheliometer is substantially nothing but a very shallow cylindrical box, A A', filled with a measured quantity of water. It is mounted on the end of a hollow rod, having at its other extremity a metal disk of the same size as the water box. When the shadow of the box exactly covers

ERICSSON'S SOLAR CALORIC ENGINE.

length of 30 feet to the car, would make 6 trains, each reaching in one continuous line of cars across the continent, so that the leading locomotive of each train would be at San Francisco before the rear had left New York—a result which appears at first so incredible that it seems best to give the figures on which we rest the statement.

Now this is for a very small part of a single year's work of the sun in raising water to produce rain on the little spot of Manhattan Island alone—a spot, geographically speaking, hardly visible on the map of the country. Again, $\frac{1}{16}$ of an

the disk the instrument is pointed true on the sun. Held in the hollow rod is an inverted thermometer, whose bulb is within the water box, A A'. This enables us to read the temperature of the water from moment to moment. It is not enough to expose it for a time to the sun and read the thermometer—this would give too small a result, because the instrument as soon as it is warmed commences to radiate the heat away again, like any other hot body; and we would like, if we could, to keep all this heat in it to measure. As we cannot, we reach the same result by finding how much is

lost, and allowing for it. Thus, the observer first leaves the apparatus in the shade (for instance) five minutes, and notices whether it loses or gains from its own radiation to surrounding objects. Then he leaves it directed to the sun, which shines full on it for five minutes more, the thermometer being read at the end of this exposure; and finally, at the end of another five minutes, during which the instrument has been left in the shade, it is read again. The half sum of the losses or gains in the shade is the radiation, and this added to or subtracted from the apparent gain in the sunshine is the actual number of degrees that the temperature of the water would have been raised, had all the solar heat been retained. Measuring in this way, we are independent of the temperature of surrounding objects.

Mr. Ericsson, the celebrated engineer, who has improved on Pouillet's apparatus, has in fact shown that we do in accurate experimenting always get more heat (other things being equal) on a day in winter than in summer, as we should, if it is the direct solar radiation alone we are after; for that will be the greatest when the sun is nearest, as it is in our northern winter. Again, measuring when the sun is high, and at all altitudes down to the horizon, we find less and less heat, as the rays go through more of our atmosphere, and hence we can make a table showing how much this absorbs for every altitude, and consequently how much we should gain if it were taken away altogether. When this is done we find, according to Mr. Ericsson's late determinations (which we substitute for Pouillet's), that the direct heat of the sun on 1 square foot in March is competent to raise 7.11 pounds of water 1° Fah. in one minute. This is what it would do if we got outside of our atmosphere; but owing to the absorbing action of this, the radiation which actually reaches us, under a vertical sun, will so heat only about 5.6 pounds. According to the mechanical theory of heat this effect is that which would be required to drive an engine of 5.6×772

$\frac{3300}{1} = 0.131$ horse power. In other words, the heat of a vertical sun after absorption by our atmosphere represents rather over one horse power to each square yard. It is true that we cannot always have a vertical sun, nor clear sky, nor can we realize in actual work this whole effect by any form of engine, but when we have made the largest deductions, the statement of the sun's power, in this form, is calculated to excite astonishment. We have here, since there are 5,280 linear feet in a mile, $5280^2 \times 0.131 = 3,659,000$ horse power to the square mile (in round numbers); so that if we suppose in actual practice one horse power realizable to ten square yards, the efficient working power of sunlight on an area much smaller than such a region, for instance, as the Adirondacks, is much greater than that of the computed actual steam power of the whole world. Upon the surface of the whole earth the heat at any time must be equal to that falling vertically on one of its great circles, which contain, roughly, about 50,000,000 square miles. Here, when we come to multiply the number of miles by the power per mile, we reach figures bewildering in their magnitude, but which are demonstrably correct. The only way this heat is utilized by conversion into power at present (steam power being dependent on coal made by the sun in past times) is by windmills and waterwheels, both supplied by the sun, as in fact in every form of power, unless we except the insignificant one of tide mills, a kind only in a very remote degree dependent on solar action.

The student must be referred for the more indirect but equally certain action of the sun in providing the coal by which our engines are driven to special treatises (the popular one on "Heat" by Tyndall is a good introduction to the subject for the general reader), but this stock of coal is by no means unlimited, and in the course of a few centuries at most it will be exhausted in Great Britain, for instance, at the present rate of consumption. We may depend that long ere that time her engineers will, with those of other countries, be turning to the immense source of power in the sun's direct rays, and that regions now barren under a tropical sun, where there is no fuel, water, or scarcely human life, will rise into new importance as the proper seats of industry, fed by the new power.

Engineers have hitherto done little for this, but we may be sure they will in the future do more. We are not writing a historical article, and, merely mentioning the curious fact that Solomon de Caus, the unhappy man of genius whose connection with the history of the steam engine is so well known, was one of the first to invent a solar engine, we pass over much that is historically interesting, to come to the present. Mr. Ericsson, whose work we have already quoted, is understood to have given a large part of his life, and particularly of his late years, to the problem. Fig. 32 is a drawing of a solar hot air engine of his invention, which is said to make 400 revolutions per minute. This is probably to be considered rather as an illustration of the feasibility of the instantaneous conversion of solar heat into power than as a useful form in practice, the circular mirror not being adapted for work on a large scale. The inventor, however, at present has not published the dispositions he is understood to have made for concentrating the heat in a larger working engine.

In France, M. Mouchot has, for many years, been pursuing similar studies; a section of one of his machines is shown in Fig. 33. This has the inconvenience of a very large heat reflector in a form which is expensive and liable to injury, but it must be remembered we are now feeling our way in the first steps of invention in his new field. Such things are, in one sense, but mechanical toys at present; but it was such toys as Hero's æolipile which preceded the steam engine. These are already more than mere toys, however, and in their promise, if not in actual performance, worth attention. If the reader wishes to know what is the best so far realized, or at least so far made public, we may refer to the *Comptes Rendus* of the French Academy of Sciences for October 4, 1875, where M. Mouchot states that he now employs a metallic mirror with a linear focus, in which focus is the elongated boiler he uses, and that he also makes use of a glass cover to let the solar radiation pass, but to retain the obscure heat re-radiated from the boiler. In the largest machine actually built, he employs, however, a mirror in the form of a truncated cone, Fig. 33, about 10 feet in diameter at its large, and 40 inches at its small section, looking like a mammoth lamp shade, with its concavity directed skyward. The material is copper, coated inside with silver leaf. A large bell glass covers the boiler, which is about 32 inches long. The whole apparatus can be made to follow the sun. On May 20, in ordinary weather, 20 liters of water at 20° C. were let into the boiler at 8:30 h., and rose to 121° (two atmospheres) in 40 minutes, and then rapidly to 5 atmospheres, beyond which, owing to the slight nature of the apparatus, it was not thought safe to go. On the 22d July, at about 1 o'clock, under uncommon heat, the apparatus vaporized 5 liters of water per hour. The inventor claims that under

favoring circumstances, he actually realizes about 10 calories per minute per meter, which is a trifle less than one horse power to ten feet square. Something exceeding this might probably be reached with the same apparatus in a drier air; upon the whole we are justified in speaking of one horse power to the square of ten feet on the side, as actually realized; one horse power to one square yard being about the limit of that which is theoretically realizable.

It must be remembered that, according to what has been stated, the sun offers us a source of power which is practically infinite both in amount and duration. According to what we believe we know with assurance, we can say that the sun is not a fire, fed by any fuel, but a glowing gas ball, maintained at an enormous temperature, and radiating enormous heat from a fund of energy maintained by the contraction of its volume, and by the impact of meteoric bodies. We can reckon with confidence that there will be no material diminution of its supply from these sources for a duration only to be reckoned by hundreds of thousands of years. As to the amount of heat supplied, it is inconceivable. The writer has made a computation of the time all the coal of the world would suffice to maintain the sun's radiation, were the actual source of it to fail, and were our whole supply of coal transported to its surface and burned there in its place. The result, otherwise stated, is that in any one second the sun radiates into space an amount greater than could be made good by totally consuming all the known coal beds of the world!

Something like 300 years separates the England of to-day, with her countless furnaces and engines, from the England of Elizabeth, in whose reign the spinning wheel was almost the most intricate piece of machinery on the island. Something like 300 years more, it is said, is all that separates the England of to-day from the future England whose furnace fires will have died out with the flame of the last bushel of coal under her surface; whose harbors send out only sailing craft; whose manufacturing population has gone to other lands, and whose "black country" is growing green again as nature covers the ashes of her burnt-out mineral wealth with new verdure for the few who remain on the soil. We do not pretend ourselves to join in such pessimist views, or try to look into the future so far, though this is a very little way compared with what we know of the rise of man to civilization. To us, in this country, such a time, if it is ever to come, is immensely distant. But what is certain is that if some such change do not take place it will be through the discovery of a new source of power, for of the old, the coal, when our underground supply is used up we cannot get any more. Let us remember, then, in time, that though the stock be great there is no renewal.

For a journal counting among its readers so many interested in the applications of power as the SCIENTIFIC AMERICAN, I have thought, elementary as this presentation of the sun's claim to interest, merely as a source of mechanical power, is, it is better to offer it. We are, in closing, led back to the suggestion with which these articles began, of the sun's influence in altering the conditions of existence for the human race.

Future ages, it has been truly enough observed, may see the seat of empire transferred to regions of the earth now barren and desolated under intense solar heat—countries which, for that very cause, will not improbably become the seat of mechanical and thence of political power. Whoever finds the way to make industrially useful the vast sun power now wasted on the deserts of North Africa, or the shores of the Red Sea, will effect a greater change in men's affairs than any conqueror in history has done, for he will once more people those waste places with the life that swarmed there in the best days of Carthage and of old Egypt, but under another civilization, where man no longer worships the sun as his god, but has learned to make it his servant.

MARS.

If the two great leaders of the planetary system have filled us with astonishment at their magnitude and velocity, and with perplexity in the contemplation of arrangements so incomprehensibly unlike our own, they have not exhausted all the resources of the season. There yet remains a much nearer and more intelligible neighbor, who possesses a peculiar interest for an opposite reason—his similarity to ourselves. This especial character of the ruddy planet has long been known to astronomers, and will naturally make him an object of careful study before we leave him too far behind; and though the opposition of this year does not diminish his distance so much as that of 1877, yet his almost startling brilliancy has been alone enough to prove it among the favorable ones; for English astronomers, at least, it is far more propitious than the last, from his greatly-increased elevation. Much had been expected at that last opposition from the broad expansion of his disk, but the indistinctness of detail was a general source of disappointment here, though the success of Schiaparelli at Milan and Green at Madeira showed that the fault lay chiefly—perhaps not exclusively—in the English sky. My own impression certainly then was that, besides the want of clear outline inseparable from so low an altitude, there was a deficiency in decidedness of form and strength of tone as compared with previous observations, the cause of which may have lain in the atmosphere of the planet, affected possibly by especial proximity to the sun in an orbit of considerable eccentricity. At any rate, we may reasonably hope to find the present season more favorable for exploration than the last; for though at nearest approach we have only had 23" of disk instead of 29.4" in 1877, success depends, with equal instrumental sharpness, much more upon altitude and steadiness of air than on increase of visible surface. Schiaparelli was enabled to obtain his most valuable results after opposition, when the diameter had decreased to 20" or even 16", and he asserts that he was able to continue his researches with advantage even till it came down to less than 6".

We have alluded to the special interest of this planet arising from its supposed close correspondence with the earth, and it may not be out of place on this occasion if we bestow a little pains in examining the ground of that supposition. This we may conveniently do by imagining what would be the telescopic aspect of our own globe at a distance not equal to that of Mars, as we should then appear about twice as large, but such as to reduce our apparent diameter to equality with his in a favorable opposition.

There is every reason to believe that our surface would then appear mapped out by a distinct separation into oceans and continents, the fluid being darker than the solid masses, and preserving their bluish-green tinge but little affected by distance. Except in very shallow parts, their darkness would be uniform from the rapid absorption of incident light, and their contour would be sharply defined.

The general hue of the land would be lighter; and at a distance where its variegated patches of color would be separately undistinguishable, the result would be a gray resulting from the mixture of many tints, except where tracts, such as the great deserts or prairies, might subtend a sufficient angle to preserve their natural hue, or where extensive forests might rival seas in depth of tone. In many places, too, brilliant streaks and patches would show where mountain masses were capped with dense clouds, or surpassed the level of perpetual snow; but our largest rivers, except possibly at some great *embouchure*, would be totally imperceptible.

Such, in its general lineaments, would be the distant aspect of our globe, if the whole lay at once distinctly before the eye. But this would never be the case. The formation and transference of masses of vapor would produce incessant and most uncertain changes. In some regions, and at certain times of the year there would be unbroken clearness; in other tracts the outlines and coloring of land and sea would be indistinct or concealed, at times for short, but occasionally for very lengthened periods. And the interposition would doubtless be always of a white aspect, since such is the character of our clouds wherever they are illuminated by the sun. Toward our polar regions this whiteness would be permanent, in the form of great spots, eccentric as regards the axis of rotation, increasing through and after the winter, with a corresponding diminution after the summer solstice. There would always be, however, a large unmelted area, even at the warmest period, and its outlines would probably be often irregular and extended from the presence of great masses of frozen clouds. Now, if these would be the probable features of the earth, presented to us at a distance of seventy or eighty millions of miles, in what respects shall we be able to trace the resemblance on Mars? We are soon brought to the conclusion that, according to the general rule already referred to, there is more analogical than identical correspondence; the inclination of axis, the eccentricity of orbit, the duration of day and night, the respective length of the seasons—from the relative similarity but not identity in these particulars, we are prepared to meet with the same kind of proportion throughout. As far as aspect goes, a solid and fluid condition may be thought to divide each superficies; but if so, the land there is in a much larger ratio to the water; and if the color of our oceans is repeated on Mars, we have little to correspond with the orange-yellow tinge, which, since it leaves unaffected the polar snows, cannot arise from atmospheric absorption. The so-called seas, too, though in some places apparently deep and dark, frequently shoal off and show subaqueous markings in a way that perhaps would be scarcely paralleled in our own.

In atmospheric conditions, indeed, we find great approach to identity; yet even here there are discrepancies; the polar snows of the earth would probably not be distinguishable from the upper surfaces of terrestrial clouds floating in any latitude, while on Mars, such peculiar whiteness, though sometimes vividly brought out in certain localities, is by no means universally concurrent with the local indistinctness and confusion that so often puzzle the areographer. The action of solar heat on the polar deposit seems identical, and yet it may be a question whether our arctic snows are marked out by as regular a contour as those of Mars, and still less would they show what has often been observed there—a strongly marked border of darkness. And however striking and suggestive may be the fact that in either globe the thermal axis is not that of rotation, we have the discrepancy that on Mars the glaciation is reduced in a much greater ratio, so that the pole, according to Schiaparelli, was in 1877, entirely free. This observer, who is fully impressed with the terrestrial theory, admits that the vertical sunlight, instead of producing clouds, as on the earth, appears to clear the sky of Mars, and thinks the atmospheric changes there of a more simple nature. That the southern hemisphere would be subject to greater extremes of temperature than the opposite, as shown by the variation in size of the white caps, might have been expected as a direct consequence of the elliptical form of its orbit greatly surpassing our own.

A passing reference will be sufficient to the brighter zone, which, according to some observers, distinguishes the edge of the disk, but which others, including myself, have never detected; or to the bluish or greenish patches sometimes noticed on the limb. Such appearances may be mere results of contrast; at any rate they may be left on one side as not directly affecting our present comparison. But there is one consideration which cannot be thus disposed of, and which, obvious as it is, seems to have been taken little into account—the very different amount of solar radiation on the two planets. The heat derived from the sun on Mars is only from $\frac{1}{2}$ to $\frac{1}{3}$ of that received by ourselves. And thus we seem reduced to the alternative of either abandoning to a considerable extent the supposed closeness of resemblance in material and constitution, or of maintaining it by the hypothesis of a supply of heat on Mars derived in some other way. No ice such as ours would be so reduced by the unaided action of that distant sun—no terrestrial continents could remain so long unclothed with snow. The dilemma is a curious one. It may not be incapable of explanation, but it certainly requires more special and careful consideration than it has yet received.

We have been looking at the subject much as though a supposed view of the earth at a suitable distance might be fairly paralleled with a corresponding representation of Mars, as drawn by the best observers. But it must be added, with much regret, that such is not yet the case. As to certain main features of that planet, there is indeed a very satisfactory agreement; but with regard to others, and as to details in general, we feel, as a first impression, some extent of disappointment. It may be fairly admitted that the disk is, after all, not large, and its markings often feeble; and there is great diversity in instruments, and eyes and hands, and aptitude for the work. Yet still an exhaustive survey, of which we cannot even indicate the materials in this place, but which we trust will be carried on, as it has been most ably commenced, by Dr. Terby, of Louvain, would show much unexplained, and some things unsatisfactory. Mädler laid the foundation of definite areography; but his successors, while enlarging, have not always confirmed his results; and, to say nothing of others who have bestowed much pains upon the subject with more or less mutual agreement, our own keen-eyed and accomplished Dawes—at least as represented by Proctor—is found to differ in some parts materially from Lockyer, Kaiser, and Secchi. At the last opposition in 1877, the subject was taken in hand with especial zeal and perseverance by Schiaparelli at Milan with an exquisitely sharp Merz object glass of 7.15 inches aperture and 10 feet 8 inches focus, and by Green, who went out purposely to Madeira with a 13-inch mirror by With, the perfect polish and critical