air. These facts add not a little to the difficulties to be overcome by the energetic observers and investigators who are trying to deduce order out of an apparent chaos.

Meteorites.—The fragments which fall immediately after the disappearance of large meteors have been carefully collected and preserved in mineralogical museums, and have been studied with special interest. The largest collections in Europe are in Vienna, Paris, London, and Berlin, some of these representing over three hundred localities. In the United States there are large collections at New Haven. Amherst, and Louisville.

In several respects these fragments differ at first sight from terrestrial rocks.

They are when found almost always covered in part or entirely with a very thin black crust, generally less than $\frac{1}{30}$ of an inch in thickness. This crust may have a bright lustrous surface, or it may be of a lustreless black. It has evidently been melted, yet so rapidly as not to change in the least the parts of the stone immediately adjacent. Streaks showing the flow of the melted matter are often seen on the surface. Upon some surfaces are what appear to be deposits of the melted matter that has flowed off from the others. Some surfaces are only browned, showing an apparently recent fracture, and some cracks are found in stones which are not yet completely broken in two.

The surfaces very often have small cup-like cavities, sometimes several inches in diameter, sometimes like deep imprints in a plastic mass made by the ends of the fingers, and sometimes still smaller. These "cupules" have not only various sizes in different stones, but even in the same stone differ considerably from one surface to another. They appear in meteorites that are almost exclusively iron, as well as in those mainly destitute of that metal, and they may be regarded as a characteristic of meteorites.

The meteorites have usually metallic iron as one of their component parts. Native iron is very rare indeed among terrestrial minerals, and its presence in the meteorites is therefore characteristic. Sometimes the iron forms the principal part of the body, giving it the appearance of a mass of that metal. Sometimes it forms only a connected framework which is filled in with mineral matter. Sometimes particles of iron are scattered through a stony mass; and a few meteorites are said to be destitute of metallic iron altogether. The metallic iron is always accompanied with nickel.

The stony meteors when broken or cut through have usually a greyish interior, and often exhibit a peculiar globular structure. From the small rounded grains that give it this appearance, the name chondrite (from χόνδρος, a ball) has been applied to this kind of meteorite. Sometimes the irregular fragments are compacted into a kind of breccia.

The pieces as we find them are always apparent fragments of some larger mass, and there is no structural appearance which would indicate that the mass might not be a fragment of a still larger one. In some of the falls fragments picked up at a distance of miles from each other fit together in their simply browned surfaces, showing that they were true fragments recently separated. In some cases surfaces of the stones are partially polished. In some a cross section of the stone exhibits thin black lines as though the melted matter of the surface had been forced into the crevices of the partially broken stone.

The stones when seen to fall, if at once picked up, are usually too warm to be taken in the hand. But cases are on record in which the stones were excessively cold. They sometimes, on striking the ground, penetrate into it from 1 to 3 feet. In extreme cases large ones have struck much deeper into soft earth. Sometimes they are broken to pieces by the impact with the hard earth.

The stones are usually not very large. Although the light of the meteor is such as sometimes to be seen over a region 1000 miles in diameter, and the detonation gives phenomena suggestive of an earthquake over many counties, yet a stone exceeding 100 ℔ is quite exceptional in our collections. The total weight secured at any fall has rarely if ever amounted to a thousand pounds. The average weight of nine hundred and fifty perfect specimens of the Pultusk fall in the Paris museum is 67 grammes, or less than $2\frac{1}{2}$ oz. One of the Hessle meteorites in the Stockholm museum weighs less than 1 grain. Many of the Emmet county meteorites (May 10, 1879) are not much larger, though the largest specimen of that fall weighs nearly 500 ℔.

Meteors traversing the Atmosphere.—We can now get a very good idea of the history of that part of a meteorite's life between its entrance into the air and its arrival at the earth. It is entirely invisible until it has reached that height at which the density of the air is enough to create considerable resistance. Up to that time it moves almost exclusively in obedience to the sun's attraction. The earth's attraction may be neglected, especially during the passage through the air. Since the velocity is a hundred times that of sound, the elasticity of the air is impotent to remove it from in front of the meteorite, or to prevent a high degree of condensation. Perhaps the air is liquefied immediately in front of the stone. Heat is developed in it enormously, and the stone being pressed closely against the hot air is melted, with an intense light. The condensed air charged with the melted matter is pushed aside, and left behind nearly in the wake of the meteor to form the train. The brightness of the train rapidly diminishes behind the meteor, so that the light of the meteor and the train, modified by irradiation, make the whole appear to a distant eye of the shape of a pear or candle-flame. The stone being a poor conductor of heat, and itself rigid, is not heated in the interior either by condensation or conduction, and may reach the ground with its surface only heated, while the interior is as cold as it had been out in space.

If the stone is a small one it will soon be used up by this intense fire. Until its front surface is rounded by the flame, the irregular resistances may cause such a stone to glance. But if the stone is larger it will lose velocity less rapidly. As it comes down into the region where the air is more dense, it will in spite of loss of velocity meet greater resistance. The air pressed hard against it burns it unequally, forming cupules over its surface. The pressure of the air cracks the stone,—perhaps scaling off small fragments, perhaps breaking it into pieces of more uniform size. In the latter case the condensed air in front of the meteor being suddenly relieved will expand, giving the terrific explosion which accompanies such breaking up. In either case a fragment may have still velocity enough to burn on for an instant in its new path and then come invisibly to the earth, covered with a coating, the greater part obtained after the principal explosion. In the latter part of the course the original velocity has almost all disappeared, so that the sound travels faster than the meteor. The air's resistance exceeds the earth's attraction, and the stones strike the ground only with the force of a spent cannon ball. It is no doubt in violent disruption that some of the fractures are made in such a way as to give the rubbed and polished surfaces.

Trains of Meteors.—The smaller meteors generally have no perceptible train. Only in exceptional cases do the trains of ordinary shooting stars remain visible longer than a fraction of a second. An unusual number of the Leonids have a bluish train. But the brighter shooting stars and the larger meteors sometimes have trains that endure for minutes, and in extreme cases for an hour. Such trains are at first long narrow lines of light, though much shorter

than the track of the meteor. They begin at once to broaden in the middle and to fade away at one or both ends. Presently they become curved, sometimes with two or three convolutions. The white cloud floats slowly away among the stars, coiling up more and more, and finally fades out of sight. The cause of all this seems to be as follows. The heated air charged with the debris of the meteor is by the meteor's impact driven off horizontally, causing the narrow train to spread into a cloud. The currents of air differing in direction at different altitudes twist the cloud into its varied fantastic forms. Attempts to obtain the spectrum of the trains have been made, and sodium and magnesium lines have been thought to be detected in them. The observation, however, is one that is not easy to make or confirm. The trains have often colours other than white, and in the case of the brighter meteors different colours are seen in the different parts of the train.

Magnitude.—Some computations have been made of the size of the shooting star meteoroids from the mechanical equivalent of the light developed by their disintegration. If all the energy of the meteor is changed into light, then these computations would be conclusive. But a part is spent in disintegrating and burning the stone, a part in heating the air, and a part in giving direct motion to portions of air. A computation based on the light developed gives only a lower limit to the size.

It seems probable that the larger meteors might be safely regarded as weighing on entering the air only a few hundreds or at most a few thousands of pounds. The smallest visible shooting stars may be equal in size to coarse grains of sand, and still be large enough to furnish all the light exhibited by them. The largest shooting stars furnish matter enough to fill with thin trains cubic miles of space, but this need not require a very large mass.

Meteoric Irons.—There have been found at various times on the surface of the earth masses of metallic iron combined with nickel. These have been so like the irons which have been known to fall, both in their structure and in composition, that they have been without hesitation classed among the meteoric irons. A mass of this character weighing 1635 ℔, found in Texas, is in the Yale College Museum. The Charcas (Mexico) iron in the Paris museum is about the same size. A ring-shaped mass somewhat smaller, from Tuczon, is in the United States National Museum in Washington. A still larger mass is in the British Museum, and many other large masses are in public collections or private possession.

Widmannstätten Figures.—If in any of the meteoric irons, whether seen to fall or found on the earth, a section is cut and polished and then etched with acids, a series of peculiar lines are developed which are known as Widmannstätten figures. The lines of iron unattacked by the acid consist of an irregular grouping of parallel rulings often lying along the faces of a regular octahedron. The exhibition of these figures and the combination of iron with nickel have been usually considered conclusive evidence of the meteoric origin of any iron mass.

Nickel Iron of Ovifak.—In 1870 Baron Nordenskiöld, in his voyage to Greenland, found on the shore of the island of Disco fifteen iron masses, the largest of which weighed 20 tons, all in an area of half an acre. In the basaltic rocks not far distant other iron masses were found embedded in the basalt. The presence of nickel with the iron, and the development of lines like the Widmannstätten figures, were at once accepted as proof of their meteoric origin, in spite of the combination with basalt. A more complete examination has, however, established the terrestrial origin of these irons, and given reasons to hope for new discoveries of relations existing between the earth and the meteors. The additional discovery of small particles of metallic iron in certain other igneous rocks proves that the union of the Ovifak irons with basalt is not exceptional.

Chemical Constitution of the Meteorites.—No new element has been found in the meteorites. Three elements most widely distributed and most important among the meteorites—iron, silicon, and oxygen—are also most abundant in our earth. Daubrée gives the following lists of elements, arranged somewhat in the degree of their importance, in meteorites (Maskelyne adds lithium and antimony):—

Iron.	Titanium.	Arsenic.
Magnesium.	Tin.	Phosphorus.
Silicon.	Copper.	Nitrogen.
Oxygen.	Aluminium	Sulphur.
Nickel.	Potassium.	Chlorine.
Cobalt.	Sodium.	Carbon.
Chromium.	Calcium.	Hydrogen.
Manganese.		

Minerals in Meteorites.—Among the minerals in the meteorites there are several which occur in the rocks on the earth. Among these are cited by Daubrée peridote, pyroxene, enstatite, triclinic felspar, chromite, magnetic pyrites, iron oxide, graphite, and probably water. Several minerals, however, are found which, so far as now known, are peculiar to the meteorites:—metallic nickel-iron, phosphide of iron and nickel (schreibersite), sesquisulphide of chromium and iron (daubréelite), sulphide of calcium (oldhamite), and chloride of iron (lawrencite).

Meteorites of different falls are in general unlike; but there are many instances in which the stones of two falls are so similarly constituted that it is not easy to distinguish them.

In four falls (Alais, Cold Bokkeweld, Kaba, and Orgeuil) the stones contain little or no iron. In these carbon appears not as graphite but in union with hydrogen and oxygen, and also with soluble and even deliquescent saline matters. The combinations are such as to suggest the existence of humus and organic remains. But after careful search nothing of this kind has been detected in them. In general the meteorites show no resemblance in their mechanical or mineralogical structure to the granitic and surface rocks on the earth. One condition was certainly necessary in their formation, viz., the absence of free oxygen and of enough water to oxidize the iron and other elements. Perhaps it is to this fact that are due the resemblances between these minerals and those of the deep-seated rocks of the earth in the formation of which free oxygen and water were also not present.

Gases in Meteorites.—The meteoric stones and irons when reduced to fine particles and placed in the vacuum of a Sprengel air-pump give off small quantities of gases which may be reasonably presumed to have been occluded by the irons at some time in their earlier history. Professor Graham found hydrogen in meteoric irons. Professor Wright has shown that a moderate heat drives off from the stony meteorites carbonic acid and carbonic oxide with a small amount of hydrogen. As the heat increases the proportion of hydrogen (and even some nitrogen) increases till at a full red heat the hydrogen given off is by far the largest portion. From the irons similar gases are given off, but the carbon compounds are not so large a component as hydrogen. The spectra seen in the tails of comets are not strikingly like those of any of these gases. But it is impossible to reproduce in the laboratory the conditions under which the matter of comet's tails is giving off its light. We cannot therefore say that these gases may not be the important parts of the cometic coma and tails.

Meteoroid as Part of a Comet.—Assuming that the meteorite and meteoroid once formed an integral part of a comet, not a little information is given us of the nature of this mysterious body. There is room also for speculation.

First, the comet may be a single hard body which comes from the cold of space into the heat of the sun, and there has fragments broken off, just as a stone is shattered in a hot fire. The nucleus of some of the comets must be very small because invisible in the telescope, and an impulse that would raise a stone on the earth only a few inches would send it permanently away from such a comet. The exposure of new surfaces to the heat of the sun might give occasion for the development of gas to form the comet's tail.

Or, secondly, the comet may be a tolerably compact aggregation of small bodies not in contact, each one being of the size of a meteoroid, and kept near to the rest, not by cohesion, but by their combined attraction. The total mass being small, some members of the group near the comet's perihelion passage can be by the sun's perturbing action thrown out into orbits quite independent of the comet itself, and yet such as relative to the sun shall resemble that of the main group. Perturbations resembling tidal waves might be preparing other members to be cast off at the next perihelion passage of the comet.

In either case, if we suppose, as seems probable, that the comet came from outside the solar system, and that a disturbance by a large planet changed the original hyperbolic orbit into an ellipse, the comet must have passed that planet as a very compact group, if not in a single mass, else the disturbance that changed the orbit would have scattered the group beyond the power of a future recognition of the common origin of the fragments.

Meteoroids as Fuel of the Sun.—The idea has been held by distinguished physicists that the meteoroids in falling into the sun furnish by their concussion a supply for the heat which the sun is constantly sending off into space,—that they are in fact the fuel of the sun. Such a view, however, receives but little support from facts which we know about meteors. The meteoroids of the August and two November periods are evidently permanent members of the solar system moving in closed orbits. The same is by inference highly probable for most of the other meteoroids, and may be true of all of them. Permanent members of the solar system, however, if they ever fall into the sun, do so only after a long period of perturbation. If any meteoroids come from stellar spaces and have any uniform or random distribution of velocities or directions, only a very small portion of these would hit the sun's surface. The far greater portion would go on in hyperbolic orbits. But the earth receives the impact of its portion of these foreign meteoroids, both in their inward and outward course, and in addition encounters a full share of the permanent members of the solar system, of which the sun receives very few or none. It is not hard to show that a supply of meteoroids to the sun sufficient to make good its daily loss of heat would require that the twenty million meteoroids which the earth daily encounters, even if all were from stellar space, should have an average weight of hundreds of tons. The facts do not warrant the admission of any such magnitude even for the large meteors, much less for the ordinary and small shooting stars. Whatever be the source of the sun's heat, all the meteoroids of which we know anything are totally inadequate to supply the waste.

The literature of meteors and meteoroids is very much scattered. It is mainly contained in the scientific journals and in transactions of learned societies. The series of valuable *Reports* of the Luminous Meteor Committee of the British Association contains not only the record of an immense amount of original observations, but also year by year a digest of most of the important memoirs.

Meteoric science is a structure built stone by stone by many builders. In this article no attempt has been made to assign to each builder the credit for his contribution. (H. A. N.)

METEORA, a remarkable group of rock-built monasteries in Thessaly, in the northern side of the valley of the Peneus, not quite 20 miles north-east of Triccala, and in the immediate vicinity of the village of Kalabaka, Stagus, or Stagoi (the ancient Æginium). From the Cambunian chain two vast masses of rock are thrust southward into the plain, surmounted by a number of huge isolated columns from 85 to 300 feet high, "some like gigantic tusks, some like sugar-loaves, and some like vast stalagmites," but all consisting of iron-grey or reddish-brown conglomerate of gneiss, mica-slate, syenite, and greenstone. On the summit of these rocky pinnacles—accessible only by aid of rope and basket let down from the top, or in some cases by a series of almost perpendicular ladders climbing the cliff to the mouth of a tunnel—stand the monasteries of Meteora (τὰ Μετέωρα). At one time they were twenty-four in number; but Holland (1812) and Hughes (1814) found them reduced to ten; at Curzon's visit (1834) there were only seven; and in 1853 not more than four of these were inhabited by more than two or three monks. Meteora *par excellence* is the largest and perhaps the most ancient. The present building was erected, according to Leake's reading of the local inscription, in 1388 (Björnståhl, the Swedish traveller, had given 1371), and the church is one of the largest and handsomest in Greece. St Barlaam's and St Stephen's (the latter founded by the emperor John Cantacuzene) are next in importance. The decorations of the churches contain a large amount of material for the history of Byzantine art, not much inferior in value to the similar treasures at Athos.

Unless the identification with the Ithome of Homer be a sound one, there is no direct mention of the rocks of Meteora in ancient literature, and Professor Kriegk suggests that this may simply be due to the fact that they had not then taken on their present remarkable form. Æginium, however, is described by Livy as a strong place, and is frequently mentioned during the Roman wars; and Stagus appears from time to time in Byzantine writers.

See Holland, *Travels in the Ionian Isles*, &c., 1815; Hughes, *Travels in Greece and Albania*, 1830; Curzon, *Visit to Monasteries in the Levant*, 1849; Leake, *Northern Greece*; Professor Kriegk in *Zeitschr. f. allg. Erdk.*, Berlin, 1858; Tozer, *Researches in the Highlands of Turkey*, 1869.

METEOROLOGY

METEOROLOGY, in its original and etymological sense, included within its scope all appearances of the sky, astronomical as well as atmospherical, but the term is now restricted to the description and explanation of the phenomena of the atmosphere which may be conveniently grouped under weather and climate. These phenomena relate to the action of the forces on which the variations of pressure, temperature, humidity, and electricity of the atmosphere depend, but in an especial sense to the aerial movements which necessarily result from these variations.

In the more exact development of meteorology, the scientific investigation of climate long preceded that of weather. Humboldt's work on *Isothermal Lines*, published in 1817, must be regarded as the first great contribution to meteorological science. The importance of this inquiry into the distribution of terrestrial temperature it is scarcely possible to overestimate, for, though the isothermals were necessarily to a considerable extent hypothetical, there cannot be a doubt that they presented a first sketch of the principal climates of the globe. Dove continued and extended the investigation, and in his great work *On the Distribution of Heat on the Surface of the Globe*, published in 1852, gave charts showing the mean temperature of the world for each month and for the year, together with charts of abnormal temperature. To this, more than to any other work, belongs the merit of having popularized the science of meteorology in the best sense, by enlisting in its service troops of observers in all parts of the civilized world.

In 1868 another series of important charts were published representing by isobaric lines the distribution of the mass of the earth's atmosphere, and by arrows the prevailing winds over the globe for the months and the year. By these charts the movements of the atmosphere and the immediate causes of these movements were for the first time approximately stated, and some knowledge was thereby attained of some of the more difficult problems of meteorology. It was shown that the prevailing winds are the simple result of the relative distribution of the mass of the earth's atmosphere, in other words, of the relative distribution of its pressure, the direction and force of the prevailing winds being simply the flow of the air from a region of higher towards a region of lower pressure, or from where there is a surplus to where there is a deficiency of air. It is on this broad and vital principle that meteorology rests, which is found to be of universal application throughout the science, in explanation, not only of prevailing winds, but of all winds, and of weather and weather changes generally. One of the more important uses of the principle is in its furnishing the key to the climates of the different regions of the earth; for climate is practically determined by the temperature and moisture of the air, and these in their turn are dependent on the prevailing winds, which are charged with the temperature and moisture of the regions they have traversed. The isobaric charts show further that the distribution of the mass of the earth's atmosphere depends on the geographical distribution of land and water in their relations to the sun's heat and to radiation towards the regions of space in different seasons.

In 1882 Loomis published a map showing the mean rainfall of the globe. This map and others that have been constructed for separate countries show conclusively that the rainfall of any region is determined by the prevailing winds considered in relation to regions from which they have come, and the physical configuration and temperature of the part of the earth's surface over which they blow. The maximum rainfall is precipitated by winds which, having traversed a large breadth of ocean, come up against and blow over a mountainous ridge lying across their path, and the amount deposited is still further increased if the winds pass at the same time through regions the temperature of which constantly becomes colder. On the other hand, the rainfall is unusually small, or *nil*, when the prevailing winds have not previously traversed some extent of ocean, but have crossed a mountain ridge and advance at the same time into lower latitudes, or regions the temperature of which is markedly higher.

While the observational data for the determination of the geographical distribution of the prime elements of climate, viz., the pressure, temperature, moisture, and movements of the atmosphere and the rainfall were being slowly but surely collected, the great importance of the study of weather came gradually to be recognized. Additional impetus was given to this branch of study from its intimate bearings on the eminently practical question of storm warnings. Synchronous weather maps, showing the weather over a considerable portion of the earth's surface, were constructed, and some advance was made in tracing the progress of storms from day to day. Unquestionably one of the first problems of meteorology is to ascertain the course storms usually follow and the causes by which that course is determined, so as to deduce from the meteorological phenomena observed, not only the certain approach of a storm, but also the particular course that storm will take. The method of practically conducting this large inquiry in the most effective manner was devised by the genius of Leverrier, and begun to be carried out in 1858 by the daily publication of the *Bulletin International*, to which a weather map was added in September 1863. This map showed graphically for the morning of the day of publication the atmospheric pressure, and the direction and force of the wind, together with tables of temperature, rainfall, cloud, and sea disturbance from a large number of places in all parts of Europe. From such weather maps forecasts of storms are framed and suitable warnings issued; but above all a body of information in a very handy form is being collected, the careful study and discussion of which is slowly but gradually leading to the issue of more exact and satisfactory forecasts of weather, and to a juster knowledge of these great atmospheric movements which form the groundwork of the science.

The most cursory glance is sufficient to show that the ever-changing physical phenomena with which it is the business of meteorology to deal are all referable to the action of the sun, it being evident that if the sun were blotted out from the sky a cold lifeless uniformity would rapidly take possession of the whole surface of the globe. Meteorological phenomena naturally group themselves into two great classes,—those dependent on the revolution of the earth on its axis, and those dependent on its revolution round the sun taken in connexion with the inclination of its axis to the plane of its orbit. The science thus divides itself into two great divisions, the first comprising diurnal phenomena and the second annual phenomena.

Diurnal March of Phenomena.

Temperature.—Of the daily changes which take place in the atmosphere, the first place must be assigned to those which relate to temperature, seeing that on these all other changes are either directly or indirectly dependent. Observations of the temperature of the air are therefore of the first importance in meteorology. A perfectly accurate observation of the temperature of the air is unquestionably among the most difficult to make of all physical observations, the difficulty being to eliminate the effects of radiation of surrounding objects. The nearest approach yet made to the solution of this important problem of physical inquiry was made by Dr Joule in a communication to the Philosophical Society of Manchester (November 26, 1867, *Proc.*, vol. vii. p. 35). But the manipulative skill and time demanded by the method there detailed render it quite unsuitable for general adoption anywhere in collecting the observational data required in the determination of this important element of climate. It is therefore necessary to fall on some method which, while it gives results that can only be regarded as approximate, secures the essential element of uniformity among the observations.

Fig. 1 represents Stevenson's louvre-boarded box for the thermometers, which is now very widely used for temperature observations. The box is made of wood, and louvred all round so as to protect the thermometers inside from radiation, and at the same time secure as free a circulation of air as is consistent with a satisfactory protection from radiation. The box is painted white, both inside and outside, and screwed to four stout wooden posts, also painted white, firmly fixed in the ground. The posts are of such a length that when the thermometers are hung in position the bulbs of the minimum thermometer and hygrometer are exactly at the same height of 4 feet above the ground, the maximum thermometer being hung immediately above the minimum thermometer. This thermometer box is placed over a plot of grass, and in a free open space to which the sun's rays have free access during as much of the day as surrounding conditions admit of. It will be observed that the thermometers are suspended on cross-laths in the centre of the box and face the door, which should always open to the north. It is not possible to overestimate the importance of seeing that uniformity of height above ground and method of protecting the thermometers is secured, since in no other way is it possible to obtain results from different places which shall be comparable with each other and thus supply satisfactory materials for the investigation and development of comparative climatology.

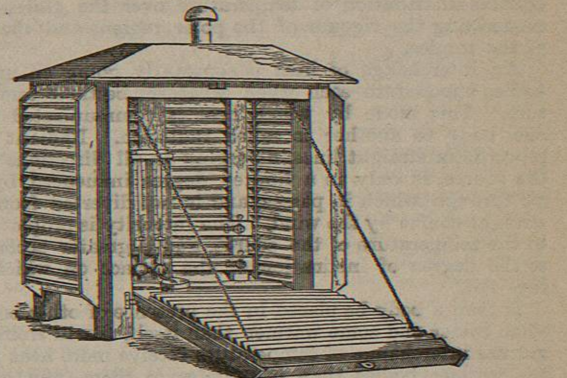

Fig. 1.—Thermometer Box.

A desired uniformity is yet far from being attained among the meteorological systems of different countries. Thus in Russia the box for the protection of the thermometers is made of zinc, on the supposition that such a box follows more closely the changes of temperature of the air than a box of wood. Owing to these international diversities of observation, it is extremely desirable that steps were taken to ascertain, by Joule's method of observing, the approximate errors peculiar to each sort of thermometer box, in order that the temperatures of different countries may be compared together in a more satisfactory manner than has yet been possible.

Interchanges of temperature among bodies take place by conduction, convection, and radiation. In meteorology the most important illustrations of conduction are the propagation downwards through the earth's strata of the changes of the temperature of the surface as it is heated during the day and cooled during the night, and the propagation of the same changes of temperature through the lowest stratum of the air which rests on the surface. Since sand and light loose soils are much worse conductors of heat than clay and dense soils, it follows that loose soils