Fig. 8.

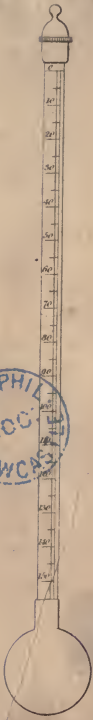


Fig. 1.

Fig. 2.

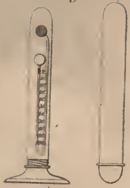


Fig. 3.

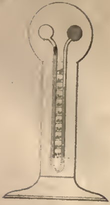


Fig. 5.

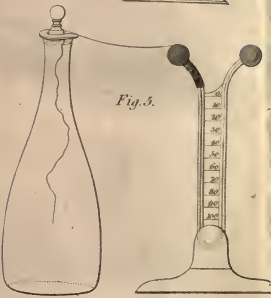


Fig. 4.

Fig. 7.

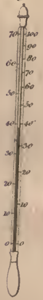


Fig. 6.

Fig. 10.

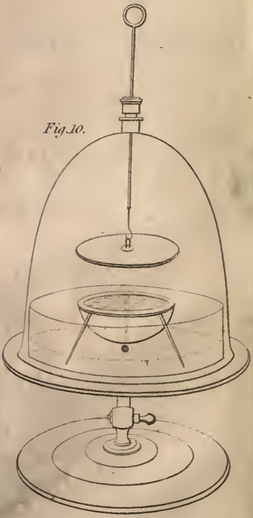
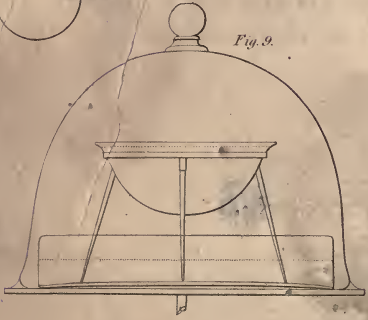


Fig. 9.



Scale of Inches.

J. Grant Sculp[t]

A

SHORT ACCOUNT

OF

Experiments and Instruments,

DEPENDING

ON THE RELATIONS OF AIR

TO

HEAT AND MOISTURE.

By JOHN LESLIE, F. R. S. E.

PROFESSOR OF MATHEMATICS IN THE UNIVERSITY OF EDINBURGH.

EDINBURGH:

PRINTED FOR WILLIAM BLACKWOOD, AND J. BALLANTYNE & CO.;
AND FOR LONGMAN, HURST, REES, ORME, & BROWN;
AND JOHN MURRAY, LONDON.

1813.

Printed by Abernethy & Walker,
Old Bank Close, Lawnmarket.

ADVERTISEMENT.

In the Preface to the '*Experimental Inquiry into the Nature and Propagation of Heat,*' I promised to resume that subject, and to extend my researches into the relations subsisting between heat and moisture, which elucidate and confirm all the former deductions.

As I was anxious to obtain still more accurate results, it became requisite to devise new experiments, and to procure apparatus of the largest dimensions, and of the most refined elaborate construction. Some of the observations, it was necessary to repeat at different seasons; and the circle of my professional avocations, joined to that of the publications which I had connected with them, could not fail to create delay, and to suspend in part my application to experimental research. Several years have thus unfortunately gone by, without allowing me sufficient time to perform, in the way which I had proposed, my original engagement. I have at length advanced so far, however, that I may hope to be able very soon to discharge that task.

In the meantime, it seemed desirable for the advancement of science, to promote the circulation of several instruments founded on my speculations, and to give the public more correct notions of their principle and their mode of operation. With this view, I was induced to draw up a concise statement, in as popular a form as the regard to accuracy would admit, but which, from the accumulation of materials, has swelled by degrees into a volume. I have only farther to add, that, in order to avoid troublesome calculations, I have satisfied myself with citing round numbers; but these, if not absolutely correct, are in general very near approximations to the truth.

College of Edinburgh,
5th May 1813.

ON

THE RELATIONS OF AIR

TO

HEAT AND MOISTURE.

THE various phenomena of heat are most easily conceived, by referring them to the operation of a peculiar fluid, possessing extreme activity, and diffused through all bodies. This fluid exists, however, only in a state of combination, and never appears under a distinct and separate form. Though subject, from different causes, to partial derangement, it constantly endeavours to recover its equilibrium among adjacent bodies. Its accumulation in any substance is invariably marked by a corresponding expansion, unless an absolute change of constitution has been induced. Thus, a lump of ice intensely cold, if exposed to a mild air, will regularly expand, till it begins to melt; and during its conversion into water, it will suffer a material contraction, but, after this change, it will again dilate, from the repeated accessions of warmth. In like manner, a bit of clay, though in the furnace it contracts, from the expulsion of part of the water combined with it, will, on being withdrawn and suffered to cool, expand by the application of any lower degree of heat than what it had before sustained.

When the heat shared among bodies is mutually balanced, they are said to have the same *temperature*. But such balance or equality of temperature is far more quickly attained in some substances than in others. Silver transmits heat more readily than platina, platina than glass, and glass than loose down. This property, by which bodies are so widely diversified, is called their *conducting power;* and it has a most extensive influence in the economy of nature.

Among different substances, too, the rise of temperature is accompanied by very different degrees of expansion. Air is found, in like circumstances, to expand 5 times more than alcohol, 20 times more than mercury, 160 times more than platina, and even 580 times more than glass.

The *thermometer* is an instrument contrived to measure its own expansions, and consequently fitted, by its nice sensibility, to indicate the temperature of surrounding bodies. Still the thermometer can mark only the heat of its own bulb, as affected by external communication; and any farther inferences drawn from its different indications are merely the result of some process of reasoning.

The primary source of heat is the sun, whose genial rays are partly detained in the atmosphere, and partly received at the surface of the land and of the ocean. The incessant addition thus made to the elementary fluid, varying with the latitude and the change of seasons, are speedily dispersed by the vehicle of aërial currents, and gradually absorbed into the general mass of our globe. Yet this annual influx of heat, however important in its transient and superficial effects, must bear no comparison to the wide accumulated store, since in the course of ages scarcely any sensible increase of temperature over the world has been distinctly ascertained.

But, even after it has gained its equilibrium, the fluid of heat is not equally dispersed among bodies, or shared out in proportion to their quantities of matter. Had an opposite system obtained, no internal change of temperature could ever have taken place; for, amidst all the mutations of form and condition to which bodies are subject, their mass continues unaltered, and would consequently retain the same measure of heat. In the actual constitution of things, a provision is happily made for those grateful alternations and interchange of elements, which enliven the face of nature. Heat combines with different substances in proportions widely varied, and depending in each on its peculiar and intimate structure. In general, it is more copious in liquids than in solids, and in the aëriform fluids than in liquids. But still the allotment among the different bodies, appears to be as various as their distinctive properties. Under similar circumstances, hydrogen gas will hold or absorb ten times as much heat, as an equal mass of atmospheric air; water twice as much as olive oil, and three times as much as concentrated sulphuric acid; sulphuric acid, again, twice as much as glass; and glass itself, twice as much as silver, and five times as much as mercury. If a pound of water heated 30 degrees, be poured into another pound of water, at the temperature of the apartment, the surplus heat will become equally shared between the two masses, the infused portion losing 15° of its heat, and the recipient gaining 15°. But if a pound of mercury, heated 30 degrees above the standard, be poured into a pound of water; while both of these now acquire the same temperature, the mercury will lose 29 degrees, and the water gain only one degree. Hence, in the state of quiescence, mercury contains 29 times less heat than water, and has its temperature 29 times more affected by equal accessions of that elementary fluid. But even the same substance, if its form be mutable, will exhibit similar differences, according to the aspect which it assumes. Thus, ice is more easily heated than water, and water than steam. The same addition of heat which would raise the temperature of ice 10 degrees, would only raise that of water 9 degrees, and that of steam 6 degrees. At each stage of transition, there is hence an apparent pause, attended with a corresponding absorption or evolution of heat.

Thus, if a vessel filled with ice, be suspended over a steady fire, the ice will continue at the freezing point, till, perhaps in an interval of half an hour, it be entirely melted; it will then grow regularly warmer, till, after 40 minutes, the water begins to boil: nor will the temperature of the liquid now receive any farther increase, the subsequent accessions of heat being wholly expended in the formation of the expelled steam, and which would require the space of three hours and a half. In the act of thawing, therefore, and again in the process of ebullition, there is a successive absorption of heat, amounting respectively to a difference of temperature in the water of about 75 and 525 of the centigrade degrees, or 135 and 945 on Fahrenheit's scale. But the heat thus absorbed is nowise distinguished from the rest, or fitted to perform any different function; it blends its action and its expansive energies with the general fluid, and merely serves to restore the equilibrium that had been disturbed by the enlarged capacity, or rather the increased attraction, of the mass with which it combines.

A similar expence of heat invariably attends the conversion of water into the gaseous state of vapour, by whatever powers that transformation is effected. Thus, dry air brought in contact with moisture, will attract it to some point of saturation, or will absorb a certain portion of the humidity, and assimilate this with its own substance; and such action is greatly augmented, either by raising the temperature of the medium, or by reducing or withholding the atmospheric pressure. The application of warmth invigorates the dissolving power of the air, while, by distending the particles of the subjected water, it facilitates the passage into vapour; and the diminution or removal of the incumbent weight of the atmosphere produces a similar effect, by giving a freer or less restrained play to the repulsion of the liquid particles, and hence assisting indirectly the attraction of the solvent medium. On this principle, depends the consumption of heat and the consequent reduction of temperature, occasioned by the evaporation of liquids which are exposed to the access of dry air.

The evolution or absorption of heat, and thence the raising or lowering of the general temperature, must therefore be the result of every change in the constitution of bodies, whether it belongs to the class of physical or of chemical phenomena. In the case of mixture or solution, the effect is limited and merely transient; but where a process of decomposition goes forward, the discharge of heat is copious and continued. Thus, if sulphuric acid be poured upon water, there will appear a remarkable evolution of heat, as the capacity of the dilute acid so formed is less than the mean capacity of both its components. Again, nitre or sal ammoniac, dissolved in water, occasions an absorption of heat or a depression of temperature, because the capacity of the saline solution is greater than the intermediate capacity of the water and of the salt. Such extrication or abstraction of heat is, however, a single act, and can produce only a momentary change of temperature in the mass affected. But when the united streams of oxygen and hydrogen gases are inflamed, or when charcoal is burnt in contact with atmospheric air, there is a continual and profuse emission of heat; for, in both cases, a decomposition is carried on, and its effects are incessantly renewed, the oxygen and hydrogen gases forming steam, which has less capacity, and the union of the charcoal changes the pure portion of common air into carbonic gas, whose capacity is likewise much lower. On the other hand, a perpetual absorption of heat is caused by the evaporation of liquids exposed to the free circulation of dry air, from the increased capacity of the invisible exhalations drawn from them and dissolved in the aërial medium. This depression of temperature, though it can be supported for any length of time, is in most cases, however, confined within very moderate limits. In general, the means within our reach of procuring the discharge of heat are of a nature far more powerful than those which occasion its absorption, or the seeming production of cold.

The gaseous substances are so loosely constituted, that a difference in their composition is sufficient to alter materially their intimate properties. Thus, common air, on being condensed 30 times, has its capacity for heat reduced to one half; and, if suddenly compressed to 20 times its ordinary density, it will disengage so much heat as to show an elevation of temperature equal to 900 degrees by Fahrenheit's scale, and sufficient for the inflammation of most bodies. On this property, is founded a pretty contrivance lately made in France, the stroke of a small condensing syringe being employed to set on fire a bit of tinder. An opposite effect, when air is suddenly rarefied, takes place; a certain quantity of heat being now absorbed, or an apparent cold produced.

The increased capacity of rarefied air is the true cause of the cold which prevails in the higher regions of the atmosphere. From the unequal action of the sun's rays and the vicissitudes of day and night, a perpetual and quick circulation is maintained between the lower and the upper strata; and it is obvious, that, for each portion of air which rises from the surface, an equal and corresponding portion must also descend. But that which mounts up, acquiring an enlargement of capacity, has its temperature proportionally diminished; while the correlative mass falling down carries likewise its heat along with it, and, contracting its capacity, seems to diffuse warmth below. A stratum at any given height in the atmosphere is hence alike affected by the passage of air from below, and by the return of air from above, the former absorbing heat, and the latter evolving it. But the mean temperature at any height in the atmosphere is still on the whole permanent, and consequently those disturbing causes must be exactly balanced, or the absolute measure of heat is really the same at all elevations, suffering merely some external modification from the difference of capacity in the fluid with which it has combined. That temperature is hence inversely as the capacity of air possessing the rarity due to the given altitude. Having therefore ascertained, by some delicate experiments, the law which connects the capacity with the rarity of air, it was not very difficult to trace the gradations of cold in the higher atmosphere, and even to mark the precise limit where the reign of perpetual congelation must commence. Thus, I find that, under the equator, the boundary of the frozen region begins at the altitude of 15207 feet, in the parallel of 45° at 7671 feet, in the latitude of London at 5950, and in that of Stockholm at 3818, while towards the pole it comes to graze along the surface *.

It is curious to examine the mode by which heat is conducted through substances differently constituted. In the case of solid bodies, there can be no actual transfer of the heated particles, but these must alternately receive and deliver their successive impressions. If heat be applied, for instance, at one end of a cylinder of metal, wood, or glass, which communicates at its other end with some extended mass, a regular descending gradation of temperature will soon be established along the whole chain of connection. But if each intermediate portion of the conductor were, during its action, to preserve unvaried the temperature which it had once acquired, no transfer of heat whatever could obtain. Each

29

* *See* Elements of Geometry, pp. 495 and 496.

successive space into which the cylinder is distinguished, must therefore undergo a certain limited oscillation, to excess and defect from the state of equilibrium, thus partially dilating and again contracting, and at each alternate act receiving from the anterior portion a minute excess of heat, which in the next it delivers to the succeeding one. A series of connected internal vibrations must hence keep shooting along the whole chain of communication, and the rate with which the heat is conveyed by this tremulous excitement and successive transfer, will depend chiefly on the extent and the celerity of each elementary vibration.

But when the conducting medium is a fluid, the mobility of the particles affected will so derange the mode of operation, as almost entirely to change its nature. The proximate portion of the medium, dilating as it becomes warmed, is gently forced to recede; and being likewise rendered specifically lighter, it rises to the surface. The heat then quickly spreads through the buoyant substance in horizontal strata, the hottest particles occupying the highest place, and the rest arranging themselves according to their respective temperatures. Thus, if a hot body be plunged in water, a portion of the heat is gradually absorbed by the surrounding liquid, and transmitted by successive fits through the internal mass, in the same manner as if this had been congealed into solid ice. The remaining portion is discharged by the slow recession of the heated particles, or the perpendicular motion produced by their mutual distension. The subsequent diffusion of this heat, which is made to descend by the successive transfer of minute differences from stratum to stratum, is performed very tardily and with extreme difficulty. The lower part of the liquid acquires in general but a very small share of the heat retained near the top.

Hence it is, that very deep collections of water exposed to the variable influence of the sun and sky, are always found to have their bottom greatly colder, and their surface warmer, than the mean temperature of the climate. The superficial portion, dilated by the action of the summer's heat, continues passively to float, without much affecting the mass below ; but, when it has felt the rigours of winter, it undergoes a contraction of volume with a corresponding increase of density, and it sinks downwards in this chilled state. During all the changes of temperature which supervene, and while the internal communication through the mass appears so tardy and imperfect, there hence is an obvious tendency to accumulate warmth at its surface, and to precipitate the opposite impressions. Accordingly the bottoms of profound lakes are uniformly and intensely cold. The same property is not indeed observed in deep open seas, because the various currents and heaving tides by which these are agitated, so effectually intermix the different portions of water, as in some degree to equalize their temperature. Near extensive banks, however, where the interchange between the higher and the lower strata becomes again impeded, no such equality seems to prevail ;

and the increasing coldness of the water drawn up from considerable depths in the ocean has lately been proposed as a sure mark of the approach of soundings, if not of the land itself.

Since water, on being heated, expands in a rapid progression, the portion of heat which it abstracts from a body immersed in it, by means of the recession and incessant change of its contiguous affected particles, must be greatly augmented in the higher temperatures. Near the freezing point, this influence becomes extremely small, and water is there scarcely a better conductor than ice; but, as it approaches to ebullition, it acquires such an increase of mobility, as to conduct heat five times faster than in its torpid state. In other liquids, the increase of temperature will occasion a similar alteration of the conducting powers, though not so marked, as their expansions deviate less from an uniform progression.

But, through air and other gaseous fluids, the conveyance of heat is still more complex; and a close investigation of that process, by unfolding certain latent properties of matter, has led to some very unexpected and interesting results. A new principle appears to combine its influence, and the rate of dispersion, in aëriform media, is found to depend chiefly on the nature of the mere heated surface. From a polished metallic surface, heat is feebly emitted; but, from a surface of glass, or still better from one of paper, it is discharged with profusion. If two equal balls of thin bright silver, one of them entirely uncovered, and the other sheathed in a case of cambric, be filled with water slightly warmed, and then suspended in a close room, the former will lose only 11 parts of its heat in the same time that the latter will dissipate 20 parts. Of this expenditure, 10 parts from each of the balls is communicated in the ordinary way, by the slow recession of the proximate particles of air, as they come to be successively heated. The rest of the heat, consisting of 1 part from the naked metallic surface, and of 10 parts from the cased surface, is propagated through the same medium, but with a certain diffusive rapidity, which in a moment shoots its influence to a distance, after a mode entirely peculiar to the gaseous fluids. The very superior propellent energy of a surface of glass or paper in comparison of that of a metallic one, lies within the compass even of ordinary observation. If a glass caraffe or a pot of porcelain be filled with boiling water, on bringing towards it the palm of the hand, an agreeable warmth will be felt at the distance of an inch or two from the heated surface; but if a silver pot be heated in the same way, scarcely any heat is at all perceptible on approaching the surface, till the fingers have almost touched the metal itself.

It is curious to inquire how such a singular diversity can arise. If the silver ball be covered with the thinnest film of gold-beater's skin, and which exceeds not the 3000th part of an inch in thickness, the power of dispersion will be augmented from 1 to 7; if another pellicle be added, there will be a farther increase of this power, from 7 to 9; and so repeatedly growing, till after the application of five coats, when the propellent energy will reach its extreme limit, or the measure of 10. In this case, the metallic surface is precluded from all contact with the air, and it must, therefore, act in consequence of its mere approximation to the external boundary. We may thence infer, that air never comes into actual contact with any surface, but approaches much nearer to glass or paper than to polished metal, from which it is separated by an interval of at least the 500th part of an inch. A vitreous surface, from its closer proximity to the recipient medium, must hence impart its heat more copiously and energetically, than a surface of metal in the same condition; and the metal, to a certain extent, can act in reducing the power of the other. When a pellicle was applied, the metallic surface immediately under it repelled partially the atmospheric boundary, and reduced the darting efflux of heat from 10, which would have been thrown by the skin alone, to about 7, or only 6 more than the efficacy of the naked metal. The repelling influence of the metallic plate was sensible even under four coats, or at the distance of the 750th part of an inch from the external surface.

By what process the several portions of heat, thus delivered to the atmosphere, shoot through the fluid mass, it seems more difficult to conceive. They are not transported by the streaming of the heated air, for they suffer no derangement from the most violent agitation of their medium. The air must therefore, without changing its place, disseminate the impressions that it receives of heat, by a sort of undulatory commotion, or a series of alternating pulsations, like those by which it transmits the impulse of sound. The portion of air next the hot surface, suddenly acquiring heat from its vicinity, expands proportionally, and begins the chain of pulsations. In again contracting, this aërial shell surrenders its surplus heat to the one immediately before it, and which is now in the act of expansion; and thus the tide of heat rolls onwards, and spreads itself on all sides. These vibratory impressions are not strictly darted in radiating lines, but each successive pulse, as in the case too of sound, presses to gain an equal diffusion. Different obstructions may, therefore, cause the undulations of heat to deflect considerably from their course. Thus, if successive rings of pasteboard be fashioned into the twisted form of a cornucopia, and its wide mouth presented at some distance to the fire, a strong heat will, in spite of the gradual inflection of the tube, be accumulated at its narrow end; in the same manner probably, as waves, flowing from an open bay into a narrow harbour, now contracted and bent aside, yet without being reflected, rise into furious billows.

But the same pulsatory system will enable the atmosphere to transmit likewise the impressions of cold. The shell of air adjacent to a frigid surface, becoming suddenly chilled, suffers a corresponding contraction, and which must excite a concatenated train of pulsations. This contraction is followed by an immediate expansion, which withdraws a portion of heat from the next succeeding shell, itself now in the act of contracting; and the tide of apparent cold, or rather of deficient heat, shoots forwards with diffusive sweep. The energy of transmission is subject, in this case also, to the same modifications from the nature of the affected surface. Thus, a goblet filled with pieces of broken ice, or still better with a frigorific mixture composed of snow and salt, will, at a moderate distance, yet seem chill; but a silver pot, filled with a similar mixture, will not cool the hand, till it has become profusely covered with dew, and therefore now presents a non-metallic surface.

But the same quality by which a surface propels the hot or cold pulses, equally fits it, under other circumstances, to receive their impressions. If a vitreous surface sends forth its heat the most copiously, it will also, when opposed to the tide, arrest with entire efficacy the affluent wave; and if, on the other hand, a surface of metal sparingly parts with its heat, it in like manner detains only a small share of each appulse, and reflects all the rest. The power of superficial absorption and that of reflection are therefore exactly contrasted, and the one always supplies the deficiency of the other. The naked bulb of a thermometer held near a goblet full of boiling water, will mark a very sensible afflux of heat; but if it be gilt or covered with tinfoil, it will scarcely seem at all affected. For the same reason, the hand cased in a glove of burnished metal may approach the fire with impunity, since the vehement pulsations of heat are mostly driven back, or turned aside from their attack. A sheet of paper, opposed to the aërial tide, will absorb the whole impression, a pane of glass will repel about one-tenth part, while a plate of polished silver will reflect nine-tenths of the heat, detaining only the remaining tenth. But if the metallic plate be covered with a pellicle of the 3000th of an inch in thickness, out of 10 parts of heat no more than 3 will be reflected, the rest being now absorbed; and by applying successively other pellicles, till a coat equal to the 500th of an inch in thickness has been formed, the quantity of reflection will gradually become insensible. The power of a metallic speculum in concentrating at its focus the pulses of heat or cold is hence very striking, while the corresponding effects of a glass mirror seem to be extremely feeble.

The very different powers of a vitreous and of a metallic surface in propagating or absorbing the pulsations of heat, are well contrasted by an experiment of the simplest and easiest kind. Let a small pane of glass about four inches square have one of its sides half covered with smooth tinfoil; or, what is more elegant, let a small square of thin mica have one side gilt half over with silver leaf. On holding the partly covered surface of the glass or mica opposite and very near the fire for the space of a few seconds, and then passing the finger lightly over the posterior surface, scarcely any warmth is perceptible under the metallic sheath, but an intense degree of heat will be felt behind the naked portion of the plate. Again, reversing its position and exposing the uncovered side to the fire, an opposite, though less marked effect is observed; the coat of metal will become sensibly hotter than the adjacent naked space; because the heat absorbed along the interior surface being afterwards more feebly discharged from the tin or silver leaf, is allowed to accumulate in that part of the screen. In this latter case, the difference of temperature produced is very nearly the double, and in the former it is no less than tenfold. But effects of the same kind, and which are alike contrasted, though inferior in degree, will be perceived, if a thin pellicle be spread over the compound surface of the glass and tinfoil, or of the mica and silver leaf, the mere proximity of the metallic surface repelling the atmosphere, and consequently enfeebling the powers of absorption and emission.

The very singular and unexpected facts now detailed merit attention, and suggest a variety of improvements in the practical management of heat. A vessel with a bright metallic surface is the best fitted to preserve liquors either long warm, or as a conservatory to keep them cool. A silver pot will emit scarcely half as much heat as one of porcelain; and even the very slightest varnishing of gold, platina or silver, which communicates to the ware a certain metallic gloss, renders this new kind of manufacture about one-third part more retentive of heat. The addition of a covering of flannel, though indeed a slow conductor, far from checking the dissipation of heat, has directly the contrary tendency; for it presents to the atmosphere a surface of much greater propulsive energy, which it would require a thickness of not fewer than three folds of this loose substance fully to counterbalance. The cylinder of the steam-engine has lately been most advantageously sheathed with polished copper.

The progress of cooling is yet more retarded, by surrounding the heated vessel on all sides, at the distance of near an inch, with a case of planished tin; and the addition of other cases, following at like intervals, augments continually the effect. With an obstruction of one case, the rate of refrigeration is 3 times slower, with two cases it is 5 times slower, with three cases it is 7 times slower, and so forth, as expressed by the succession of the odd numbers. By multiplying the metallic cases, therefore, and disposing them like a nest at regular intervals, the innermost could be made to retain the same temperature with little variation for many hours or even days. Such an apparatus would obviously be well calculated for various culinary and domestic purposes.

In the conveyance of heat by means of steam, the surface of the conducting tubes should have a metallic lustre. On the contrary, if it be intended by that mode to warm an apartment, they should be coated on the outside with soft paint, to facilitate their discharge of heat. For the same reason, metallic pots are more easily heated on the fire, after their bottoms have become tarnished or smoked. If a bright surface of metal be slightly furrowed or divided by fine flutings, it will emit heat sensibly faster, because the prominent ridges, thus brought closer to the general atmospheric boundary, will excite the pulsations with augmented energy.

On the other hand, a plate of metal, however thin, if only burnished on each side, will form the most efficacious screen. A smooth sheet of pasteboard, gilt over both sides, would answer the same purpose. But a complete and elegant screen might be composed of two parallel sheets of China paper, placed about an inch asunder, and having their inner surfaces gilt, and their outsides sprinkled with flowers of gold and silver.

Since, in a still atmosphere, the momentary flow of heat from any vessel, whatever this may contain, depends merely on the condition of its surface, the whole accumulated discharge, during similar descents of temperature, is evidently proportional to the time elapsed. Hence a very simple and accurate method is suggested, for ascertaining the capacity of different liquids or their specific attraction to heat. Into a glass ball, two or more inches in diameter and blown extremely thin, with a narrow short neck, and having a delicate thermometer inserted through it; the liquid to be examined, which had been previously warmed a few degrees, is carefully introduced by means of a funnel. The ball is then made to rest against the tapering points of three slender glass rods at the height of several inches above the table, and sheltered from any irregular agitation of the air of the apartment by a large receiver passed over it. The number of seconds which the thermometer now takes to sink from one given point to another, or to the middle of its distance from the limiting temperature, is noted by help of a stop-watch; and the ball being thoroughly emptied and again successively filled with other liquids, the like observations are repeated. These several intervals of time, allowing a slight correction for the matter of the shell itself and of the inserted bulb of the thermometer, will consequently express the proportional quantities of heat contained in equal bulks of the successive liquids. But their densities being already known, it is hence easy to compute their respective capacities, or the quantities of heat which equal weights of them are capable of containing. By a process grounded on the same principles, the capacity of a solid, when broken or reduced to a gross powder, may be determined.

The same regulated mode of cooling will serve to detect with precision the expenditure of heat, and to discriminate its various allotment, in the different gases. For this purpose, a ball of about three inches in diameter, and formed of bright and very thin silver, is preferable; and it may be successively covered with a pellicle or with cambric, or painted with a coat of ivory-black. Not to multiply unnecessary details, it will perhaps be deemed sufficient to cite the case of hydrogen gas, which is by far the most distinguished. The portion of heat emitted in this energetic species of gas by the system of pulsations, whether from a vitreous or a metallic surface, if not exactly, is very nearly the same as in atmospheric air; but that other portion which is abstracted by the gradual recession of the nearest heated particles of the fluid, exceeds no less than four times the corresponding discharge in the ordinary medium. Why such a striking difference should arise, can hardly be conjectured. Hydrogen gas, though ten times lighter than air, yet contains, in the same volume, an equal quantity of heat; and it is fitted, by its very superior elasticity, to transmit the pulsatory impressions more than three times faster. It must, therefore, as a counterbalance, receive those impressions three times slower from the heated surface. But if such influence be confined, as it would seem most probable, to the mere boundary of the medium or its thinnest conterminous shell, the measure of heat imbibed at a given rise of temperature from the attenuated expanse, would be diminished between two and three times. This mutual compensation of effect nearly agrees with the actual result. With respect to the quadrupled increase of that portion of heat which is abstracted by the slow but continued renewal of the adjacent stratum of the fluid, we must refer it chiefly to the very great mobility of hydrogen gas, exceeding three times that of common air. If these strata were supposed to have in both cases the same thickness, they would each of them carry off the same share of heat.

The portions of heat transmitted by pulsation through hydrogen gas, from a painted and a metallic surface, being, as before, expressed respectively by 10 to 1, the other portion, which is altogether independent of the nature of the cooling surface, and is dispersed by abduction, or the incessant retreat of the strata of the fluid as they come to be successively affected, will amount to 40. Under like circumstances, therefore, the whole expenditure of heat from a painted and a metallic surface, and which in atmospheric air was denoted by 20 and 11, will in hydrogen gas be represented by 50 and 41. Those opposite surfaces are thus less contrasted in a medium of hydrogen gas, their different rates of discharging heat being nearly in the proportion of 5 to 4.

The silver ball cased with cambric, cools $2\frac{1}{2}$ times faster, if immersed in hydrogen gas; but when exposed naked in the same fluid, it loses its heat almost four times as fast as in common air.

The superior mobility of hydrogen gas accelerates remarkably the dispersion of heat, by the process of abduction. But the exposing of a heated body to the action of any current of a fluid substance, will occasion a similar expenditure of heat, and which is exactly proportioned to the celerity of the stream. If a very large bulb of a thermometer be suddenly plunged into water flowing at the rate of one-third of a mile in the hour, it will be found to lose its heat twice as fast, as when immersed in the stagnant pool; and a current of two miles in the hour would, therefore, cause through the liquid a dissipation of heat no less than seven times more rapid than usual. A similar acceleration of effect is produced, by the impulse of a stream of air. With a velocity of about four miles in the hour, the superadded influence of a current equals the ordinary power of abduction. Hence the play of a breeze of eight miles an hour will double the rate of cooling from a painted, and will triple that from a metallic, surface; but a wind sweeping with a velocity of forty miles in the hour, would accelerate the cooling of the painted surface six times, and that of the metallic one no less than eleven times, thus bringing them both near an actual equality of performance. In general, the hourly velocity of wind might be computed, by multiplying eight miles into the proportional surplus effect exerted in the refrigeration of a vitreous or painted surface.

But even in still air, if the body exposed to its action have a very considerable elevation of temperature, the progress of cooling will be sensibly quickened, by the continual ascent of the heated portions of the medium, and which form in fact a stream, varying in force according to the intensity of excitement. Supposing the excess of temperature to be 30 centesimal degrees, or 54 by Fahrenheit's scale, this gentle perpendicular flow of heated air will conjoin an influence equal to the ordinary abductive dispersion of heat, and therefore corresponding to that of a current which moves at the rate of four miles an hour. Hence, if the silver ball be 90 centesimal degrees hotter than the encircling air, the effect of the vertical stream is tripled, or the aggregate expenditure, from the painted and from the naked surface, will be expressed by 50 and 41, the dissipation arising from the increased flow of the medium amounting in each of them to 30. By a singular coincidence, this proportion is precisely the same as what obtains near the equilibrium of temperature in an atmosphere of hydrogen gas. But hydrogen gas betrays in its own constitution still greater modifications. At the same elevation of 90 centesimal degrees of temperature, the combined powers of cooling which it exerts on the contrasted surfaces, are expressed by 170 and 161.—It would be fatiguing, however, to pursue this intricate analysis much farther.

The meteorological phenomena on which the nature of climate chiefly depends, are more immediately connected, however, with the relations of air and moisture. The vapour which exhales from the surface of our globe, and rises into the atmosphere, is again, by the operation of certain disturbing causes, precipitated in the form of clouds, dew and rain, or of snow and hail. To discover the disposition of the air with respect to moisture, is therefore a problem of great importance; and an instrument which should at any time indicate with facility and precision the actual state of the medium in regard to humidity or dryness, must be considered as a valuable acquisition to science. But the act of evaporation itself, from which all those various appearances derive their origin, is attended by two distinct circumstances that seem to offer the means of constructing such an instrument,—the dilatation imparted to the ambient medium,—and the depression of temperature produced on the humid surface.

1. Steam, in whatever way it is formed, has probably double the elasticity of common air, or it would, under the same pressure, occupy about twice as much space. In uniting with that fluid, it must hence communicate an expansion which is exactly proportioned to the quantity dissolved, or to the portion of moisture required for the complete saturation of the air. This principle appeared to suggest the means of constructing an accurate *Hygrometer**, to which my researches had been early directed. Inverting a small barrel tumbler, I ground the mouth perfectly flat; and having drilled a hole through the bottom, I cemented into it, a sort of syphon gage or slender recurved tube with a narrow bore, passing through a perforated cap of lead, and holding a portion of nut oil tinged with alkanet root, a scale being affixed with divisions corresponding to the 10,000 parts of the ordinary elasticity or pressure of the air. Having now spread a few drops of water over the surface of a bit of plate

* From ὑγρος, *moist* or *humid*, and μετρον, *a measure.*

glass, and slipped the tumbler upon this, the included air quickly dissolved as much moisture as was sufficient for its saturation, and marked the expansion thus acquired, by forcing the column of oil to rise proportionally. The quantity of effect was often very considerable, amounting in fine weather to 100 or 120 degrees. This little apparatus satisfied my expectation, but, as it always required a certain portion of address, I soon abandoned it for other instruments, which promised to be more easily and readily managed. With some modification, however, it would prove very serviceable in a variety of delicate physical inquiries, by detecting the minutest alterations of volume which take place in the union of different substances, and thus pointing out the curious and extended influence of chemical action.

2. But the process of evaporation has not been hitherto examined with attention, or its consequences rightly understood. The depression of temperature which always accompanies it, has been hastily sup-

posed to be proportional to the rate with which the moisture is dissipated, and to be therefore augmented by every circumstance that can accelerate this effect. If water contained in a porous vessel, expose on all sides its surface to a current of air, it will cool down to a certain point, and there its temperature will remain stationary. The rapidity of the current must no doubt hasten the equilibrium, but the degree of cold thus induced will be still the same. A little reflection may discover how this takes place. Though the humid surface has now ceased to grow colder, the dispersion of invisible vapour, and the corresponding abstraction of heat, still continue without intermission. The same medium, therefore, which transports the vapour, must also furnish the portion of heat required for its incessant formation. In fact, after the water has been once cooled down, each portion of the ambient air which comes to touch the evaporating surface must, from its contact with a substance so greatly denser than itself, be likewise cooled down to the same standard, and must hence communicate to the liquid its surplus heat, or the difference between the prior and the subsequent state of the solvent, and which is proportioned to the diminution of temperature it has suffered. Every shell of air that in succession encircles the humid mass, while it absorbs, along with the moisture which it dissolves, the measure of heat necessary to convert this into steam, does at the same instant thus deposite an equal measure of its own heat, on the chill exhaling surface. The abstraction of heat by vaporization on the one hand, and on the other its deposition at the surface of contact, are, therefore, opposite contemporaneous acts, which soon produce a mutual balance, and thereafter the temperature induced continues without the smallest alteration. A rapid circulation of the evaporating medium may quicken the operation of those causes; but, so long as it possesses the same drying quality, it cannot in any degree derange the resulting temperature. The heat deposited by the air on the humid surface becomes thus an accurate measure of the heat spent in vaporizing the portion of moisture required for the saturation of that solvent at its lowered temperature. The dryness of the air is therefore, under all circumstances, precisely indicated, by the depression of temperature produced on a humid surface which has been exposed freely to its action.

In this investigation, we have only considered the effect arising from the recession or the quickened transfer of the contiguous portions of the ambient medium. But the conterminous air must besides communicate heat to the water by pulsation ; and consequently the balance of temperature would be liable to incidental variations, if moisture, with its embodied heat, were not likewise abstracted by some corresponding process. And such is the harmonious adaptation of these elements. The discharge of vapour appears to be subject precisely to the same conditions as the emission of heat, and in both cases the proximity of a vitreous or a metallic surface produces effects which are entirely similar. Let two pieces of thin mirror-glass, or what is called Dutch plate, be selected, about four inches and a half square; and having applied a smooth coat of tinfoil, four inches square, to one of these, cover them both with a layer of the thinnest goldbeater's skin, which will adhere closely on being wetted, and after it has again become dry, cut it on each into an exact square of four inches and a quarter: Now place the two glass plates horizontally in the opposite scales of a fine balance, and adjust them to an exact counterpoise: then, with a hair pencil, spread two grains of water over the surface of each pellicle: in a few seconds, the plate which is coated with tinfoil will preponderate, and after the former has lost all its moisture, this will be found to retain still three-tenths of a grain. The proximity of the subjacent metal to the humid surface, therefore, impedes the process of evaporation, in the ratio of 17 to 20; the very same, as in like circumstances, had been the retardation of the efflux of heat. From this and other experiments, we learn, that some constant portion from a humid surface is always abstracted by the pulsation of the aërial medium. The steam exhaled, in uniting with the air, communicates to this elastic fluid a sudden dilatation, which will continue to propagate itself in successive waves.

Nor is the mode of transmission, by the play of alternate pulses, confined to heat and moisture alone; smells would appear to be conveyed through the atmosphere by a similar agency. It is well known that, though the wind disperses widely the odorous particles, yet their scent will, to a certain way, penetrate even against the current. Nay, the action of smell may, by means of a tapering tube, be concentrated on the nostril, nearly after the same manner as the impressions of sound are collected and heightened in the ear-trumpet. Having spread musk over a circular bit of pasteboard, I placed it a few inches before a small metallic reflector, in the focus of which was suspended a glass bulb covered with cambric, and another similar bulb set an inch aside from it: In a few minutes, these were both examined, and the one which had occupied the focus smelt more strongly of musk than the other. The experiment was next varied, by stretching across the speculum a sort of chaplet of pea-blossoms, marked with slight incisions; on presenting a small disk of pasteboard covered with dry ammonia, the blossoms became of a greenish hue wherever the juices transuded, but the colour was evidently the most intense near the focus. In these cases, the odorous substance must, in the act of dissolving in the air, have excited a sort of pulsatory impression like that which is caused by the production of sound. The only difference appears to lie in this, that smell and moisture, consisting of matter sensibly ponderable, somewhat resemble wrecks floating on the waves, and are consequently not carried forward with the same accuracy, or to such a great distance, as heat, which possesses the inherent and extreme subtilty of light itself.

Having therefore ascertained the great law of evaporation, and shown that the coldness occasioned by it, is not, in any degree, affected by agitation or other extraneous influence, nothing seemed wanting to construct an *Hygrometer* on just principles, but to contrive a thermometer that should mark the smallest alterations of temperature. At first I employed a very delicate thermometer with a short range, open at the top, where a small cap of glass or ivory was attached. A cup made of thin porous earthen-ware, nearly of the shape of a lady's thimble, but somewhat larger, and filled with water, was exposed to the air, while the thermometer lay beside it in an horizontal position. *(See fig.* 4.*)* After a few minutes, the thermometer was lifted up and plunged vertically into the cup; and the thread of quicksilver, which had extended through the whole length of the bore, being, by this change of position, cut off at the top of the tube, immediately contracted, and marked, by the space of its descent, the diminution of temperature in the liquid.

On a larger scale, but altogether unconscious of the true principle, the natives of the more sultry climates have long practised the method of artificially cooling their liquors by means of evaporation. The rude species of pottery so common among such people, could not fail to suggest the application. The Moors introduced into Spain those unglazed earthen jugs, named *bucaros* or *alcarrazas*, which, being filled with water, present to the atmosphere a surface constantly humid, and furnish by evaporation, during the dry and hot weather, a refreshing beverage. The same practice has been adopted by degrees in various parts of the south of Europe. In India, during certain months, the apartments are kept comparatively cool, by dashing water against the matting of reeds or bamboos, which line the doors and the outside of the walls. Even the more luxurious mariners, in their voyages between the tropics, are accustomed to cool their wines, by lapping the bottle with wet flannel, and suspending it from the yard or under the cabin-windows. In all such cases, the effect is accelerated, though not augmented, by the swiftness of the current of air. What have been called *Egyptian coolers*, and lately produced by our potters, are less perfect in their operation. Being very thick, they require only to be soaked in water, and the evaporation from their surface cools the adjacent air. On the inside, however, where the bottle is placed, the action, in consequence of the confined humidity, must be enfeebled. In damp weather, those vessels are entirely useless.

The mode above described, for discovering the dryness of the air, though susceptible of considerable precision, yet, as it always required a sort of manipulation, was not quite satisfactory; and, in meditating farther on the subject, I was led to the invention of the *Differential Thermometer*, an instrument extremely simple in its construction, and of singular utility in various delicate physical researches. It is indeed only a modification, though a most essential one, of the air thermometer, consisting of a recurved or double stem like the letter U, terminated by two hollow balls which contain air, and holding an intermediate portion of sulphuric acid tinged with carmine, the only substance apparently that will, under the peculiar circumstances, strike a fine and permanent colour. When these balls are of the same temperature, the liquor will remain stationary; but if one of the balls be warmer than the other, the liquor, urged by the increased elasticity of the air, will descend proportionally on that side. The reason why I prefer such a fixed and ponderous liquid as sulphuric acid, is that, in the subsequent changes of temperature, it may not affect the dryness, and therefore elasticity, of the included masses of air which press against it. Alcohol is lighter, and, in its motions, nimbler; but then, by mixing its vapour with the differently heated portions of air, it would dilate them unequally, and disturb the accuracy of the indication. To measure the difference of heat between the two balls, I have adopted a *milligrade* scale, or I distinguish the whole interval between freezing and boiling water into 1000 equal parts. (*See fig.* 1.)

If the ball of the differential thermometer that serves as a reservoir of the liquid, be gilt completely with thick silver leaf, this modification will form the *Pyroscope**; an instrument which is adapted to measure the pulsatory commotion of the air, or the intensity of the heat darting continually from the fire into a room. The hot pulses are mostly thrown back from the bright metallic surface, but, upon the naked ball of glass, they produce their full impression, and consequently make the coloured acid to sink proportionally in the stem. In this construction, the light of the fire, which is always comparatively feeble, passing through the diaphanous ball, and being reflected from the brilliant convexity of the other, has no disturbing influence. The calorific action marked by the pyroscope diminishes, on receding from the fire, in the ratio of the square of its distance; yet such is the sensibility of this instrument, as to be still affected at the re-

* From πῦρ, *fire*, and σκέπτομαι, *I examine.*

motest part of the room. Placed therefore at the same given distance from any grate, it will indicate the absolute force of the fire, or will measure the tide of heat which flows into the apartment. The facility of making observations of this kind may, it is evident, be of considerable use in various practical concerns. To insure the accuracy of the instrument, however, the metallic coat should be very carefully applied, and no external trace left of the size which is employed to fix the silver leaf. The ordinary modes of gilding and enamelling are insufficient.

But the pyroscope will mark likewise the pulsations from a cold surface. In a warm room, it is visibly affected at a few inches from an earthen jug filled with water just drawn from the well. A sheet of wet paper stretched before the counteracting balls, will also, when the atmosphere is tolerably dry, produce, from its chilled surface, a certain corresponding impression.

This instrument serves besides to confirm the existence of the hot or cold pulses excited in the air. Having procured a cone of planished tin, with the top cut off, near 6 inches wide at the mouth, and about 14 inches long, it was divided, in the direction of its axis, into two equal portions, the inside of each of them being painted with lamp black. Turning one of these semi-cones towards the fire, and setting in its narrow neck the naked or sentient ball of the pyroscope, the impression was increased from 20°, its direct and unaided effect, to 25° ; but, on adapting likewise the other half of the cone, it rose to no less than 70°. Now if such augmentation of heat were occasioned by any internal reflections, the effect would only be doubled in the complete cone, or carried from 25° to 30°. This great accumulation must, therefore, be referred to some other source; and what can appear more probable as the cause, than the gradual concentration of the aërial pulsations, in their advance to the ball of the pyroscope?

If the differential thermometer have one of its balls diaphanous, and the other coated with China ink, or rather blown of deep black enamel, it will become a *Photometer**, and indicate the comparative force of the light to which it is exposed. The rays which fall on the clear ball pass through it, without suffering obstruction; but those which strike the dark ball are stopt and absorbed at its surface, where, assuming a latent form, they act as heat. This heat will continue to accumulate, till its farther increase comes to be counteracted by an opposite dispersion, caused by the rise of temperature which the ball has acquired. At the point of equilibrium, therefore, the constant accessions of heat derived from the action of the incident light, are exactly equalled by the corresponding portions of it, again abstracted in the subsequent process of cooling. But, in still air, the rate of cooling is, within moderate limits, proportioned to the excess of the temperature of a given surface above that of the surrounding medium. Hence the space through which the coloured liquid sinks in the stem, will

* From φῶς, *light*, and μέτρον, *a measure*.

measure the momentary impressions of light or its actual intensity. To prevent any extraneous agitation of the air from accelerating the discharge of heat at the surface of the black ball, and thereby diminishing the quantity of aggregate effect, the instrument is always sheltered, and more especially out of doors, by a thin glass case. The addition of this translucid case is quite indispensable. It not only precludes all irregular action, but maintains, around the sentient part of the instrument, an atmosphere of perpetual calm. Under the same force of incident light, the temperature of the black ball must still rise to the same height above that of its encircling medium. The case will evidently have some influence to confine the heat actually received, and hence to warm up the internal air. Wherefore, corresponding to this excess, the black ball will acquire a farther elevation of temperature; but the clear ball, being immersed in the same fluid, must experience a similar effect, and which will exactly counterbalance the former. The difference of temperature between the opposite balls thus continues unaltered; and neither has the size or the shape of the case, nor the variable state of the exterior atmosphere with respect to rest or agitation, any influence whatever to derange or modify the results exhibited by this delicate instrument. The photometer exhibits distinctly the progress of illumination from the morning's dawn to the full vigour of noon, and thence its gradual decline till evening has spread her sober mantle; it marks the growth of light from the winter solstice to the height of summer, and its subsequent decay through the dusky shades of autumn; and it enables us to compare, with numerical accuracy, the brightness of different countries,—the brilliant sky of Italy, for instance, with the murky air of Holland.

But, with respect to photometrical observations, I have not yet had opportunities for collecting a sufficient body of facts. In the latitude of Edinburgh, the direct impression of the sun at noon, during the summer solstice, amounts to 90 degrees; but it regularly declines, as his rays become more oblique. At the altitude of 17°, it is already reduced to the one half; and at 3° above the horizon the whole effect exceeds not one degree. In the same parallel of latitude, the greatest force of the solar beams, in the depth of winter, measures only 25 degrees. Their diminished vigour is evidently caused by the dispersion and absorption which they must suffer in their protracted slanting passage through the atmosphere. Between a fourth and a fifth part of the whole light of the sun is lost in a vertical descent to the surface of the earth; but, in our insular sky, a thin haze, even during the finest weather, generally floats near the horizon, and the successive waste corresponding to each equal number of aërial particles which a very oblique ray encounters in its track, will often amount to the third.

Of the quantity of indirect light which is reflected from the sky, we are apt to form a false estimate, in consequence of its being so much attenuated by diffusion. But, though extremely fluctuating, it is often very considerable. In this climate, it may amount to 30 or 40 degrees in summer, and to 10 or 15 in winter. This secondary light is most powerful when the sky is overspread with thin fleecy clouds; it is feeblest in two very different conditions,—either when the rays are obstructed by a mass of thick congregated vapours,—or when the atmosphere is quite clear and of a pure azure tint. In mists and low fogs, the diminution of the light is comparatively small, it being then affected more from indistinctness than through any want of intensity. When the sky is obscured by a dense body of clouds, the darkness seems to be much increased in proportion to the obliquity of the solar rays. In summer, the photometer, placed in the open air at noon, seldom or never marks less than 10 degrees; but, in some of those sable-shrouded days, which, in this remote region, deform the winter, I have repeatedly observed, that the whole effect, under similar circumstances, did hardly exceed even one degree.

In the higher regions of the atmosphere, the rays of the sun, not being impaired by such a length of passage, are more vigorous than at the surface of the earth; but the diffuse indirect light of the sky, as it is reflected from a rarer mass of air, is therefore proportionally feebler. It would be most interesting, to make observations of this kind on the lofty summits of the Alps or the Andes. The traveller who visits those elevated tracts, is struck with the dark hue of the azure expanse, through which his keen eye may, even during the day time, discern the brighter planets and some stars of the first magnitude.

When the photometer stands quite detached out of doors, it must evidently receive the rays which come from all sides. But set in the inside of the window, it can only feel the impression caused by a part of the sky; and unless it chance to front the quarter from which the sun shines, it will there seldom indicate more than 15 degrees. On drawing the instrument back into the room, the effect will rapidly decrease; for the intensity of action is obviously proportional to the visual space included by the window. Near two degrees of light are required, to enable one to read or write with pleasure; a greater portion of it offends by its excessive glare, and a much smaller quantity tires and strains the eyes.

Placed in open air, the photometer is not only affected by the light sent from the sky, but also, in some measure, by what is reflected from the ground. This derangement, however, is generally very small, and may easily be excluded altogether, by fixing a black screen or circular horizontal rim about the glass-case near the top of the scale. The reflection from a green field perhaps exceeds not the twentieth part of the whole incidence ; but it increases considerably as the colour inclines to whiteness. From a smooth sandy beach, the reflected light will amount to the third part of what is received from the sky ; and from a wide surface of snow, it will reach to five-sixths of the direct impression ; the numerous facets of the bright snowy flakes, which are presented in every possible position, detaining only one-sixth of the incident rays, and scattering the rest in all directions.

The photometer affords a ready mode of ascertaining the various degrees of transparency. Of 100 parts of the whole incident light, cambric transmits 80, and, when wetted, 93. Fine paper suffers 49 parts to pass through it; but, soaked in oil, it will allow the passage of 80 parts. The wide dispersion which the rays suffer in traversing paper and other like substances, clearly shows that they are not sent directly through the supposed vacuities or pores, but escape by some intricate tracks, and experience in their progress various deflections occasioned by the repulsive and attractive energies of the proximate matter. The addition of water or oil to the cambric or paper, forms a real chemical union, and bestows on the compound an intermediate character, more nearly inclined however to the nature of a fluid.

By help of the photometer, we can estimate the relative density of various artificial lights, and even compare their power of illumination with that of the solar rays. But into this inquiry, however practically useful, I have scarcely entered at all. On placing the balls of the photometer two inches from the flame of an ordinary wax candle, an impression was received of six degrees; and, on gradually drawing back the instrument, this effect diminished, as we might expect, in the ratio of the square of the distance. Consequently, at the distance of four feet, where the flame would present to the photometer the same visual magnitude as the sun himself, its action would be reduced to the 96th part of a degree. But the full impression of the solar rays, if not enfeebled by their passage through the atmosphere, would amount to 125 degrees. Wherefore the light emitted by the sun is 96 times 125, or 12,000 times more powerful than that of a wax candle; or, if a portion of the luminous solar matter, rather less than half an inch in diameter, were transported to our planet, it would throw forth a blaze of light equal to the effect of twelve thousand candles.

Since the operation of the photometer depends, on the mutual balance of the action of light, with its subsequent effort to diffuse itself in the latent form of heat, this instrument is hence fitted to discover, with delicate precision, the relative conducting powers, not only of different gases, but of the same gas in its various states of modification. While the absorption of the incident rays continues the same, the change of temperature which they produce on the sentient ball must be in the inverse ratio of the energy of the refrigerating process. Under an equal degree of absorption, a metallic surface is twice as much affected as one of glass, because, by its constitution, it cools twice as slow. If the surrounding medium conduct the accumulated heat more tardily than before, the impression made on the opaque ball will be augmented; or if, on the contrary, it performs the dispersion with more rapidity, the effect will be proportionally diminished.

For the investigation of the conducting powers of different media, I prefer a photometer of the simplest kind, being no other than a differential thermometer with straight upright stems, and having its sentient ball blown of black glass, or coated with a leaf of coloured metal. Set on the transferrer of an air-pump, it is then covered by a narrow receiver, of a clear uniform substance, and swelling regularly near the top. The included air can thus be rarefied to any required degree, and other gases occasionally introduced in its place. In this state, the instrument is exposed to a bright sun, while another photometer, of the ordinary construction, and placed in a similar situation, serves to measure the corresponding effects.

While the comparative photometer indicated 100 degrees, the impression made in air which had been rarefied 256 times, amounted to 185 on the ball of black glass, and rose even to 620 on a coat of coloured metal. In such a thin medium, therefore, the heat is conducted nearly twice as slow from a vitreous surface, and more than three times slower from a metallic one. But, in hydrogen gas of the common density, the effect, compared with the same standard, was only 44 degrees on a black ball and 56 on a gilt ball. This gas hence conducts more than twice as fast as atmospheric air from a surface of glass, and almost four times faster from one of metal. The same gas being rarefied 256 times, its impression on the black ball was 96 degrees, and on the gilt one 156, being more than doubled in the former, and almost tripled in the latter. If the rarefaction be therefore pushed to a certain length, hydrogen gas will have its conducting power reduced to nearly the same as that of common air.

The photometer has two general forms; the one *portable*, in which the black ball is about an inch higher than the other, and bent forward to the same vertical line or the axis of the translucid cylindrical case, (*see fig.* 2.); and the other *stationary*, having both its balls of the same height, and reclining in opposite ways; the case being composed of a wide cylinder surmounted by the larger segment of a hollow glass sphere. *(See fig. 3.)*. The portable photometer admits likewise an outer case of ebony or mahogany, which not only protects it from risk or injury, but occasionally serves when out of doors for holding it in an erect position. The other form of the instrument, however, though in some respects less commodious, is yet on the whole better adapted for nice observations, since besides receiving the light more regularly, its balls, from being on the same level, are not liable to be any how disturbed in their indications by the different strata of unequally heated air.

But the sensibility of the photometer may be very considerably augmented, by help of a judicious combination of cases. If the black ball be encircled by a series of concentric shells of glass, though they freely admit the influx of light, yet they will greatly retard its subsequent dispersion in the form of heat, and therefore promote a high degree of accumulation. Nor is the impression thus excited at all disturbed or diminished, by any counteracting efforts of the clear ball, which being situate without the inclosure and in open space, maintains the temperature of the atmosphere. These spherical shells, each composed of two adapted segments, are chosen as thin and clear as possible, their diameters rising in regular succession, by a difference of at least half an inch. Every additional case would nearly double the impression which is made on the instrument. With six cases, therefore, it would become ten times more sensible, and consequently fitted to measure the dilute shadings of light. The extent of the scale must necessarily be contracted in proportion to the enlargement of the degrees.

There is still another photometrical combination, but which is calculated only for measuring parallel rays. It consists of a small reflector made of copper plated with silver and nicely hammered into a deep parabolic figure, the black ball of a wide differential thermometer being fixed in the focus, and the front of the speculum covered with a circle of clear glass having a slight degree of convexity. This compound instrument, placed at the remote side of a room and directly facing the window, will indicate, with great precision, the very minute and variable quantities of light which, during all the changes of the seasons and fluctuations of the sky, will penetrate across an apartment.

The ball of the differential thermometer which contains the supply of coloured liquid, being covered with several coats of cambric or tissue paper, and wetted with pure water, the instrument now forms a complete *Hygrometer;* for it will mark, by the descent of the column in the opposite stem, the constant diminution of temperature which is caused by evaporation from that humid surface, and it must consequently express the relative dryness of the ambient air. In a very short space, seldom indeed exceeding two minutes, the full effect is produced; and under the same circumstances, it will continue unaltered, till the whole of the moisture has exhaled. To exclude entirely the mixture of photometrical influence, or prevent any derangement which the action of light might otherwise occasion, the opposite balls are made to exhibit nearly the same colour and opacity, the naked one being blown of green or blue glass, and the papered one besides covered with a bit of thin silk, of rather a light shade, so as to take a deeper tint when moistened.

The hygrometer has, like the photometer, two different forms; the one *portable*, and the other *stationary*. The former, having its balls in the same perpendicular line, is protected by a case of wood or ivory, and fitted for carrying in the pocket; two or three drops of pure water from the tip of a quill or a hair pencil being applied to the surface of the covered ball, and the instrument held in a vertical position as often as it is used. *(See fig. 6.)*. The latter form is calculated for somewhat greater accuracy than the other, since its balls, though bent opposite ways, are on the same level. In this construction of the instrument, the covered ball, after being once wetted, is kept constantly moist, by means of some fibres of floss-silk passing close over it, and immersed, at the distance of a few inches in a tall glass decanter full of water, with a stopper which leaves open a small projecting lip. *(See fig. 5.)*. The capillary attraction of these filaments conveys the liquid to the surface of the humid ball, as fast as it wastes by evaporation; but to insure their regular action, the silk should be previously soaked in hot water, to extract any gum that may adhere to it, and the mouth of the decanter should stand a little higher than the balls of the hygrometer. When thus arranged, the hygrometer will, without any help, perform accurately for weeks or even months; and after the silky filaments have become choked with dust, their activity may be again restored by washing them carefully with a fine wet brush.

The condition of the atmosphere with respect to dryness is extremely variable. In our climate, the hygrometer will, during winter, mark from 5 to 25 degrees; but, in the summer months, it will generally range between 15 and 55 degrees, and may even rise, on some particular days as high as 80 or 90 degrees. In thick fogs, the instrument stands almost at the beginning of the scale; it commonly falls before rain, and remains low during wet weather; but it mounts powerfully in continued tracts of clear and warm weather. The greatest dryness yet noticed, was at Paris in the month of September, when it reached to 120 degrees. But for want of observations, we are totally unacquainted with the real state of the air in the remote and tropical climates.

When the indication of the hygrometer does not exceed 15 degrees, we are directed by our feelings to call the air damp; from 30 to 40 degrees we begin to reckon it dry; from 50 to 60 degrees we should account it very dry, and from 70 degrees upwards we might consider it as intensely dry. A room is not comfortable, or perhaps wholesome, if it has less than 30 degrees of dryness; but the atmosphere of a warm occupied apartment will commonly produce an effect of upwards of 50 degrees.

But this hygrometer will perform its office even if it be exposed to frost. The moisture spread over the surface, and imbibed into the coat of the papered ball, will first cool a few degrees below the freezing point, and then congeal quickly into a solid compound mass. The moment in which congelation begins, a portion of heat liberated in that act brings the ball back to the temperature of freezing, and the coloured liquor, in proportion to the coldness of the external air, starts up in the opposite stem, where it remains at the same height, till the process of consolidation is completed. After the icy crust has been formed, evaporation again goes regularly forward; and if new portions of water be applied, the ice will, from the union of those repeated films, acquire a thickness sufficient to last for several days. The temperature of the frozen coat becomes lowered in proportion to the dryness of the atmosphere. The measure of heat deposited on the chill surface by the contact of the ambient air is then counterbalanced by the two distinct, though conjoined measures of heat, abstracted in the successive acts of converting the exterior film of ice into water and this water into steam; which transformations that minute portion must undergo, before it can unite with its gaseous solvent. But the heat required for the melting of ice being about the seventh part of what is consumed in the vaporization of water, it follows that the hygrometer, when the surface of its sentient ball has become frozen, will, in like circumstances, sink more than before by one degree in seven. This inference is entirely confirmed by observation. Suppose, in frosty weather, the hygrometer, placed on the outside of the window, to stand at 28 degrees; it may continue for some considerable time at that point, until the congelation of its humidity commences: but after this change has been effected, and the equilibrium again restored, the instrument will now mark 32 degrees.

The theory of this hygrometer will enable us to determine not only the relative, but even the absolute dryness of the air or the quantity of moisture which it can absorb, by comparing the capacity of that solvent with the measure of heat required to convert a given portion of water into steam. To discover the capacity of air, is however a problem of great difficulty, and it has not been yet ascertained with much precision. It is generally estimated, I am convinced, by far too high; and from several concurring observations, I should reckon the capacity of air to be only three-eighth parts of that of water. But 600 centigrade degrees, or 6000 on the millesimal scale, being consumed in the vaporization of water, this measure of heat would prove sufficient to raise an equal mass of air 16,000 millesimal degrees, or those 6000 degrees augmented in the ratio of 8 to 3. Now, at the state of equipoise, the quantity of heat that each portion of the aërial medium deposites in touching the chill exhaling surface, or what answers to the depression of temperature which it suffers from this contact, must, as we have seen, be exactly equal to the opposite measure of heat abstracted by it in dissolving its corresponding share of moisture. Wherefore, at the temperature of the wet ball, atmospheric air would take up moisture amounting to the 16,000th part of its weight, for each degree marked by the hygrometer. Thus, supposing the hygrometer to mark 50 degrees, the air would then require humidity equal to the 320th part of its weight for saturation at its reduced temperature. When the papered ball of the hygrometer is frozen, the degrees on this instrument must have their value increased by one-seventh, so that each of them will now correspond to an absorption of moisture equal to the 14,000th part of the weight of the air.

But the value of those degrees becomes augmented in a much higher proportion, if the hygrometer be immersed in hydrogen gas. Since this very dilute medium has ten times the capacity of common air, the quantity of heat which, under similar circumstances, it will deposite on the evaporating surface, must likewise, from the same principle of mutual balance, be tenfold greater, and consequently each hygrometric degree will indicate an absorption of moisture equal in weight to the 600th part of the solvent. The energy of hydrogen gas is therefore not less remarkable in dissolving moisture than in containing heat.

If a large receiver, having a delicate hygrometer suspended within it, be placed on a brass plate and over a metal cup containing some water; the included air will, from the solution of the moisture, become gradually damper, and this progressive change is marked by the instrument. Yet the mass of air will never reach its term of absolute humidity, and before the hygrometer points at 5 degrees, the inside of the receiver appears covered with dew. While the humifying process therefore still goes on, the close attraction of the glass continually robs the contiguous air of a portion of its moisture; so that, a kind of perpetual distillation is maintained through the aërial medium; the vapour successively formed, being again condensed on the vitreous surface. But if, instead of the receiver, there be substituted a vessel formed of polished metal, the confined air will pass through every possible degree of humidity, and the hygrometer will, after some interval, arrive at the beginning of its scale.

The contrasted properties of a vitreous and a metallic surface in attracting and repelling moisture, may be shown still more easily. In clear, calm weather, let a drinking glass and a silver cup be placed empty near the ground, on the approach of evening; and as the dampness begins to prevail, the glass will become insensibly obscured, and next wetted with profuse dew, before the metal has yet betrayed any traces of humidity.

Glass and the metals, particularly silver, thus again manifest similar dispositions with respect to heat and moisture, and their distinctive powers would seem to proceed from the same cause, or from the different approximations of the atmospheric boundary. But this conclusion is at once put beyond all doubt, by an experiment made with a modification of the hygrometer. Let each ball of a pyroscope be covered with a coat of the thinnest gold-beater's skin and moistened equally, any excess of humidity being taken away by touching the necks of those balls with a folded bit of cambric. In this state, supposing the dryness of the room to be 60 degrees, the coloured liquor will, for the space of two or three minutes, remain stationary at the commencement of the scale ; but it will then begin to descend, and will in five minutes sink to 20 degrees, where it will continue for a short time, and afterwards slowly mount again till it recovers its position of rest. It is evident, therefore, since the opposite effects are at first completely balanced, that the same change of temperature must have been effected by evaporation on both the balls, or that the encircling air dissolved a quantity of moisture at each surface exactly proportioned to the heat which it there deposited. The efficacy of air in warming up such chilled surfaces, was already shown to be modified, by the proximity of the subjacent glass and metal, in the ratio of 20 to 17. Consequently, if the evaporation had been as copious from the gilt as from the vitreous surface, the effect produced on the former would have amounted to 60 degrees, and on the latter to only 51 degrees; or the liquor, instead of remaining perfectly balanced, would have subsided 9 degrees in the stem. It follows, therefore, that the naked ball must spend 20 parts of moisture, while the gilt one loses only 17; and hence the former will become sooner dry than the latter, or the covered pyroscope will soon act partially as a hygrometer, indicating the difference between the states of its opposite balls. On applying another pellicle to each ball, the effects of evaporation were balanced for nearly five minutes, when the liquor under the vitreous surface began to sink, and in about ten minutes it fell to 12 degrees, from which it afterwards slowly remounted. More coats being added, similar appearances, though less striking, were observed, till they had acquired a thickness equal to the 500th part of an inch; after which, no alteration took place, and the column of liquor was held in steady equipoise during the whole time that any moisture remained on both the balls.

If the papered ball of an hygrometer be suffered to become dry, the instrument, even in that state, will mark, though for a short time only, the different condition of the media into which it is transported. Thus, the air of a room being supposed to have 50 degrees of dryness, on carrying the quiescent hygrometer into another apartment of 70 degrees, the column of liquor would fall near 20 degrees, from the renewed evaporation of that portion of moisture which had still adhered to the coats of paper. But if the same instrument were carried into an apartment of only 30 degrees of dryness, the coloured liquor would actually rise near 20 degrees above the beginning of the scale, the paper now attracting the excess of humidity from the air. This vapour, in combining with it, passes into the state of water, and therefore evolves a corresponding share of heat. The equilibrium, however, unless the coats of paper have a considerable thickness, is again restored in a very few minutes.

Those changes are most readily perceived, on immersing the quiescent hygrometer alternately in two receivers containing air drier and damper than that of the room. If a pyroscope, having both its balls covered with gold-beater's skin, be treated in the same way, it will indicate an effect, though momentary indeed, of a similar kind: For, in air which is drier, the pellicle of the naked ball will throw off its moisture more freely than that of the gilt ball; and in damper air it will, on the contrary, imbibe the surplus humidity with greater eagerness; thus losing some portion of heat in the one process, and gaining a minute accession in the other. The quantity of moisture concerned in producing such fleeting alterations, may not exceed the thousandth part of a grain.

The separate and distinct effects of evaporation,—the coldness it occasions,—and the quantity of moisture it abstracts,—are obviously seen in the hygrometer, as contrasted with an instrument which I have lately formed to measure the quantity of exhalation from a humid surface in a given time, and which I therefore call an *Atmometer* *. (*See fig.* 8.) This instrument consists of a thin ball of porous earthen-ware, two or three inches in diameter, with a small neck, to which is firmly cemented a long and rather wide tube, bearing divisions, each of them corresponding to an internal annular section, equal to a film of liquid that would cover the outer surface of the ball to the thickness of the thousandth part of an inch. These divisions are ascertained by a simple calculation, and numbered downwards to the extent of 100 or 200; to the top of the tube is fitted a brass cap, having a collar of leather, and which, after the cavity has been filled with distilled or boiled water, is screwed tight. The outside of the ball being now wiped dry, the instrument is suspended out of doors, and exposed to the free action of the air.

---

* From ἀτμος, *exhalation* or *vapour*, and μετρον, *a measure.*

Evaporation is always proportioned to the extent of the humid surface. If a sheet of wet paper be applied to a plate of glass, it will, in a close room, lose its weight exactly at the same rate, whether it be held vertically or horizontally, and whether it occupies the upper or the under side of the plate. The quantity of evaporation from a wet ball is the same as from an equal plane surface, or from a circle having twice the diameter of the sphere. In the atmometer, the humidity transudes through the porous substance, just as fast as it evaporates from the external surface; and this waste is measured by the corresponding descent of the water in the stem. At the same time, the tightness of the collar, taking off the pressure of the column of liquid, prevents it from oosing so profusely as to drop from the ball; an inconvenience which, in the case of very feeble evaporation, might otherwise take place. As the process goes on, a corresponding portion of air is likewise imbibed by the moisture on the outside, and being introduced into the ball, rises in a small stream, to occupy the space deserted by the subsiding of the water in the tube. The rate of evaporation is nowise affected by the quality of the porous ball, and continues exactly the same when the exhaling surface appears almost dry, as when it glistens with abundant moisture. The exterior watery film attracts moisture from the internal mass with a force inversely as its thickness, and will therefore accommodate the supply precisely to any given degree of expenditure. When this consumption is excessive, the water may be allowed to percolate, by unscrewing the cap, avoiding however the risk of letting it drop from the ball.

In still air, the indications of the hygrometer, and those of the atmometer, bear the same proportion ; and the quantity of evaporation for every hour is expressed, in thousandths of an inch in depth, by the twentieth part of the hygrometric degrees. For example, in this climate the medium dryness in winter being reckoned 15°, and in summer about 40°, the daily exhalation from a sheltered spot will amount in winter to a thickness of .018, and in summer to .048 decimal parts of an inch. If we reckon the mean daily evaporation from the ground while screened at .030, the waste during the whole year will amount to near 11 inches, being scarcely the half perhaps of what, under the circulation of the atmosphere, actually obtains. The dissipation of moisture indeed is vastly accelerated by the action of sweeping winds,—the effect being sometimes augmented 5 or 10 times. In general, this augmentation is proportional, as in the case of cooling, to the swiftness of the wind, the action of still air itself being reckoned equal to that produced by a celerity of 8 miles each hour. Hence the velocity of wind is easily computed, from a comparison of the indications of an hygrometer with an atmometer, or of a sheltered, with those of an exposed, atmometer. Thus, suppose the hygrometer to mark 40 degrees, or the column in a sheltered atmometer to subside at the rate of 2 divisions each hour, while in one exposed to the current, the descent is 12 divisions; then, as 2 is to 10, the superadded effect of the wind, so is 8 to 40 miles, its velocity during the hour.

It is curious to remark, what a small proportion of any stream of air can acquire heat or moisture, by flowing over a warm or a humid surface. Supposing the air to have 20 degrees of dryness, the ordinary evaporation would every hour equal a film of the thousandth part of an inch thick. But this portion of moisture would be sufficient, we have seen, to saturate 800 times its weight of air at such a low state of dryness; or reckoning the air 850 times lighter than water, this weight would correspond to that of a cylinder of air $57\frac{1}{2}$ feet high, and having its base equal to the surface of the humid ball,—or to a cylinder 230 feet high, and of the same diameter as that ball. Now, since the ordinary evaporation at 20 degrees of the hygrometer, is equal to the increased effect occasioned by a current of air, moving with the velocity of 8 miles in the hour, and forming therefore against the ball a cylinder of 42,240 feet in height;

it hence follows, that not more than the 184th part of this advancing column can be humified, by its streaming over the surface of the ball. Such communication of moisture is no doubt confined within the narrow limits of physical contact. Each minute portion of air which comes to graze along the humid surface has its velocity retarded, and acquiring new elasticity from the moisture which it dissolves, it is quickly thrown back into the current. On the rapidity of these successive contacts, will depend the absolute quantity of evaporation.

But, in perfectly calm air, the power of evaporation, if it be very considerable, will yet, as in the case of a heated surface, create an artificial stream, which mingles its influence with the ordinary dissipation of moisture. When the hygrometer marks 75 degrees, this current will have a corresponding velocity of one mile every hour, and must therefore augment the regular effect of evaporation by an eighth part. In general, to find the correct hourly evaporation in a medium of still air, as expressed in atmometric divisions, or the thousandths of an inch of superficial thickness, after having divided by 20, the number of degrees indicated by the hygrometer, let the quotient be increased in the ratio of that number to 600. Thus, if the hygrometer were to mark 30 degrees, then 1.5 is the approximate measure of evaporation; and since 30 is contained 20 times in 600, the correction to be added to 1.5 is likewise its twentieth part, or .075; so that the hourly evaporation, estimated in atmometric divisions, amounts to 1.575, and the daily to 18.9. This correction is however in most instances so small, that it may, without material inaccuracy, be entirely overlooked. But, in confined hydrogen gas, at the same state of dryness, the atmometer is as much affected as if it were exposed in open air to a wind having the velocity of 12 miles an hour; and consequently the dispersion of moisture in such a powerful medium is, like that of heat under such circumstances, two and a half times more profuse than in atmospheric air.

The atmometer is an instrument evidently of extensive application and of great utility in practice. To ascertain with accuracy and readiness the quantity of evaporation from any surface in a given time, is an important acquisition, not only in meteorology, but in agriculture, and the various arts and manufactures. The rate of exhalation from the surface of the ground is scarcely of less consequence than the fall of rain, and a knowledge of it might often direct the farmer advantageously in his operations. On the rapid dispersion of moisture, depends the efficacy of drying houses, which are too frequently constructed most unskilfully, or on very mistaken principles. But the purposes to which the atmometer so aptly applies, were hitherto supplied in a rude and imperfect manner. The loss that water sustains in a given time from evaporation, has commonly been estimated by weight or measure. If a piece of flannel, stretched by a slender frame, be wetted and suspended in the free air, its dissipation of moisture, after a certain interval, is found by help of accurate scales; or if water in a shallow pan be exposed in a similar situation, its daily waste is detected by the application of a finely divided rod or gage. But these methods are extremely troublesome, and are subject besides, especially the latter one, to great inaccuracy. Both the flannel and the sheet of water require to be sheltered against the wind and rain, and consequently they will not exhibit, like the atmometer, the real exhalation which takes place from the ground. The bottom and sides of the pan must also, from their extent of dry surface, affect the temperature of the water, and consequently modify the quantity of evaporation.

An atmometer suspended in still air might therefore, on taking into account the time intervened, answer nearly the purpose of the hygrometer; and this mode can be employed with advantage, in discovering the mean dryness of an apartment after the lapse of hours or days. But the delicacy of the hygrometer indicates directly, and almost spontaneously, the actual dryness of the medium. This instrument is hence indispensable in all meteorological observations, and may contribute essentially towards laying the foundation of a juster and more comprehensive knowledge of the various modifications which take place in the lower regions of our atmosphere. Heat and moisture are the chief agents which nature employs in producing those incessant changes; and if the invention of the thermometer has tended so much to correct and enlarge the views of physical science, may not the introduction of an accurate hygrometer be expected to confer a similar benefit, and to direct our researches into many departments that are still unexplored? To possess the means, for instance, of comparing distant climates, must be deemed highly important. We have at length acquired tolerably complete notions of the gradation of warmth, in the whole extent from the frigid to the torrid zone; but, concerning the degrees of dryness which actually prevail in remote parts of the globe, we are left merely to draw conjectural inferences from a few loose reports, depending on the imperfect and often illusive impressions received by the organs of sense. It would be most interesting to ascertain the dampness which has been supposed to pervade the American Continent and its adjacent Archipelago, and to detect the dryness which scorches the sandy deserts of the interior of Africa, and parches the wide and lofty plains of Upper Asia. Nor would it be less curious to discover the real qualities of those singular winds, which, under the names of *sirocco*, *harmattan*, and *simoom*, infest the hotter climates, and are described by travellers as working such strange and formidable effects on the animal frame. Even in this island, the several winds have their distinct characters. If it blows from the northern quarter, the hygrometer generally inclines to dryness; but a southerly wind, along with warmth, invariably brings an excess of humidity. In clear and calm weather, the air is always drier near the surface during the day than at a certain height above the ground, but it becomes damper on the approach of evening, while, at some elevation, it retains a moderate degree of dryness through the whole of the night. If the sky be clouded, less alteration is betrayed in the state of the air, both during the progress of the day and at different distances from the ground; and if wind prevail, the lower strata of the atmosphere, thus agitated and intermingled, will be reduced to a still nearer equality of condition.

In the regulating of many processes of art, and in directing the purchase and selection of various articles of produce, the application of the hygrometer would render material service. Most warehouses, for instance, require to be kept at a certain point of dryness, and which is higher or lower according to the purposes for which they are designed. The printing of linen and cotton is carried on in very dry rooms, but the operations of spinning and weaving succeed best in air which rather inclines to dampness. The manufacturer is at present entirely guided by observing the effects produced, and hence the goods are often shrivelled, or otherwise injured, before he can discover any alteration in the state of the medium. But were an hygrometer, even of the most ordinary construction, placed in the room, it would exhibit every successive change in the condition of the air, and immediately suggest the proper correction. The same means could be employed most beneficially, in attempering the atmosphere of public hospitals.

That wool and corn have their weight considerably augmented by the presence of moisture, is a fact well known. Without supposing that any fraudulent practices are used, this difference, owing merely to the variable state of the air in which the substances are kept, may yet in extreme cases amount to 10 or even 15 *per cent.* Grain or paper preserved in a damp place, will be found to swell nearly after the same proportion. But the real condition of such commodities might easily be detected, by placing the hygrometer within a small wired cage, and heaping over this, for a few minutes, a quantity of the wool or grain which is to be examined.

The hygrometer will enable us to compare with accuracy the various absorbent powers of different substances. These powers are totally distinct from the force of capillary action, and appear to be as much diversified as the other intimate properties of bodies. When water ascends the narrow bore of a glass tube, or spreads itself through the interstices of sand, it occasions no change whatever in their internal constitution, and the glass and the sand retain precisely the same place and condition as before. But when wood or ivory, linen or paper, imbibe moisture, this act of absorption is invariably attended in them, by a corresponding diminution of the aggregate volume, and some disengagement of heat. The instrument already described, for measuring the expansion which air acquires on being damped, shows a very visible contraction of bulk in the union of a bit of linen with a few drops of water. The heat evolved in this union is not less remarkable, and it is always proportioned to the dryness of the previous state of the absorbing substance. Let a large piece of cambric or linen be dried intensely before the fire, and then lap it about the bulb of a delicate thermometer, and introduce them both into a tall narrow glass, which is placed in a close room, with a stopped phial containing water set beside it. After the space of an hour or two, when this apparatus has acquired the same temperature, pour a little water from the phial upon the cambric, and the bulb of the thermometer will become instantly affected, and indicate an extrication of heat, amounting perhaps to three or four degrees on Fahrenheit's scale. With oak saw-dust, which has been previously parched, the effect is still more striking; and the well-known fact, that biscuit recently baked feels hot in the mouth, must evidently be referred to the same principle. But the hygrometer itself, in its quiescent state, displays conspicuously, although on a smaller scale, properties which are entirely similar. If the papered ball be suffered to grow dry, and two or three drops of water at the ordinary temperature be applied to it, the coloured liquor will quickly rise in the opposite stem five or perhaps ten millesimal degrees, according to the thickness of the coat and its previous intensity of dryness. This impression however is only momentary, and soon succeeded by the proper hygrometric action. Heat was therefore at first disengaged, during the act of combination of the water with the bibulous paper.

But those absorbent substances, besides assimilating to their essence a portion of the liquid which touches them, are likewise disposed to attract, though with various energy, the humidity from the atmosphere. The more solid, as well as the softer, materials exert this power, and which is exactly analogous to that of the concentrated acids and the deliquescent salts. In their several affinities to moisture, the earthy bodies discover the most essential differences of constitution. To examine these properties, let the substance be dried thoroughly and almost roasted before a strong fire, and introduced immediately into a phial with a close stopper; the powder, having undergone that sort of preparation, is at any time afterwards thrown partially into a very large wide-shaped bottle, and shut up till it has attracted its share of humidity from the confined air; and a delicate hygrometer, being now let down into the bottle, indicates the measure of the effect produced by absorption. In this way, it was found that, about the temperature of 60 on Fahrenheit's scale, alumine causes a dryness of 84 degrees in the air included with it; the carbonate of magnesia, 75; the carbonate of lime, 70; silica, 40; the carbonate of barytes, 32; and that of strontites, only 23. These simple bodies also betray other differences in their internal constitution. The absorbing powers of silica, barytes and strontites, are not only feeble, but of small extent, and these earths become very soon saturated with humidity. Alumine and magnesia, on the other hand, have their energy scarcely impaired by repeated absorptions. It is singular, that marble and quicklime should produce exactly the same effect, and that in general no sensible difference in that respect can be perceived between the pure earths and their carbonates. The great absorbent power of the argillaceous, compared with the siliceous bodies, likewise deserves particular notice. But many of the compound earths and stones possess the power of attracting moisture from the air, in a still higher degree. These substances need only be pounded or broken into small fragments, and then exposed, for a certain time, near a strong fire. Pipe clay, though it contains a large proportion of silica, occasioned a dryness of 85 degrees; whinstone or trap, though very compound, produced an effect equal to 80 degrees; and sea-sand, having an admixture of shells, gave a dryness of 70 degrees. But torrefaction seems remarkably to diminish the faculty of the earthy substances to attract moisture. Clay, roasted in a strong fire, causes a dryness of only 35 degrees; and urged in a blacksmith's forge, it affords no more than 8, while whinstone or trap, by the same treatment, has its energy reduced to 23 degrees. The absorbent power of earths depends, therefore, as much on their mechanical condition, as on the species of matter of which they are composed. Whatever tends to harden them, diminishes the measure of effect; and hence apparently the reason, why the action of fire impairs their desiccating quality. Quartz or silica, which in a blacksmith's forge had suffered a reduction to 19 degrees, after being soaked in water for the space of a week and again dried, showed an effect equal to 35 degrees, and would probably in time have recovered the whole of its original power. The process by which nature gradually divides, softens, and disposes stony bodies to absorb moisture, is beautifully illustrated in the case of our whinstone or trap. A piece of solid trap produced, we have seen, a dryness of 80 degrees by the hygrometer; another piece, decayed and crumbling, gave 86 degrees; but another piece of the same rock, already reduced to mould, afforded 92 degrees. The ameliorating influence of culture is exemplified in sea-sand: fine sand caused a dryness of 70 degrees; sand collected from the paths of a sheep-walk near the beach, 78 degrees; and the same sand, lately brought into cultivation, 85 degrees. Still these effects are inferior to that of garden mould, which amounts to 95 degrees, and to which decomposed trap approaches the nearest. This material, in its mouldered state, constitutes the basis of our richest agricultural districts. Other cultivated soils exert a similar power of absorption, and which appears always proportioned to their respective goodness. Nor are such increased energies to be ascribed to the amelioration from manure, since this ingredient separately has less influence than the earths themselves. It therefore seems highly probable, that the fertility of soils depends chiefly on their disposition to imbibe moisture.

I have just glanced at a theory which, if it were confirmed by farther experience, would greatly enlarge the boundaries of useful science. The art of chemical analysis, however much it has been refined, yet fails totally in detecting the intimate constitution of bodies. Stones, the most opposite in their aspect and general characters, are sometimes composed of the same elements, united too in like proportions. On the nature of soils, the improvements in chemistry have as yet thrown scarcely any light whatever; and notwithstanding the mighty promises held forth to us, agriculture is still obliged, it must be confessed, to grope her way, by the glimmering of rude experience. The various absorbent powers of earths offer something like a principle of distinction among them. The operations of tillage serve to open and mellow the soil; while the process of paring and burning, if it goes farther than the mere destruction of the noxious roots and fibres, bakes and hardens the surface, rendering it unfit for the purposes of vegetation, till, after some lapse of time, it again recovers its proper constitution. In volcanic countries, likewise, the fields of lava require the influence of many centuries, to fit them for cultivation. For comparing the absorbent powers of the various kinds of soil, the hygrometer might easily be adapted. The subject now started is at least of such a promising nature as to claim our serious attention.

The variations both in weight and bulk which absorbent bodies undergo, have been employed to indicate the disposition of the air with respect to moisture. For this reason, such substances are likewise termed *hygroscopic* *; since they are always affected by the state of the ambient medium, though they may not precisely measure its degrees of humidity or dryness. But neither heat nor moisture is passively diffused, or yet shared among different bodies in equal proportions. Under the same change of circumstances, 100 grains of ivory will attract from the atmosphere 7 grains of humidity; the same weight of boxwood, 14 grains; of down, 16; of wool, 18; and of beech, 28. Other sub-

* From ὑγρὸς, *humid* or *moist*, and σκέπτομαι, *I examine.*

stances will, in their respective measures of absorption, discover still wider differences.

The dry or humid state of the air is therefore discovered, from the variable weight of certain bodies exposed to its influence. Rock salt has been applied to that purpose; but potash, the muriate of lime, sulphuric acid, and most of the deliquescent substances, whether in a solid or a liquid form, act the most powerfully. Other materials of a firm or adhesive consistence manifest the same properties, though in a lower degree. Plates of slate-clay or of unglazed earthen-ware, the shavings of box or horn, paper or parchment, wool or down,—all act as hygrometers. But these substances, especially the harder kinds of them, unless they be extremely thin, receive their impressions very slowly, and hence they cannot mark with any precision the fleeting and momentary state of the ambient medium. Nor is the weight which they gain by exposure, proportioned to the real dampness of the air; for the measures of their successive absorption increase in a most rapid progression, as they approach to the point of absolute humidity.

But to weigh the substances with the accuracy befitting such experiments, is a very delicate and troublesome operation. Those thin bodies are liable, besides, to become in time covered with dust, which, while it must evidently augment their weight, cannot be detached from them without injuring their slender texture. The increase of bulk which they acquire from the portion of moisture attracted into their substance, furnishes therefore a more certain and convenient indication of the state of the atmosphere. The solid vegetable and animal fibres are connected by a fine soft netting, in which the power of absorption appears chiefly to reside. Hence the presence of moisture always enlarges the breadth of such substances, without affecting in any sensible degree their length. This effect is visible in the swelling of a door by external dampness, and in the shrinking of a pannel from the opposite cause. But the substances, such as paper or parchment, which have a diffuse or interlaced texture, are extended, by the absorption of humidity, almost equally in every direction. On the contrary, twisted cord or gut, being swelled by moisture, suffer a corresponding longitudinal contraction, accompanied likewise, if not confined, by some uncoiling of their fibres.

All these properties have severally been employed in the construction of hygroscopes. The expansion of the thin cross sections of box or other hard wood, the elongation of the human hair or of a slice of whale-bone, and the untwisting of the wild oat, of catgut, of a cord or linen thread, and of a species of grass brought from India,—have at different times been used with various success. But the instruments so formed are either extremely dull in their motions, or if they acquire greater sensibility from the attenuation of their substance, they are likewise rendered the more subject to accidental injury and derangement ; and all of them appear to lose in time insensibly their tone and proper action.

I have lately revived a method of measuring the expansion of absorbent cohesive substances, by their enlargement of capacity when disposed into a shell; and have, by successive steps, carried the hygroscope thus formed to as high a state of improvement, as perhaps such an imperfect instrument will admit. A piece of fine grained ivory, about an inch and quarter in length, is turned into an elongated spheroid, as thin as possible, weighing only 8 or 10 grains, but capable of containing, at its greatest expansion, about 300 grains of mercury; and the upper end, which is adapted to the body by means of a delicate screw, has a slender tube inserted, 6 or 8 inches long, and with a bore of nearly the 15th part of an inch in diameter. (*See fig.* 7.). The instrument being now fitted together, its elliptical shell is dipped into distilled water, or lapped round with a wet bit of cambric, and after a considerable interval of time, filled with mercury to some convenient point near the bottom of the tube, where is fixed the beginning of the scale. The divisions themselves are ascertained, by distinguishing the tube into spaces which correspond each of them to the thousandth part of the entire cavity, and equal to the measure of about three-tenths of a grain of mercury. The ordinary range of the scale will include 70 of these divisions. To the upper end of the tube, is adapted a small ivory cap, which allows the penetration of air, but prevents the escape of the mercury, and thereby renders the instrument quite portable.

This hygroscope is largely, though rather slowly, affected by any change in the humidity of the ambient medium. As the air becomes drier, it attracts a portion of moisture from the shell or bulb of ivory, which, suffering in consequence a contraction, squeezes its contained mercury so much higher in the tube. But if, on the contrary, the air should incline more to dampness, the thin bulb will imbibe moisture and swell proportionally, allowing the quicksilver to subside towards its enlarged cavity. These variations, however, are very far from corresponding with the real measures of atmospheric dryness or humidity. Near the point of extreme dampness, the alterations of the hygroscope are much augmented; but they diminish rapidly, as the mercury approaches the upper part of the scale. The contraction of the ivory answering to an equal rise in the dryness of the air, is six times greater at the beginning of the scale than at the 70th hygroscopic division; and seems in general to be inversely as the number of hygrometric degrees, reckoning from 20 below. I have therefore placed another scale along the opposite side of the tube, the space between 0 and 70 of the hygroscope being distinguished into 100 degrees, and corresponding to the unequal portions from the number 20 to 120 on a logarithmic line. This very singular property is more easily conceived from the inspection of the figure. The scale might be safely extended farther, by continuing the logarithmic divisions. Thus, 320 degrees by the hygrometer would answer to 108 of the hygroscope, or to a contraction of 108 parts in a thousand in the capacity of the bulb. But at the dryness of 300, I have never found the contraction of the ivory to exceed 105.

Boxwood, I likewise formed into a hygroscope, of the same shape and dimensions; but this absorbent material swells twice as much with moisture as ivory does, and therefore requires its inserted tube to be proportionally longer or wider. The contractions of box are still more unequal than those of ivory. Near the point of extreme humidity, those alterations in the capacity of the bulb seem to be more than twenty times greater than, under like changes in the condition of the atmosphere, take place towards the upper part of the scale. The space included between the commencement and the 140th millesimal division of the scale, might hence be marked with 100 hygrometric degrees, corresponding to the decreasing portions of a logarithmic line from 5 to 105.

In noticing the rapidly declining contractions which ivory and box undergo, I would not be understood, however, to state the quantities with rigorous precision; I merely consider the numbers given above as very near approximations to the truth. I should be ashamed to confess how much time I have already consumed, in tracing out the law of those contractions. Such experiments are rendered the more tedious, from the protracted action of the hygroscope, which often continues travelling slowly for the space of a quarter or even half an hour. This tardiness is indeed the great defect of all instruments of that nature, and utterly disqualifies them from every sort of delicate observation.

The very large expansions which the hygroscope shows on its approach to extreme humidity, explains in a satisfactory manner the injury which furniture and pieces of cabinet-work sustain from the prevalence of dampness. On the other hand, the slight alteration which the instrument undergoes in a medium of highly dry atmosphere, seems to have led most philosophers to believe that there is an absolute term of dryness, on the distance of which, from the point of extreme moisture, they have generally founded the graduation of the different hygroscopes proposed by them. This opinion, however, is far from being correct, and might give occasion to most erroneous conclusions. No bounds can be set to the actual dryness of the air, or the quantity of moisture which it is capable of holding, and which, by the joint application of heat and rarefaction to the solvent, may be pushed to almost indefinite extent.

The ivory hygroscope, after being for several hours immersed in air of 150 or 200 degrees of dryness, was apt of a sudden to split longitudinally. But if the bulb endured such a range of contraction, it appeared in some instances to take at least *another set*, or to accommodate its constitution, by imperceptible gradations, to the state of the surrounding medium. If this remark were confirmed, it would elucidate finely the atomical system of bodies, and establish the successive limits of corpuscular attraction and repulsion.

But though the bulbous hygroscope is, in extreme cases, liable to much uncertainty and some risk, it may yet be used with visible advantage, in a variety of situations, as an auxiliary merely to the hygrometer. The very sluggishness of the instrument, when the value of its divisions has been once ascertained, fits it so much the better for indicating the mean results. After being long exposed in situations hardly accessible, it may be conveniently transported for inspection before it can suffer any sensible change. The hygroscope could be, therefore, employed with success to discover the degree of humidity which prevails at certain considerable elevations in the atmosphere. It might be likewise used for ascertaining readily the precise condition of various goods and commodities. Thus, if the bulb were introduced, for the space perhaps of half an hour, into a bag of wool, a sack of corn, or a bale of paper, it would, on being withdrawn from their contact, mark the dryness or humidity of those very absorbent substances.

The softer absorbent substances are not only themselves affected by the state of the ambient medium, but are capable, when they expose a broad attractive surface, of assimilating to their previous condition, air and other gaseous fluids confined over them. Flannel, for instance, which has been intensely dried before a strong fire, will support a remarkable degree of dryness in a close receiver; yet after a few repeated applications, it soon becomes saturated with humidity, and loses its power of absorption. Muriate of lime has a vigorous and extended energy; but the substance which answers best on the whole as an absorbent, and which continues for a long time to attract moisture with almost undiminished force, is the concentrated sulphuric acid. By the action of this material, I am enabled to maintain, for weeks or even months together, a magazine of dry air, which affords the means of accurately graduating the differential thermometer and its several modifications. But, by exposing, at the same time, under the receiver a surface of water in given proportion to that of the acid, the confined air may easily be reduced to any inferior state of dryness.

The presence of heat likewise augments very considerably all those absorbent powers. Thus, while in winter the introduction of sulphuric acid under a receiver and in a room without fire, scarcely sinks the hygrometer 40 degrees, it will, even in our feeble summers, occasion a dryness of 100 or 120 degrees. On this principle, water may be rendered cool in the sultriest climates, and in every state of the atmosphere; for nothing more is required than, to expose it to evaporate from a porous vessel, in a medium of confined air, and near the action of a large surface of sulphuric acid. Nay, with that arrangement, artificial congelation is produced, if the external temperature should come but as low as 38 or 40 degrees on Fahrenheit's scale. Wine also could be cooled, by casing the sides of the bottle with wet flannel, and shutting it up in a wide shallow box, which is lined with lead or composed of glazed earthen-ware, and has its bottom covered, perhaps to the thickness of half an inch, with a stratum of the acid. If this box, with its contents, were placed in a cellar, the wine would, at all times in this island, have its temperature reduced, in the space of four or five hours, to 40 or 42 degrees by Fahrenheit's scale. By the same very simple contrivance, wine or water might, in the tropical countries, be cooled, from 80 degrees on the same scale, to 55, or even lower. Nor is the desiccating efficacy of the acid sensibly impaired, till it has absorbed an equal bulk of moisture, and has consequently on successive days occasioned the moderate refrigeration of more than fifty times its weight of wine or water.

The application of heat constantly increases the dryness of the air, or its disposition to dissolve moisture. This property is so generally known, that the evaporating power of the medium is very seldom in practice referred to any other cause. Drying houses, for example, are commonly constructed as if heat were to produce the whole effect, no means being employed for aiding the escape of the air, after it has become charged with humidity, and consequently rendered unfit for performing any longer the process of evaporation.

The influence of warmth in augmenting the dryness of the air, or its disposition to imbibe moisture, explains most easily a singular fact remarked by some accurate observers. If two equal surfaces of water be exposed in the same situation, the one in a shallow, and the other in a deep vessel of metal or porcelain; the latter is always found, after a certain interval of time, to have suffered, contrary to what we might expect, more waste by evaporation than the former. This observation was once made the ground of a very absurd theory, although the real explication of it appears abundantly simple. Amidst all the changes that happen in the condition of the ambient medium, the shallow pan must necessarily receive more completely than the deeper vessel, the chilling impressions of evaporation, since it exposes a smaller extent of dry surface to be partly heated up again by the contact of the air. The larger mass being, therefore, kept invariably warmer than the other, must in consequence support a more copious exhalation.

If heat augments the dryness of the air, its absence produces an opposite effect. When the external air is colder than that of an apartment which is rather disposed to humidity, the windows come to be covered with dew on the insides of the panes. The massy walls of cellars and untenanted buildings, being relatively cool during the summer months, appear then generally dripping with moisture. A caraffe, filled with water fresh drawn from the well, and set on the table in a hot room, becomes soon covered over with dew; and this effect takes place more speedily, when the surrounding air inclines to dampness. Nor will the deposition of moisture cease, until the glass decanter, with the water contained in it, has approached to the heat of the room. On this principle, it has been proposed to construct a sort of rude hygrometer, by observing the depressed temperature at which the dew again begins to disappear from the surface of a small globlet filled with cold water. The point of atmospheric saturation will evidently be lower in proportion to the dryness of the room.

But air must become drier, from having deposited a part of the moisture which it held in solution. A cold body introduced under a large receiver, may therefore occasion a very considerable dryness in the confined medium. Thus, when the temperature of the room is about 70 degrees by Fahrenheit, a goblet filled with water at 50 degrees, being placed within a receiver of perhaps thrice its surface, a delicate hygrometer suspended near the middle of the vacant space, marked 45 degrees. A wide saucer of glass or porcelain, containing water equally cold, produces almost the same effect. The air included between the cold mass and the receiver, losing its heat on the one side, and again recovering this partly on the other, assumes a certain intermediate temperature; but each portion of it which successively comes to touch the glass, the porcelain, or the water, being chilled by such contact, surrenders its surplus humidity, and then mingling with the rest of the air, regains the mean state of warmth, and consequently has, in proportion to that change, its dryness or power of solution renewed. The medium thus rendered drier, being therefore capable of performing evaporation, may, by acting on a humid surface, produce a degree of cold little inferior to that of the mass itself, from the introduction of which under the receiver the whole chain of effects originated. If a freezing mixture be formed with salt and snow or pounded ice in a deep and wide saucer, and placed under a large receiver, about an interval of three or four inches from a small cup of porous earthen-ware filled with water; this water will soon become frozen, and remain so for several hours, till the whole of the ice or snow has melted down into a liquid state. The sides of the saucer, from the deposition of moisture conveyed by the air from the cup, become incrusted with hoar frost, which keeps constantly increasing in thickness as long as the action of the frigorific mixture lasts. If a covered dish were substituted for the saucer, the icy crust, formed over the whole of its external surface, would serve to measure the comparatively small quantity of exhalation from the cup, which was required to freeze the water, and afterwards to support congelation. When the cup containing the water is placed below, instead of above, the magazine of cold, especially under a tall receiver, the evaporating process suffers indeed some reduction, but still the frigorific operation is on the whole rendered more powerful; for the chilled air falling downwards, though it acquires little dryness, yet communicates to the water the impressions of most intense cold with scarcely any diminution.

To discover the precise law by which equal additions of heat augment the dryness of air or its power to retain moisture, is a problem of great delicacy and importance. Two different modes were employed in that investigation, but which led to the same results. The one was, in a large close room, to bring an hygrometer, conjoined with a thermometer, successively nearer to a stove intensely heated, and to note the simultaneous indications of both instruments; or to employ two nice thermometers, placed beside each other, and having their bulbs covered respectively with dry and with wet cambric. By taking the mean of numerous observations, and interpolating the intermediate quantities, the law of aqueous solution in air was laboriously traced. But the other method of investigation appeared better adapted for the higher temperatures. A thin hollow ball of tin, four inches in diameter, and having a very small neck, was neatly covered with linen; and, being filled with water nearly boiling, and a thermometer inserted, it was hung likewise in a spacious close room, and the rate of its cooling carefully marked. The experiment was next repeated, by suspending it to the end of a fine beam, and wetting with a hair pencil the surface of linen, till brought in exact equipoise to some given weight in the opposite scale; ten grains being now taken out, the humid ball was allowed to rest against the point of a tapered glass tube, and the interval of time, with the corresponding diminution of temperature, observed, when it rose again to the position of equilibrium. The same operation was successively renewed; but, as the rapidity of the evaporation declined, five, and afterwards two, grains only were, at each trial, withdrawn from the scale. From such a series of facts, it was easy to estimate the quantities of moisture which the same air will dissolve at different temperatures, and also the corresponding measures of heat expended in the process of solution.

By connecting the range of observations, it would appear, that air has its dryness doubled at each rise of temperature, answering to 15 centesimal degrees. Thus, at the freezing point, air is capable of holding a portion of moisture represented by 100 degrees of the hygrometer; at the temperature of 15 centigrade, it could contain 200 such parts; at that of 30, it might dissolve 400; and, at 45 on the same scale, 800. Or, if we reckon by Fahrenheit's divisions, air absolutely humid holds, at the limit of congelation, the hundred and sixtieth part of its weight of moisture; at the temperature of 59 degrees, the eightieth part; at that of 86 degrees, the fortieth part; at that of 113 degrees, the twentieth part; and at that of 140 degrees, the tenth part. While the temperature, therefore, advances uniformly in arithmetical progression, the dissolving power which this communicates to the air mounts with the accelerating rapidity of a geometrical series.

It hence follows, that, whatever be the actual condition of a mass of air, there must always exist some temperature at which it would become perfectly damp. Nor is it difficult, from what has been already stated, to determine this point in any given case. Thus, suppose the hygrometer to mark 52, while its wet ball has a temperature of 20 centesimal degrees or 68 by Fahrenheit; the dissolving power of air at this temperature being 252, its distance from absolute humidity will therefore be 200, which is the measure of solution answering to 15 centesimal degrees or 59 by Fahrenheit. The same air would consequently, at the depressed temperature of 59 degrees, shrink into a state of absolute saturation; and if cooled lower, it would even deposite a portion of its combined moisture, losing the eightieth part of its weight at the verge of freezing.

The hygrometer, it was shown, does not indicate the actual dryness of the air, but the dryness which it retains, after being reduced to the temperature of the humid ball. The real condition of the medium, however, could easily be determined, from the gradations already ascertained in the power of solution. Suppose, for example, that the hygrometer should mark 42 degrees, while the thermometer stands at 16 centigrade; the moist surface has therefore the temperature of 11.8 centigrade, at which the dissolving energy is less by 37 degrees than at 16 centigrade; and hence the total dryness of the air, at its former temperature, amounted to 79 degrees. A small table of the solubility of moisture, would greatly facilitate such reductions.

That the quantity of moisture which air can hold increases in a much faster ratio than its temperature, is a great principle in the economy of nature. It seems first to have been traced from indirect experience by the sagacity of the late Dr James Hutton, who made it the foundation of his most ingenious and solid theory of rain. Air in cooling becomes ready to part with its moisture. But how is it ever cooled in the free atmosphere? Only by the contact or commixture surely with a colder portion of the same fluid. But that portion of air which is chilled must equally in its turn warm the other. If, in consequence of this mutual change of condition, the former be disposed to resign its moisture, the latter is more inclined to retain it; and consequently, if such opposite effects were balanced, there could, on the whole, be no precipitation of humidity whatever. The separation of moisture on the mixing of two masses of damp air at different temperatures, would therefore prove, that the dissolving power of air suffers more diminution from losing part of the combined heat than it acquires of augmentation from gaining an equal measure of it; and consequently this power must, under equal accessions of heat, increase more slowly at first than it does afterwards, thus advancing always with accumulated celerity.

The result of this induction agrees entirely with the law of solution in air, which has been already pointed out. It is the simplest of the accelerating kind; and the relation of an arithmetical to a geometrical progression, seems applicable to other properties of the gaseous or elastic fluids. An example will elucidate the nature and extent of the aqueous deposition caused by the commixture of opposite portions of air. Suppose equal bulks of this fluid, in a state of saturation, and at the different temperatures of 15 and of 45 centesimal degrees, to be intermingled; the compound arising from such union will evidently have the mean temperature of 30 degrees. But, since at those temperatures the one portion held 200 parts of humidity, and the other 800, the aggregate must contain 1000 parts, or either half of it 500; at the mean or resulting temperature, however, this portion could only suspend 400 parts of humidity, and consequently the difference, or 100 parts, amounting to a hundred and sixtieth of the whole weight of the air, must be precipitated from the compound mass. Nor was it requisite that such portions of air should be perfectly damp. For instance, if the colder air had a dryness of 40, and the warmer, that of 110 hygrometric degrees, the former consequently holding 160 parts of moisture, and the latter 690; after commixture, they would each contain 425 parts, and therefore of those 25 parts, or a measure equal to the six hundred and fortieth of the general mass, would still be deposited.

I have now selected an extreme case, and yet the quantity of moisture set loose might appear to be remarkably small. The difficulty is, therefore, to reconcile the measure of such deposits as deduced from theory, with the actual precipitations from the atmosphere. The lower mass of air which surrounds our globe may have a mean temperature of about 50 degrees on Fahrenheit's scale; and were it consequently forced, by some internal change of constitution, to discharge the whole of its watery store, this would not exceed the 80th part of its weight, or form a sheet of more than five inches deep. Our atmosphere must hence, in the course of a year, deposite five or ten times as much humidity as it can at once hold in solution. But since only a very minute portion of the combined moisture is in fact, at any given time, separated from the air, it follows that the relative processes of evaporation and precipitation must rapidly succeed each other, promoted no doubt by the incessant circulation which is maintained between the higher and the lower strata. Every humid discharge from the atmosphere must, therefore, of necessity be local and temporary.

The mixture of differently heated masses of air is hence insufficient alone to form any very sensible deposit. To explain the actual phenomena, we must have recourse to the mutual operation of a chill and of a warm current, driving swiftly in opposite directions, and continually mixing and changing their conterminous surfaces. By this rapidity, a large volume of the fluid is brought into contact in a given time. Suppose, for instance, the one current to have a temperature of 50, and the other that of 70 degrees, by Fahrenheit's scale; the blended surfaces will, therefore, assume the mean temperature of 60 degrees. Consequently the two streams throw together 200 and 334.2 parts of moisture, making 567.1 parts for the compound, which at its actual temperature can only hold 258.6 parts; the difference, or 8.6 parts, forms the measure of precipitation, corresponding to the 1860th of the whole weight of the commixed air. It would thus require a column of air 25 miles in length, to furnish, over a given spot and in the space of an hour, a deposit of moisture equal to the height of an inch. If the sum of the opposite velocities amounted to 50 miles an hour, and the intermingling influence extended but to a quarter of an inch at the grazing surfaces, there would still, on this supposition, be produced in the same time, a fall of rain reaching to half an inch in altitude. These quantities come within the limits of probability, and agree sufficiently with experience and observation. But in higher temperatures, though the difference of heat between the opposite strata of air should remain the same, the measure of aqueous precipitation is greatly increased. Thus, while the deposit of moisture from the mixing of equal masses of air at the temperatures of 40 and 60 degrees, is only 6.6, that from the like mixture at 80 and 100 degrees, amounts to 19. This result is entirely conformable to observation, for showers are the most copious during hot weather and in the tropical climates. The dew which falls, about the close of evening, in some sultry regions, such as Egypt, is alone sufficient to drench the surface of the earth.

Dr Hutton's account of the production of rain, though it may want still farther expansion, is grounded therefore on correct general principles. A more precise and complete acquaintance with meteorological facts, which is only to be derived from multiplied observations with the hygrometer, would enable us to pursue and illustrate the details of this beautiful theory. The measure of precipitation from the atmosphere depends on a variety of circumstances,—on the previous dampness of the commixed portions of the fluid,—their difference of heat,—the elevation of their mean temperature,—and the extent of combination which takes place. When this deposition is slow, the very minute aqueous globules remain suspended and form clouds; but if it is rapid and copious, those particles conglomerate, and produce, according to the state of the medium with regard to heat, rain, hail or snow. In fine calm weather, after the rays of a declining sun have ceased to warm the surface of the ground, the descent of the higher mass of air gradually chills the undermost stratum, and disposes it to dampness, till their continued intermixture produces a fog, or low cloud. Such fogs are towards the evening often observed gathering in narrow vales, or along the course of sluggish rivers, and generally hovering within a few inches of the surface. But in all situations, these watery deposits, either to a greater or a less degree, occur in the same disposition of the atmosphere. The minute suspended globules, attaching themselves to the projecting points of the herbage, form dew in mild weather, or shoot into hoar frost when cold predominates. They collect most readily on glass, but seem to be repelled by a bright surface of metal.

But the profuse precipitation of humidity is caused by a rapid commixture of opposite strata. The action of swift contending currents in the atmosphere brings quickly into mutual contact vast fields of air over a given spot. The separation of moisture is hence proportionally copious. In temperate weather, this deposition forms rain; but, in the cold season, the aqueous globules, freezing in the mid air into icy spiculæ, which collect in their slow descent, become converted into flakes of snow. Hail is formed under different circumstances, and generally in the sudden alternations of the fine season, the drops of rain being congealed during their fall, by passing through a lower stratum of dry and cold air.

From a variety of nice experiments, we have seen, that the different effects of heat and of steam are yet modified by the same laws. A conformity may, therefore, be expected in the relations of air to those active fluids. As rarefaction enlarges the capacity of air, it likewise augments the disposition to hold moisture; at the same time, that the removal of the ordinary pressure facilitates the expansion of the liquid matter, and its conversion into a gaseous form. Accordingly, if the hygrometer be suspended within a large receiver from which a certain portion of air is quickly abstracted, it will sink with rapidity. In summer, the additional dryness thus produced amounts to about 50 hygrometric degrees each time the air has its rarefaction doubled; so that, supposing the operation of exhausting to be performed with expedition, and the residuum reduced to a sixty-fourth part, the hygrometer would mark in all the descent of 300°. But this effect is only momentary, for the thin air very soon becomes charged with moisture, and consequently ceases to act on the wet ball of the hygrometer. The cold, however, excited on the surface of that ball, by such intense evaporation, will have previously frozen the coating.

It hence appears, that the loftier regions of the atmosphere are comparatively drier than those below, or that, at the same temperature, the attenuated fluid is capable of holding a larger share of humidity. Thus, on the slope of Chimborazo, an hygrometer, if placed in a tent where the air has been warmed to the moderate condition that prevails on the shores of Lima, would stand about 40 degrees higher than at the level of the sea. Without such a constitution of the elements, indeed, our globe must have been shrouded in perpetual darkness; for the cold which reigns in the upper strata, would have prevented the humidity from ascending to a great elevation, and have precipitated it in fogs or clouds. In the actual state of things, the diminution of temperature which we encounter in ascending, predominates at first over the augmented power of aqueous solution; and the air becomes successively damper, till we reach a certain height in the atmosphere, at which the opposite effects of cold and rarefaction are balanced, and where the extreme of humidity must of course obtain. Above that limit, which is the proper region of the clouds, the influence of the rarity of the medium must transcend the effects of its chillness, and the air will now become gradually drier, till it insensibly melts away into the clear ethereal expanse *. From the modified relations of heat and pressure is thus deduced the seat of the clouds, or the boundary beyond which they can seldom rise, which will be found to run generally about two miles above the line of perpetual congelation, being most elevated under the equator, and bending downwards near the poles.

Since air, by being rarefied, has its scale of watery solution so much extended, the application of heat must hence occasion an effect proportionally greater upon a thin medium. If a cold body be, therefore, conveyed under a receiver from which the air is partly extracted, it will produce a very intense dryness. Thus, at the ordinary temperature, a frigorific mass of salt and pounded ice, when its encircling air is from fifty to an hundred times attenuated, will cause an hygrometer,

---

* Apparet divûm numen, sedesque quietæ:
Quas neque concutiunt venti, neque nubila nimbis
Adspergunt, neque nix acri concreta pruina
Cana cadens violat: semperque innubilus æther
Integit, et largè diffuso lumine ridet.

placed at a short distance from it, to sink at least 200 degrees, and still more if the room be warm. Having therefore mixed common salt with three times its weight of ice in a large covered dish of glass or porcelain, nearly equal to the width of a tall receiver passed over it, and having introduced, a very few inches either above or below it, a porous earthen cup about one half or a third part of the same diameter, and filled with water; on rarefying the confined air to the utmost, the small body of water exposed to vigorous evaporation will, at all seasons, speedily congeal, and remain in this frozen state till, after the space perhaps of an hour, the compound mass has melted into brine and lost entirely its power of cooling. The quantity of icy crust gradually formed on the external surface of the dish containing the frigorific mixture, indicates the measure of exhalation from the cup, which is required to produce and support the congelation during the period of its existence. On a principle analogous to what is now stated, Dr Wollaston, to whose acuteness and refined ingenuity, the physical sciences are so deeply indebted, has recently proposed a very simple and portable apparatus, by which a small portion of water, at a short distance from a freezing mixture, may at any time be visibly converted into ice.

The increased power of aqueous solution which air acquires as it grows thinner, being ascertained and carefully investigated, my next object was to combine the action of a powerful absorbent with the transient dryness produced within a receiver by rarefaction. Having introduced a surface of sulphuric acid, I perceived with pleasure that this substance only superadded its peculiar attraction for moisture, to the ordinary effects resulting from the progress of exhaustion; and what was still more important, that it continued to support, with undiminished energy, the dryness thus created. The attenuated air was not suffered, as before, to grow charged with humidity; but each portion of that medium, as fast as it became saturated by touching the wet ball of the hygrometer, transported its vapour to the acid, and was thence sent back denuded of the load, and fitted again to renew its attack with fresh vigour. By this perpetual circulation, therefore, between the exhaling and the absorbing surface, the diffuse residuum of air is maintained constantly at the same state of dryness. But the powers, both of vaporization and of absorption being greatly augmented in the higher temperatures, the same limit of cold nearly is in all cases attained by a certain measure of exhaustion. When the air has been rarefied 250 times, the utmost that, under such circumstances, can perhaps be effected, the surface of evaporation is cooled down 120 degrees of Fahrenheit in winter, and would probably sink near 200 in summer. Nay, a far less tenuity of the medium, still combined with the action of sulphuric acid, is capable of producing and supporting a very intense cold. If the air be rarefied only 50 times, a depression of temperature will be produced amounting to 80 or even 100 degrees of Fahrenheit's scale.

We are thus enabled, in the hottest weather, and in every climate of the globe, to freeze a mass of water, and to keep it frozen, till it gradually wastes away by a continued but invisible process of evaporation. The only thing required is, that the surface of the acid should approach near to that of the water, and should have a greater extent, for otherwise the moisture would exhale more copiously than it could be transferred and absorbed, and consequently the dryness of the rarefied medium would become reduced, and its evaporating energy essentially impaired. The acid should be poured to the depth perhaps of half an inch in a broad flat dish, which is covered by a receiver of a form nearly hemispherical ; the water exposed to congelation may be contained in a shallow cup, about half the width of the dish, and having its rim supported by a narrow metallic ring upheld above the surface of the acid by three slender glass feet of two or three inches in height. *(See fig. 9.)* It is of consequence that the water should be as much insulated as possible, or should present only a humid surface to the contact of the surrounding medium, for the dry sides of the cup might receive, from communication with the external air, such accessions of heat, as greatly to diminish, if not to counteract the refrigerating effects of evaporation. This inconvenience, however, is in a great measure obviated, by investing the cup with an outer case at the interval of about half an inch. If both the cup and its case consist of glass, the process of congelation is viewed most completely; yet when they are formed of a bright metal, the effect appears altogether more striking. But the preferable mode, and that which prevents any waste of the powers of refrigeration, is to expose the water in a pan of porous earthen-ware. If common water be used, it will evolve air bubbles very copiously as the exhaustion proceeds; in a few minutes, and long before the limit of rarefaction has been reached, the icy spiculæ will shoot beautifully through the liquid mass, and entwine it with a reticulated contexture.

As the process of congelation goes forward, a new discharge of air from the substance of the water takes place, and marks the regular advances of consolidation. But after the water has all become solid ice, which, unless it exceed the depth of an inch, may generally be effected in less than half an hour, the circle of evaporation and subsequent absorption is still maintained. A minute film of ice, abstracting from the internal mass a redoubled share of heat, passes, by invisible transitions, successively into the state of water and of steam, which, dissolving in the thin ambient air, is conveyed to the acid, where it again assumes the liquid form, and, in the act of combination, likewise surrenders its heat.

In performing this experiment, I generally seek at first to push the rarefaction as far as the circumstances will admit. But the disposition of the water to fill the receiver with vapour, being only in part subdued by the action of the sulphuric acid, a limit is soon opposed to the progress of exhaustion, and the included air can seldom be rarefied above a hundred times, or till its elasticity can support no more than a column of mercury about three-tenths of an inch in height. But a much smaller rarefaction, perhaps from ten times to twenty times, will be found sufficient to support congelation after it has once taken place. The ice then becomes rounded by degrees at the edges, and wastes away insensibly, its surface being incessantly corroded by the play of the ambient air, and the minute exhalations conveyed by an invisible process to the sulphuric acid, which, from its absorption of the vapour, is all the time maintained above the temperature of the apartment. The ice, kept in this way, suffers a very slow consumption; for a lump of it, about a pound in weight and two inches thick, is sometimes not entirely gone in the space of eight or ten days. During the whole progress of its wasting, the ice still commonly retains an uniform transparent consistence; but, in a more advanced stage, it occasionally betrays a sort of honeycombed appearance, owing to the minute cavities formed by globules of air, set loose in the act of freezing, yet entangled in the mass, and which are afterwards enlarged by the erosion of the solvent medium.

The most elegant and instructive mode of effecting artificial congelation, is to perform the process under the transferrer of an air pump. A thick but clear glass cup being selected, of about two or three inches in diameter, has its lips ground flat, and covered occasionally, though not absolutely shut, with a broader circular lid of plate glass, which is suspended horizontally from a rod passing through a collar of leather. (*See fig.* 10.). This cup is nearly filled with fresh distilled water, and supported by a slender metallic ring, with glass feet, about an inch above the surface of a body of sulphuric acid, perhaps three quarters of an inch in thickness, and occupying the bottom of a deep glass bason that has a diameter of nearly seven inches. In this state, the receiver being adapted, and the lid pressed down to cover the mouth of the cup, the transferrer is screwed to the air pump, and the rarefaction, under those circumstances, pushed so far as to leave only about the hundred and fiftieth part of a residuum; and the cock being turned to secure that exhaustion, the compound apparatus is then detached from the pump, and removed into some convenient apartment. As long as the cup is covered, the water will remain quite unaltered; but on drawing up the rod an inch or more, to admit the play of the rare medium, a bundle of spicular ice will, in the space perhaps of five minutes, dart suddenly through the whole of the liquid mass; and the consolidation will afterwards descend regularly, thickening the horizontal stratum by insensible gradations, and forming in its progress a beautiful transparent cake. On letting down the cover again, the process of evaporation being now checked or almost entirely stopped, the ice returns slowly into its former condition. In this way, the same portion of water may, even at distant intervals of time, be repeatedly congealed and thawed successively twenty or thirty times. During the first operations of freezing, some air is liberated; but this extrication diminishes at each subsequent act, and the ice, free from the smallest specks, resembles a piece of the purest crystal.

This artificial freezing of water in a cup of glass or metal, affords the best opportunity for examining the progress of crystallization. The appearance presented, however, is extremely various. When the frigorific action is most intense, the congelation sweeps at once over the whole surface of the water, obscuring it like a cloud. But in general the process advances more slowly; bundles of spiculæ, from different points, sometimes from the centre, though commonly from the sides of the cup, stretching out and spreading by degrees with a sort of feathered texture. By this combined operation, the surface of the water soon becomes an uniform sheet of ice. Yet the effect is at times singularly varied; the spicular shoots, advancing in different directions, come to inclose, near the middle of the cup, a rectilineal space, which, by unequal though continued encroachment, is reduced to a triangle; and the mass below being partly frozen and therefore expanded, the water is gradually squeezed up through the orifice, and forms by congelation a regular pyramid, rising by successive steps; or if the projecting force be greater, and the hole more contracted, it will dart off like a pillar. The radiating or feathered lines which at first mark the frozen surface, are only the edges of very thin plates of ice, implanted at determinate angles, but each parcel composed of parallel planes. This internal formation appears very conspicuous in the congealed mass which has been removed from a metallic cup, before it is entirely consolidated.

When cups of glass or metal are used, the cold excited at the open surface of the liquid extends its influence gradually downwards. But if the water be exposed in a porous vessel, the process of evaporation, then taking effect on all sides, proceeds with a nearly regular consolidation towards the centre of the mass, thickening rather faster at the bottom from its proximity to the action of the absorbent, and leaving sometimes a reticulated space near the middle of the upper surface, through which the air, disengaged by the progress of congelation, makes its escape. When very feeble powers of refrigeration are employed, a most singular and beautiful appearance is in course of time slowly produced. If a pan of porous earthen-ware, from four to six inches wide, be filled to the utmost with common water till it rise above the lips, and now planted above a dish of ten or twelve inches diameter, containing a body of sulphuric acid, and having a round broad receiver passed over it; on reducing the included air to some limit between the twentieth and the fifth part of its usual density, according to the coldness of the apartment, the liquid mass will, in the space of an hour or two, become entwined with icy shoots, which gradually enlarge and acquire more solidity, but always leave the fabric loose and unfrozen below. The icy crust which covers the rim, now receiving continual accessions from beneath, rises perpendicularly by insensible degrees. From each point on the rough surface of the vessel, filaments of ice, like bundles of spun-glass, are protruded, fed by the humidity conveyed through its substance, and forming in their aggregation a fine silvery surface, analogous to that of fibrous gypsum or satin-spar. At the same time, another similar growth, though of less extent, takes place on the under side of the pan, so that continuous icy threads might appear vertically to transpierce the ware. The whole of the bottom becomes likewise covered over with elegant icy foliations. Twenty or thirty hours may be required to produce those singular effects; but the upper body of ice continues to rise for the space of several days, till it forms a circular wall of near three inches in height, leaving an interior grotto lined with fantastic groupes of icicles. In the meanwhile, the exfoliations have disappeared from the under side, and the outer incrustation is reduced, by the absorbing process, to a narrow ring. The icy wall now suffers a regular waste from external erosion, and its fibrous structure becomes rounded and less apparent.

Of its altitude, however, it loses but little for some time; and even a deposition of congealed films along its coping or upper edge, seems to take place, at a certain stage of the process. This curious effect is owing to a circumstance, which, as it serves to explain some of the grand productions of nature, merits particular attention. The circular margin of the ice, being nearer the action of the sulphuric acid than its inner cavity, must suffer, by direct evaporation, a greater loss of heat; and consequently each portion of thin air that rises from the low cavity, being chilled in passing over the colder ledge, must deposite a minute corresponding share of its moisture, which instantly attaches itself and incrusts the ring. Whatever inequalities existed at first in the surface of the ice, will hence continually increase.

This explication seems to throw some light on the origin of those vast bodies of ice which occur within the Arctic Circle, and which, towering like clustered peaks above the surface of the ocean, have received the name of *icebergs.* They frequently project above an hundred feet, and must therefore have ten times as much depth concealed under water. To suppose them to have been detached from a solid field of such tremendous thickness, would seem utterly improbable. It may indeed be doubted, whether any part of the ocean be ever naturally frozen. The ice which I have formed from salt water by the frigorific process, was always incompact, inclosing brine within its interstices, and resembling the aspect of what is called water-ice, or dilute syrup congealed. Perhaps an extremely slow congelation, descending regularly from the surface, may press down the saline particles, which are never absolutely detached from the water, and thus force them to combine more largely with the mass below. But even admitting this idea, it would be still required to account for the great elevation of those icy cliffs. The most satisfactory mode probably of explaining the phenomenon, is to refer it to the operation of a general principle, by which the inequalities on the surface of a field of ice must be constantly increased. The lower parts of the field, being nearer the tempered mass of the ocean, are not so cold as those which project into the atmosphere, and consequently the air which ascends, becoming chilled in sweeping over the eminences, there deposites some of its moisture, forming an icy coat. But this continued incrustation, in the lapse of ages, produces a vast accumulation, till the shapeless mass is at length precipitated by its own weight.

Other natural phenomena will receive illustration from the facts disclosed by the refrigerating process. In the rigorous climes of the north, the alternations of the seasons are most rapid. On the approach of spring, the thick fields of ice which, in Russia or Canada, cover the Neva or the St Lawrence, break up with overwhelming fury, accompanied too by tremendous explosions. Nor is this noise to be ascribed to the mere crash of the falling fragments. In those frightful climates, the winter at once sets in with most intense frost, which probably envelopes the globules of air separated from the water in the act of congelation, and, invading them on all sides, reduces them to a state of high condensation. When the mild weather begins, therefore, to prevail, the body of ice, penetrated by the warmth, becomes soft and friable; and the minute but numerously interspersed globules of imprisoned air, exerting together their concentrated elasticity, produce the most violent explosive disruptions.

If we examine the structure of a hail-stone, we shall perceive a snowy kernel incased by a harder crust. It has very nearly the appearance of a drop of water suddenly frozen, the particles of air being driven from the surface towards the centre, where they form a spongy texture. This circumstance suggests the probable origin of hail, which is perhaps occasioned by rain falling through a dry and very cold stratum of air. As the congealed drops arrive impregnated with cold at the mild atmosphere near the ground, they besides acquire, from external deposition, a sort of snowy investure. An experiment might even be devised for illustrating this formation. Suppose a capillary funnel, through which a little water would percolate so slowly as to drop only every two or three minutes, were placed at the top of a very tall and narrow receiver that has its air made extremely dry by the joint influence of rarefaction and absorption; the successive drops would, in their descent, be frozen into globules resembling hail.

In rarefied hydrogen gas, the process of artificial congelation is performed with still greater rapidity than in atmospheric air. No material advantage, however, can be derived from this property; for, in the former medium, the cold actually excited is yet, under like circumstances, about a tenth part less. In performing this experiment, the apparatus is disposed in the usual mode and the air extracted, and hydrogen gas being immediately introduced from a gazometer, the rarefaction is again renewed. If this subtil gas dissolve a larger portion of moisture, it likewise communicates to the exhaling surface a corresponding augmented share of heat. Ice, confined under hydrogen gas, at every degree of density, wastes more than twice as fast by evaporation, as under common air of the same elasticity.

But the combined powers of rarefaction and absorption are capable of generating much greater effects than the mere freezing of water. I have in winter, when the density of air included within a receiver was reduced to about the five hundredth part, excited a cold of 125 degrees by Fahrenheit's scale below the temperature of the room. In the fine season, therefore, and with a better arrangement, a still more intense refrigeration might no doubt be produced. Such frigorific energy, however, is at all times sufficient for effecting the congelation of mercury. Accordingly, if mercury, contained in a hollow pear-shaped piece of ice, be suspended by cross threads near a broad surface of sulphuric acid under a receiver; on urging the rarefaction, it will become frozen, and may remain in that solid state for the space of several hours.

But this very striking experiment, is easily performed without any foreign aid. Having introduced mercury into the large bulb of a thermometer, and attached the tube to the rod of a transferrer, let this be placed over the wide dish containing sulphuric acid, in the midst of which is planted a very small tumbler nearly filled with water: After the included air has been rarefied about fifty times, let the bulb be dipped repeatedly into the very cold but unfrozen water, and again drawn up about an inch; in this way, it will become incrusted with successive coats of ice, to the thickness perhaps of the twentieth part of an inch: The water being now removed, the pendant icicle cut away from the bulb, and its surface smoothed by the touch of a warm finger, the transferrer is again replaced, the bulb let down within half an inch of the acid, and the exhaustion pushed to the utmost: When the syphon-gage has come to stand under the tenth of an inch, the icy crust starts into divided fissures, and the mercury, having gradually descended in the tube till it reach its point of congelation, or 39 degrees below nothing, sinks by a sudden contraction almost into the cavity of the bulb ; and the apparatus being then removed and the ball broken, the metal appears a solid shining mass, that will bear the stroke of a hammer.

Such enormous powers of refrigeration seem to open a wide prospect of future discovery. If the machinery of the air pump were improved,—if a fluid were selected more evaporable than water,—and if an absorbent substratum were employed of greater energy than sulphuric acid,—we might expect to produce effects that quite transcend the ordinary limits. Alcohol, for instance, will, under like circumstances, cause by its evaporation at least ten degrees on Fahrenheit's scale more cold than water ; its fumes being constantly withdrawn from the thin air, by the power of the same absorbent. But the muriate of lime, though generally feebler in its action, yet appears, at a certain state of preparation, to attract humidity more greedily than sulphuric acid. Other deliquescent substances will no doubt be found to possess similar, and perhaps still higher, powers of absorption. By those joint energies, exerted in vaporizing and again condensing, an extreme cold may be procured, capable of perhaps effecting new combinations among bodies. Some liquids that have hitherto resisted congelation, will hence be frozen, and certain gaseous fluids converted into liquids.

But almost every practical object is attained, through far inferior powers of refrigeration. Water is the most easily frozen, by leaving it, perhaps for the space of an hour, to the slow action of air that has been rarefied only in a very moderate degree. This process meets with less impediment, and the ice formed by it appears likewise more compact, when the water has been already purged of the greater part of its combined air, either by distillation or by long continued boiling. The water which has undergone such operation, should be introduced as quickly as possible into a decanter, and filled up close to the stopper, else it will attract air most greedily, and return nearly to its former state in the course of a few hours.

Artificial congelation is always most commodiously performed on a large scale. Since the extreme of rarefaction is not wanted, the air pump employed in the process admits of being considerably simplified, and rendered vastly more expeditious in its operation; Two or three minutes at most will be sufficient for procuring the degree of exhaustion required, and the combined powers of evaporation and absorption will afterwards gradually produce their capital effect. In general, I prefer plates of about a foot in diameter, and which can be connected at pleasure with the main body of the pump. The dish holding the sulphuric acid is nearly as wide as the flat receiver; and a set of evaporating pans belongs to it, of different sizes, from seven to three inches in diameter, which are severally to be used according to circumstances. The largest pan is employed in the cold season, and the smaller ones may be successively taken as the season becomes sultry. On the whole, it is better not to overstrain the operation, and rather to divide the water under different receivers, if unusual powers of refrigeration should be required. As soon as the air is partly extracted from one receiver, the communication is immediately stopped with the barrel of the pump, and the process of exhaustion is repeated on another. In this way, any number of receivers, it is evident, may be connected with the same machine. If we suppose but six of these to be used, the labour of a quarter of an hour will set as many evaporating pans in full action, and may therefore in less than an hour afterwards produce nearly six pounds of solid ice. The waste which the water sustains during this conversion is extremely small, seldom indeed amounting to the fiftieth part of the whole. Nor, till after multiplied repetitions, is the action of the sulphuric acid considerably enfeebled by its aqueous absorption. At first that diminution is hardly perceptible, not being the hundredth part when the acid has acquired as much as the tenth of its weight of water. But such influence gains rapidly, and rises with accelerated progression. When the quantity of moisture absorbed amounts to the fourth part by weight of the acid, the power of supporting cold is diminished by a twentieth; and after the weights of both these come to be equal, the refrigerating energy is reduced to less than the half. Sulphuric acid is hence capable of effecting the congelation of more than twenty times its weight of water, before it has imbibed near an equal bulk of that liquid, or has lost about the eighth part of its refrigerating power. The acid should then be removed, and concentrated anew by slow distillation.

But though the freezing of water is always performed to the best advantage in a large apparatus, a limit will soon occur to the scale of magnitude. Since the efficacy of the process depends on the quick circulation maintained between the opposite exhaling and absorbing surfaces, and consequently on their close proximity, the very extent of those surfaces must have a tendency to retard and enfeeble their operation. Accordingly, when the earthen pan is unusually wide, the central portion of its water, being most distant from the acid, seldom becomes firmly congealed. The measure of cold produced, at the same temperature, and with the same rarefaction, is determined, by the mutual proportion of the humid and of the absorbent substance. If the communication between them were quite instantaneous, the effect resulting from such contending powers would be an exact mean. But the humifying influence of the water and the desiccating action of the acid, are each of them greater in their immediate vicinity. Neither does the evaporation, therefore, nor the subsequent absorption, take place to the full extent. In most cases, it will be sufficiently near the truth, to estimate the effect on a supposition that the surface of the acid were doubled, or that of the acid were reduced to the one half. Thus, if the differential thermometer, having its sentient ball incrusted with ice, in the rare medium, beside the acid, alone marked 300 degrees of dryness; assuming the humid surface to be only the fourth part of that of the absorbent, the action would be shared in the ratio of one to a half, or the dryness of the thin fluid encircling the water would reach but to 200 degrees, and occasion a depression of temperature of no more than 36 degrees on Fahrenheit's scale; and if both the surfaces were equal, the effective dryness would be reduced to 100, and the cold resulting from the operation diminished from 54 to 18 degrees.

When the exhaling and absorbing surfaces are rightly disposed and apportioned, the moderate rarefaction, from twenty to forty times, which is adequate to the freezing of water, may be readily procured by the condensation of steam. In all manufactures where the steam-engine is employed, ice may, therefore, at all times be formed in any quantity, and with very little additional expence. It is only required, to bring a narrow pipe from the condensing vessel, and to direct it along a range of receivers, under each of which the water and the acid are severally placed. These receivers, with which the pipe communicates by distinct apertures, may, for the sake of economy, be constructed of cast-iron, and adapted with hinges to the rim of a broad shallow dish of the same metal, but lined with lead to hold the acid. Other improvements, of a practical nature, might easily be devised, to suit particular objects.

But the excessive dryness of the rare medium, exposed to the action of an absorbent, is capable of being usefully turned to other purposes, besides that of congelation. Birds and other small objects in natural history, if introduced within a receiver beside a body of sulphuric acid, would by rarefaction become, in a short time, most effectually dried, without suffering any derangement or injury of their parts, which the violent heat of an oven is apt to occasion. Some anatomical preparations might be managed in the same way. This process, indeed, exactly resembles what nature is said to perform on the bodies of those unfortunate pilgrims, who are suddenly overwhelmed by tornadoes amidst the sandy and arid plains of Arabia.

In a similar way, could gunpowder be conveniently brought to any required degree of dryness, without incurring the risk of those terrible explosions which so frequently happen in the ordinary mode of operation. The powder and the acid being exposed in distinct but communicating chambers, and the included air only slightly rarefied, might easily, by means of a simple machinery, be driven alternately from the one to the other, and thus made to transport and deposite its watery store. In some cases, without employing rarefaction at all, it may be sufficient merely to force the air which has been dried by being confined with a body of sulphuric acid, to pass over the surface of the gunpowder. But it would be premature to enlarge on a subject, which, from its general importance, seems to claim the consideration of our public Boards.

The process which has been so fully described, for producing dryness, and thence the cooling and congelation of water, may be justly deemed an object of extensive utility. In this island, the use of ice at table is considered as a mere luxury; but, in the hot climates, that practice is viewed in a very different light, as an indispensable necessary of life, and highly grateful and salubrious. The ancients were accustomed to cool their liquors during summer, by the infusion of pure snow carried down on purpose from the mountains. But, about the middle of the fifteenth century, the method was discovered in Italy, of freezing water anew, by application of the superior cold produced from the mixture of snow with salt or nitre. In the East Indies, great expence and attention are bestowed, in procuring the refreshment of cool drinks. On the coast of Malabar, the air is generally too humid, for producing any considerable effect by evaporation; but, in the interior of the province of Bengal, during the continuance of the dry season, when a piercing wind generally blows from the lofty mountains of Thibet, films of ice about the thickness of a shilling or half-a-crown are gathered in the mornings from the surface of shallow earthen pans set close to the ground, in pits lined with the bamboo reed, and which have been filled the preceding evening with water previously boiled and again suffered to cool. These thin sheets of ice are immediately rammed together into a compact mass, and sent down, packed in wool, to Calcutta. But during at least four months of the year, this resource totally fails; and the settlers, deprived of their usual indulgence, then suffer from excessive languor.

In the West Indies again, and the adjacent shores of America, our colonists are, at all times, left without any such relief, to assuage the burning heats of a pestilent climate. Even at home, ice-houses often fail in their construction, and are seldom found to answer in the southern and western districts, such as Devonshire and Cornwall. To procure ice, therefore, independent altogether of the disposition of the sky, is a benefit of no small importance. A minute fragment of ice will yet be sufficient in melting to chill a very large body of water. But the cold affusion has been employed with the happiest success at certain stages of fever. Cooling draughts may, in many cases, too, be administered with obvious advantage; and though medical writers are not always consistent either with themselves or with nature, the uniform belief and experience of whole nations sufficiently establish the utility of the application of cold, both externally and internally, in a wide variety of disorders which assail the human frame. It may not therefore be too much, perhaps, to expect, that an enlightened and provident government will be disposed to encourage the introduction of refrigerating machines into our military hospitals in the tropical climates, and likewise on board Indiamen and the larger ships of war.

I must now close this lengthened train of investigation. Without entering much into detail, I have endeavoured to exhibit the principal facts and reasonings in a compressed form. It will therefore not be judged superfluous, perhaps, in conclusion, to take a concise retrospect of the whole.

The various effects of heat are deducible from the operation of a peculiar subtle fluid, probably the same as light, which combines with bodies in very different proportions. Hydrogen gas contains the largest share of it, and mercury comparatively the smallest. This heat is primarily derived from the incidence of the solar rays, but distributed on the earth by a very unequal allotment, according to the obliquity which the surface of our globe presents to the sun in the different latitudes. The original inequality, however, is greatly reduced, by that perpetual, though indirect communication, which is maintained by the motion of the atmosphere between the poles and the equator. The currents from the south convey warmth into the northern regions, and the opposite currents, in their turn, transporting cold, serve to mitigate the burning heats within the tropics. From this fact, combined with the supposition, that such a mutual transfer is, by the agency of oblique winds, effected completely twice every year between the poles and the equator, the mean temperature of any place, at the level of the sea, may be derived by calculation, agreeing remarkably nearly with the results of actual observation. Again, the cold which prevails in the higher spaces of the atmosphere is occasioned by a similar but far more speedy communication, supported between the lower and upper strata. Thin air, by its constitution, holds a comparatively larger share of heat. Any portion of the ambient medium that ascends from the surface must have its temperature diminished, and the corresponding portion which falls down will, as to sense, become warmer. In consequence of the rapid and complete interchange which obtains, the same absolute measure of heat exists at all heights in the atmosphere, and its apparent decrease proceeds wholly from that enlargement of capacity which the attenuated fluid acquires. Theory here corresponds exactly with observation.

Heat is not only distributed among bodies in various proportions, but it spreads through them with very different degrees of celerity. Through dry wood or eider-down it works its way with extreme difficulty; yet, through the dense substance of silver, it travels with a rapid progress. In solid bodies, heat is conducted by means of a repeated transfer, each portion in the train of communication being successively affected, and always delivering its surplus warmth to the next portion in advance. But, in liquids, the mode of diffusion is more complex; and besides the successive transfer of heat along the extended mass, a much larger expenditure is produced, by the continual migration of the heated parts of the medium. In the gaseous or elastic fluids, again, there is combined another and most unexpected element of dispersion. A part of the heat discharged from a warm body is always darted to a distance by a sort of rapid vibratory commotion, exerted, like the impression of sound, on the ambient air. This portion, emitted from a surface of glass or paper, will in general amount to half of the whole expenditure; but, from a bright metallic surface, it is about ten times less. A vitreous surface, on the other hand, will, if opposed to the tide of heat, receive nearly the whole impression, while one of polished metal will detain only the tenth part, reflecting back all the rest. To this curious and interesting branch of the subject of heat, I have particularly directed my researches; and the application of the differential thermometer, which was contrived to indicate the smallest changes in the temperature of its communicating balls, has proved a safe and easy guide in tracing out some of the more recondite properties of matter. A variation of that instrument, called the pyroscope, and having one of its balls gilt, is especially fitted for such examination. The peculiar effects exhibited, seem to proceed from those different degrees of contact which must obtain between the air and the surface of glass or of metal, the approximation, and consequently the impression received or communicated, being much greater in the former than in the latter.

Different bodies not only contain heat in various proportions, but undergo mutations in that respect at every change which occur in their constitution or internal arrangement. Water is subject to striking alterations in its affinities to heat. In the form of ice, it holds a tenth part less heat than before; but, in the state of steam or vapour, it contains above a half more than it did in its liquid condition. Hence 135 degrees of heat by Fahrenheit's scale are evolved in the act of congelation, and 945 absorbed in the conversion of water into steam. Evaporation from a humid surface, therefore, makes it colder. But to this depression of temperature there is an evident limit, when the encircling air communicates, by its contact, exactly as much heat as it absorbs, in uniting with the quantity of vaporized moisture, sufficient for its saturation. The cold thus induced, hence marks the dryness of the ambient medium. On this principle, I have constructed the hygrometer, which promises to become an instrument not only useful towards the extension of philosophy, but of [illegible] service in the improvement of the arts and manufactures. It derives elucidation from comparison with the atmometer, which, though grounded on simpler data, is yet susceptible of considerable delicacy.

Heat and moisture, in all their relations, appear to follow the same laws. If rarefaction enlarges the capacity of air for heat, it likewise communicates an increased power of containing humidity. The higher regions of the atmosphere are hence comparatively drier than the lower, or, at the same temperature, they would have a greater effect on the hygrometer. In ascending, therefore, those elevations, the continual diminution of heat augments at first the dampness of the air, till we reach its extreme limit, or the ordinary seat of the clouds, above which the effect of attenuation begins to predominate over the cold, and the air grows progressively drier and clearer, till at length it melts away in the resplendent fields of ether.

The power of air to contain or dissolve moisture is augmented by heat in a rapid progression, doubling for each rise of temperature corresponding to 27 degrees on Fahrenheit's scale. When two parcels of humid air at different temperatures are mingled together, the mean temperature of the compound being, therefore, unable to hold their aggregate moisture, disencumbers itself of the surplus load. If this commixture be produced by the meeting of opposite currents in the atmosphere, a very considerable deposition may take place. When the humidity is slowly parted with, it remains suspended in the shape of fogs or clouds; but when it is more copiously detached, it forms rain or hail. Snow is caused by the freezing of the minute aqueous globules at the instant of their precipitation, but hail seems to derive its origin from the congelation of the large accumulated drops in their subsequent descent through a cold and dry stratum of air.

Most of the softer substances are disposed to attract moisture with various degrees of force. On this property, is founded the construction of all the hygroscopes which have been at different times proposed. Even the earthy bodies, if previously heated before a strong fire, and kept stopped in glass decanters, have a power to abstract moisture from the confined air, and therefore to render it artificially dry. Cultivated soils possess eminently the same disposition, and which appears the more conspicuous in proportion to their fertility.

The concentrated sulphuric acid and the powdered muriate of lime, particularly the former, are on the whole the most energetic and lasting absorbents. But air which has been desiccated by their operation, is fitted, through its invigorated powers of evaporation, to excite greater cold. Hence water or other liquors may at all times be considerably cooled, and with very little trouble or expence.

But far more intense cold is created, by combining the power of an absorbent with that of rarefaction. If water in a small porous pan be set above a wide surface of sulphuric acid, and covered by a low receiver from which the air is mostly extracted, it will soon congeal, and will remain in that frozen state for a very long time, till the ice become insensibly wasted away by a continued process of evaporation. A sort of invisible aërial distillation is carried on under the glass; for the thinness of the medium and the absence of atmospheric pressure, occasion nearly the same effect on the humid substance, as the application of fire alone. The steam exhaled from the surface of the pan is conveyed to the acid, where it condenses and gives out its component heat. After the ice has been formed, the same circulation is still maintained. Heat is indeed merely transferred from the exhaling to the absorbing surface; and the solid cake remains considerably colder, while the sulphuric acid is kept always warmer, than the atmosphere of the room. A temperature many degrees below the point of freezing water can thus be procured at all seasons. The congelation of mercury has already been effected by this process; and after receiving farther extension and improvement, it may no doubt come in time to be applied to a variety of the most useful and beneficial purposes in life.

FINIS.
