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The experiments prove that there is no *circulation* of the ſap during the bleeding ſeaſon;* but that, as Hales thought, its aſcent is uniform. It is poſſible, however, that while the tree is in leaf, the ſap may take a different courſe. But the determination of this point requires a further ſet of experiments.

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II. *The Theory of Rain.* By James Hutton, *M. D. F. R. S. &c.*

PART I.

Inveſtigation of the Law of Nature, on which is to be founded a Theory of Rain.

THE ſubject of this paper is to inveſtigate the rule directing the action and effects of heat and cold, and to form from thence a theory for rain on the evaporation and condenſation of water. The breath of animals becomes viſible in a cold atmoſphere, and tranſparent ſteam becomes miſt in air of a colder temperature. To account for theſe effects, the air inſpired is to be conſidered as a menſtruum diſſolving water on the lungs, and becoming ſaturated in that degree of heat. The ſolution being cooled, the water ſeparated from the menſtruum becomes viſible. So water may by means of heat be rendered an elaſtic fluid, which being condenſed the water appears. But this appearance is not the effect of the general principles of heat and cold: to explain it the knowledge of a particular law is required, and it is to be obſerved, that the effects of heat and cold in relation to air and vapour are not uniform.

The diſſolving power of air on water may vary in different proportions to the heat. The ſolution may vary as the heat, or in a greater or leſs ratio: that is the increments of each may be conſtant, or thoſe of the heat being conſtant, the increments of the ſolution may be accelerated or retarded.

This may be repreſented geometrically. (Plate X. Fig. 1.) Let CH repreſent the ſcale of the thermometer, am, br, perpendicular ordinates, the quantity of water held in ſolution by a given quantity of air of the temperatures a and b. Join mr and draw the curves mgr, mdr. Then it is evident that the ordinates to mr mark a ſolution varying as the heat; the ordinates to mdr, a ſolution varying in a greater ratio, and to mgr in a leſs ratio than the heat.

The ordinates to the line mr, drawn from a point, denoting the temperature of the mixture, repreſent the quantity of water contained, (diſſolved or not) in an unit of the mixture, for the ordinates ma, rb, are as the quantities contained in a unit of air of the temperatures a and b, and as upon mixture the heat and water are uniformly diſſolved, they vary in the ſame proportion, and may be expreſſed by the ſame meaſure.

Suppoſing equable ſolution, mix equal portions of ſaturated air, temperatures 10 and 40, the mixture of temperature 25 is repreſented by op, which alſo repreſents the quantity of water in an unit of the mixture, and the quantity of water held in ſolution by an unit of air of temperature 25.

So two portions of temperature 40, being mixed with one of temperature 10, the temperature produced 30, will be expreſſed by wq.

In

In the curve *m d r*, let equal portions of the ſolution in 40 and 10 be mixed, then *o p* is the quantity of water contained in this mixture, at the mean heat 25, whilſt *o e* is the ordinate of ſolution, conſequently *e p* is the quantity of water that cannot be retained in ſolution, in this medium temperature produced by the mixture.

In the curve *m g r*, let equal portions in 40 and 10 be mixed, and the ordinate being drawn in the medium degree of heat 25, *o k* will be the whole power of ſolution, *n* the quantity of water that air is capable of diſſolving in this degree of heat, but *o p* being the quantity of water actually in the mixture, the air is underſaturated with humidity, by the quantity *p k*.

Thus, the actual curve of evaporation being known, the effect of any mixture of two portions of different temperatures may be aſcertained. If the ſolution of water in air increaſes equally with the heat, there will be neither ſuper nor underſaturation in a mixture of portions of different degrees of heat. If this ſolution increaſes with heat, but in a decreaſing rate, there will be underſaturation. If it increaſes with heat in an increaſing rate, there will be ſuperſaturation.

The laſt caſe applies to the phænomena of breath and ſteam rendered viſible in mixing with air colder than themſelves, and to various appearances, that may occur in mixing together ſeveral portions of air, differently ſaturated with humidity, and in different temperatures. For it is not every mixture of atmoſpherical fluid in different temperatures, that forms a viſible condenſation, this effect depending on the degree of ſaturation with humidity. But if two portions of the atmoſphere both ſaturated with humidity ſhould be mixed, let there be but a difference in their temperatures, a condenſation proportionate to this difference will take place.

This rule of condenſation may be applied to the theory of rain, which is the diſtillation of water firſt diſſolved in the atmoſphere, and then condenſed from that ſtate of ſolution. Water is indeed condenſed in a cloud, and clouds may ſubſiſt without rain: but, without condenſation of acqueous vapour in the atmoſphere, no rain can be produced.

A convincing proof of this is given by M. de Maupertuis, who, in his *Diſcours ſur la méſure de la terre*, ſays, that at Tornea, upon the opening of a door, the external air immediately converts the warm vapour of the chamber into ſnow, which then appears in what he calls «de gros tourbillons blancs." So at Peterſburgh in 1773 a gentleman broke a window in a crouded aſſembly, to relieve the company ſuffering from the cloſeneſs of the room, and the cold air ruſhing in, formed a viſible circumgiration of a ſnowy ſubſtance.

The wiſe ſyſtem of nature could not be carried on without this particular law of aqueous condenſation. By the circulation of the fluid atmoſphere the heat of torrid regions is carried away, and the cold of frigid regions temperates the exceſſive heat on the earth's ſurface in ſummer. And thus, by tranſporting the heat and cold of diſtant regions, the parts of the earth moſt diſtant from the ſea may be ſupplied with ſhowers of rain at every ſeaſon of the year; but if the mixing together of the atmoſpherical ſtreams produced no condenſation, in the ſummer the earth would be parched with drought, and in the winter deluged with rain.

At preſent from the influence of the aſcending ſun, two oppoſite currents of air are formed in the ſummer hemiſphere, one moving along the ſurface of the earth from the pole to the equator, the other flowing above in an oppoſite direction. Theſe

oppoſite

oppoſite currents whilſt ſeparate might paſs each other without producing rain, but when ſufficient portions are mixed, not only clouds but ſhowers will be produced, ſince the ſudden formation of a mean degree of heat, in the mixture of two portions of different temperatures, muſt condenſe a quantity of vapour ſufficient to form rain.

Without this law of condenſation of evaporation, neither rain nor dew could take place any where in the ſummer hemiſphere, perhaps not even in the tropical latitudes: there would be evaporation and a general tendency to ſaturate the atmoſphere with water, but the mixture of different portions of air would only temper the ſaturation without producing a condenſation of vapour in the mean degrees of heat. At night, from the influence of the cold, the atmoſphere would become gradually clouded: this cloudineſs would increaſe to a general diſtillation of condenſed vapour, which would be uniformly continued, until the returning ſummer ſhould change the ſtate of condenſation to evaporation. And inſtead of the beautiful return of ſeaſons, tempered with various degrees of heat and refreſhing ſhowers, ſix months rain and ſix months drought would follow each other in an invariable ſucceſſion.

PART. II.

The Theory of Rain applied to natural Appearances.

1. *On the generality of rain.*

SUPPOSING the earth to be wholly covered with water, the ſun to be ſtationary in the equator, and the earth immoveable, there would be a circulation in the atmoſphere from the dark to the illuminated, and from the heated to the place of greateſt cold. There would be two regions of extreme heat and cold, and between them one of temperate heat and continual rain.

Suppoſing the earth to turn round its axis, the torrid region would become a zone, and be temperate compared with its former ſtate, and there would be perhaps alternately condenſations and evaporations of the atmoſphere. From this zone we might paſs through another ſubject to continual rain, till we arrive at a point of great cold and congelation.

Were this aqueous globe to be moved round the ſun with a certain inclination of its axis, heat and cold muſt be alternately produced in every part of it, by which would be produced either annual ſeaſons of rain, or diurnal ſeaſons of condenſation and evaporation, or both theſe ſeaſons in ſome degree.

In this globe the effects would be conſtant, and the ſeaſons fixed and determinate. The irregular ſurface of our globe muſt evidently produce different effects: the fluid atmoſphere is effected with the heat of each part of the ſurface, with which it comes in contact; and the ſeveral parts of this elaſtic fluid, whether ſaturated or not with aqueous vapour, will be ſubject to the utmoſt irregularity of mixture.

Hence over the whole globe, there will be occaſionally rain and evaporation more or leſs. Wind and rain will be variable, in proportion as each place is ſituated in an irregular mixture of land and water: wind is regular in proportion to the uniformity of the ſurface, and rain in proportion to the regular changes of thoſe winds, by which the mixture of air neceſſary for rain is produced. Thus our theory agrees with the facts in nature.

2. *Of the regularities of rain.*

In the Indian fea there are periodical trade winds: thefe ftreams of atmofphere muft produce fomewhere a mixture of different portions of the fluid mafs, and, if rain is the confequence, we muft conclude, that thofe mixed portions of the air have been fufficiently faturated with moifture, and in different temperatures. This is actually the cafe, there are regular appearances of rain, which correfpond to the regular caufes now affigned.

According to our theory, there fhould be in the iflands under the line in the middle of the Indian ocean, periodical condenfations correfponding to the diurnal influence of the fun, and nocturnal motions in the atmofphere. It is fo in fact. Sea and land breezes are felt there regularly every day, and in the diurnal commotions of the atmofphere, there will be frequently portions of it, fufficiently faturated with vapour, and mixed in different degrees of heat.

But the great annual rains on the tropical continent of Afia and Africa, illuftrate ftill better this explanation. The rains are in the feafon of the fummer folftice, and fair weather is produced by the removal of the heating caufe. The place of the air, elevated by the heat of the fun at this feafon, is fupplied with other air faturated with moifture from the neighbouring feas: this air, being alfo elevated, muft be either tranfported from thence towards the polar regions, or fall down in rain. It is evident that the former fuppofition does not take place, for then there would be no rain, but this air in its elevation mixes with thofe portions, which have loft their heat to a fufficient degree, that the commixture may produce a condenfation of water.

Suppofing the continent not to have as in the tropical parts of Afia and Africa a fufficient fupply of water, the fummer's fun will produce drought rather than rain, except when tranfient ftreams of air, proper for the purpofe, occafion fhowers of great importance to vegetation, but not to be confidered as a general feafon for rain. On the decline of the fummer, the atmofphere becomes difpofed to produce rain with every mixture of a different temperature. And hence the autumnal rains and winter fnows, which fall with all the regularity of the tropical rains.

3. *Of apparent exceptions from the generality of rain.*

It is no exception to the theory laid down, that in a few places there is no rain, as there may be fome local caufes which produce this variation from the general rule. The lower Egypt, and a narrow fpot on the coaft of Peru, are the only inftances of this fingular occurrence. With refpect to the latter, we might conclude, from Ulloa's obfervations on the fteadinefs of the wind blowing on the coaft of Peru, that there would be either continual rain or no rain at all. In the laft cafe the vapours from the fea might be carried over the coaft, to be condenfed by mixing with other ftreams of cold atmofphere in the Andes, where it rains abundantly for moft part of the year.

Since there are but two places without rain on the earth, we are not on that account to fet afide the general rule, but prefume, that there are wanting certain conditions requifite to condenfe humidity in the air. The caufe of rain, though often exerted, will not produce always the full effect; a fcanty condenfation of aqueous vapour produces mifts on the earth, and clouds in the atmofphere above. And in taking the gradation from

from one extreme of tranſparent atmoſphere to the other of the denſeſt cloud, from the falling of the gentleſt miſt to the heavieſt rain, hail and ſnow, we have an indefinite variety of appearances, all flowing from one ſimple principle.

4. *Comparative eſtimate of climates in relation to rain.*

In eſtimating the quantity of rain in different climates, the two principles on which it depends muſt always be kept in view. 1ſt. There muſt be a meeting of different ſtreams of air in proper degrees of heat, and therefore the mixture of winds and their temperature muſt be conſidered. 2d. The quantity of rain depends, *cæteris paribus*, on the quantity of humidity contained in theſe ſtreams of air.

From the irregularity of the earth's ſurface, the mountains, woods, and barren deſarts, a great variety will take place in reſpect of the action of theſe two principles. Mountains will break the ſtreams of air, and to that and not to any attraction muſt we attribute the greater quantity of rain and thunder in mountainous countries, than in the plains. There will be alſo more rain on land than on the ſea, for the latter being plane has not the power of varying the direction, and mixing together the ſtreams of air.

As far as the principle of humidity is concerned, the greateſt quantity of rain ſhould fall, *cæteris paribus*, on land contiguous to a great ſea in a tropical ſituation, and the leaſt quantity in the moſt inland part of Europe and Aſia, in a temperate latitude. The firſt poſition is proved by a fact, that in the Eaſt Indies 104 inches of rain have fallen in one place in a ſeaſon, at leaſt three times the quantity falling in the temperate latitudes. Not having any meteorological regiſter with reſpect to the ſecond poſition, we muſt determine it from other facts. The Caſpian ſea and the lakes in North America lie nearly in the ſame latitudes, and conſequently there ſhould be, *cæteris paribus*, an equal evaporation from equal ſurfaces. The water received by the Caſpian ſea is all evaporated, but to the lakes, there is a conſiderable outlet, and as the Caſpian ſea receives its water from a much greater portion of land than the lakes, there ought according to this rule to be no outlet to the latter. But as there is an outlet, we muſt couclude, that much more rain falls in North America, than on a ſimilar ſituation in Europe and Aſia. Still it may be alledged, that the evaporation from the lakes may be leſs than that from the Caſpian, and conſequently there might be a redundancy of water without the ſuppoſed greater portion of rain. But from whence could this greater evaporation proceed? The cold is much greater on the lakes than by the Caſpian ſea, and this cold ariſes from the ſame cauſe which produces the greater quantity of rain.

5. *The theory applied to meteorological obſervations.*

In meteorological obſervations, three things are to be conſidered. 1. The quarter from whence the wind comes. 2. The degree of heat in the atmoſphere indicated by the thermometer. 3. The weight of the atmoſphere indicated by the barometer.

In conſidering the quarter from whence the wind comes, we are liable to many deceptions. For as the direction of the wind on a particular ſpot is no proof, that that direction has been the ſame for a great diſtance, we may confound a ſouth wind with one coming directly from the weſt, and miſtake a north for a weſterly wind. Hence the direction of the wind at a given place in an iſland like ours, is to be corrected by its temperature, as there is reafon to conclude, that the thermometer is in this refpect a better guide than the local appearance.

Thermometrical obfervations are variable. A certain allowance is in general to be made for the diurnal influence of the fun. Nothing changes fo much the temperature of the atmofphere, as a change in the direction of the wind. A fouthern atmofphere tranfported over this ifland, muft produce a heat above the mean temperature of the feafon, and a northern atmofphere muft produce the contrary effect. An eaftern or a weftern atmofphere, may not neceffarily produce any change in the place of obfervation. And hence we may obferve the propriety of the general rule, for determining the region from whence the atmofpherical ftream proceeded, viz. that we are to afcribe more to the heat and cold of the fluid compared with our mean temperature for the feafon, than to the direction in which the ftream paffes over our heads.

The barometer is a juft meafure of the weight of our atmofphere. From certain changes in it, connected with a difpofition to rain, philofophers have improperly concluded, that the rarity of the atmofphere is an immediate caufe of rain. The neceffary confequence of rain is to make the atmofphere lighter, by the quantity of water feparated from the air; but as the quantity of rain fallen bears no proportion to the quantity of loft preffure, indicated by the barometer, the appearance of the barometer cannot be confidered as the caufe or the effect of rain. In fact, thefe changes in the barometer are not confined to the place, where there is a change of weather; at the diftance of 400 miles and perhaps much more, two barometers rife and fall nearly in the fame manner, though it is frequently rainy weather at one place, while it is fair at the other.

The change in the weight of the atmofphere is the confequence of fome great emotion in that fluid body, and different parts being confequently mixed, there is a probable caufe for the production of rain. But it does not appear, why the fall of the barometer fhould, any more than its fudden rife, be a neceffary indication of rain; though we may account for the indication of a continuance of fair weather on the gradual rife of the barometer. For fuppofing fair weather and an undifturbed atmofphere in this quarter of the earth, the neceffary evaporation from the furface muft gradually increafe the weight of the atmofphere, and the barometer muft rife with a gradual progrefs.

The barometer is fubject to greater changes in the temperate, than in the torrid regions. For the ftate of the atmofphere of the latter, bounded on each fide by temperate regions, cannot be fo affected, as that of one liable to change from the extremes of heat and cold on its oppofite fides. Befides, the change from heat to cold, depending on the fun, is much the greateft in the temperate regions.

The barometer is neceffarily connected with motions in the atmofphere, but not equally affected by every motion. It is affected only by thofe, which produce accumulation and abftraction of the fluid. And as every commotion of the atmofphere may under certain conditions be a caufe for rain, the barometer, though of greater ufe in determining heights, may be made of importance in meteorological obfervations.

Within the tropicks, though the variation of the barometer is fmall, there are greater falls of rain than in the temperate zones. But in the former fituation, where the atmofphere is faturated with vapour and of great heat, a fmall quantity of air of different temperature is required; and the converfe is true in the temperate regions.

Thus

Thus there will be greater temporary accumulations and abſtractions of atmoſphere, and conſequently greater changes of the barometer in the latter, than in the former ſituation.

Thus natural appearances confirm our theory, which eſtabliſhes for the immediate cauſe of rain, the mixture of ſeveral portions of atmoſphere in different temperatures of heat. We may now conſider the natural appearances which attend rain in this iſland.

1. According to our theory, calmneſs or ſteady breezes are the attendants of fair weather, and the converſe is equally true. People indeed, who reaſon from obſervation alone, attribute wind to the ſhower as an effect, whereas it is a cauſe.

2. When rain begins in calm weather, wind may be expected, and a calm follows rain that begins in windy weather, on this principle, that wind is the cauſe of rain, and in the oppoſition of winds, a calm is produced.

3. During a calm and clear ſky, ſhowers never happen, with ſqualls of wind ſudden ſhowers appear. In calm weather before rain the heaven is overclouded, and the rain is general; when attended with wind, it is unſteady. Theſe facts neceſſarily imply a mixture of hot and cold ſtreams of air for the production of rain.

4. Sometimes the operation is viſible; clouds are ſeen moving in oppoſite directions, and experienced ſeamen have obſerved, that this oppoſition, or as it is termed the clouds going againſt the wind, is a ſure ſign of a heavy rain.

5. The changes of the temperature of our atmoſphere attend the alterations of rain and fair weather. A wind from the ſouth replete with humidity, brings warm weather, if rain ſucceeds, it is followed by a change of wind, and the air becomes colder. If a north wind prevails, and is ſucceeded by rain, there is a change of wind and temperature of the air.

It is common on the coaſt of Hudſon's bay, for a ſtorm to come on from the north weſt, attended with ſnow and hail, when the thermometer is at 90° and the ſky perfectly ſerene. It ſoon clears up, but the temperature of the air is changed; from 90° the thermometer falls to 50° for a ſhort time, and then gradually riſes. This points out the agitation of the air as the cauſe, and not the conſequence of rain. Not that agitation alone is the cauſe of rain, there muſt be in the mixed atmoſphere alſo a ſaturation of humidity ſufficient to co-operate with it.

6. Rain happens in all weathers, from the greateſt degree of heat down to the freezing point. In a ſettled froſt, when it begins to ſnow, the thermomer riſes, when the ſnow has fallen the ſky becomes clear and the cold increaſes.

7. The climate of our iſland is (according to a fanciful expreſſion of the profeſſors) temperance in extreme. The winds are very variable, and conſequently from the mixture of different ſtreams, there muſt be a great condenſation of aqueous vapours. The quantity of rain, falling in a year, is not a ſufficient teſtimony of the prevalence of this condenſation, as without rain there may be a great condenſation of aqueous vapour. A known fact, that for one day or hour of ſunſhine, there are two or three of cloudineſs, determines the queſtion.

8. To inveſtigate the effect of this aqueous condenſation in our atmoſphere on heat and cold, we are to conſider, that it may be produced by a mixture of air either hotter or colder than our atmoſphere, whoſe temperature will be brought to a greater or leſs degree of heat, according to the nature of the ſupervening air producing cloudineſs. If the heat of the atmoſphere is above the mean temperature for the ſeaſon,

ſeaſon, and there is a change from a ſerene ſky to cloudineſs, the atmoſphere will be cooled, and *vice verſa.*

A clear ſky is perfectly conſiſtent with the extremes of heat and cold. It is the mixture of hot and cold atmoſphere, which produces cloudineſs. Hence the common obſervation is explained, that the air is always cold or below its mean temperature for the ſeaſon, when the ſky is clear. The country people call it froſty, though in the middle of ſummer, and probably find hoar-froſt in the morning in the higher parts of the country, and the making of ice in Bengal juſtifies this obſervation.

9. Hail and ſnow formed on the ſame principles are equally explained by this theory. Hail is evidently formed by the collection of molecules of the nature of ſnow, by means probably of electrical attraction.

10. Thunder, a phænomenon often attending rain, deſerves conſideration. But from our ignorance of the principles, on which electricity is the cauſe of condenſing vapour in the atmoſphere, we can only conclude, conſiſtently, with appearances, that there is, in the caſe of thunder with violent rain, a more ſudden attraction of the condenſed particles of water, than what happens upon other occaſions.

III. *Mr. Playfair's Remarks on the Cauſes which affect the Accuracy of Barometrical Meaſurements, which follows here in the Edin. Tranſactions, admitting of very little Abridgment, we ſhall, in order to do Juſtice to ſo valuable a Paper, inſert it in our Appendix at the End of the Volume.*

IV. *On the Uſe of Negative Quantities in the Solution of Problems, by Algebraick Equations. By* William Greenfield, *M. A. &c.*

THE introduction of negative roots is attributed to Albert Girard, whoſe work, entitled, *Invention nouvelle en Algebra,* was publiſhed in 1629, whereas the Geometry of Des Cartes, to whom Montucla aſcribes this invention, was not publiſhed till 1637. Des Cartes indeed, not aware of the advantage to be derived from the uſe of negative quantities, obſerves only that the ſhifting of a line or point from one ſide of a given line or point to the other, makes no difference, except of the ſigns + and — in the equation.

The uſe of negative quantities was not for ſome time familiar to mathematicians. In the *Elementa Curvarum* of John de Witt, publiſhed by Schooten, at the end of his edition of Des Cartes' Geometry, no notice is taken of negative abſciſſæ and ordinates, and in the four equations belonging to ſtraight lines, 1. $y = \frac{bx}{a}$; 2. $y = \frac{bx}{a} + c$. 3. $y = \frac{bx}{a} - c$. 4. $y = -\frac{bx}{a} + c$, he no where ſhews that each of theſe equations by changing the ſigns of y or x, gives the relation of the abſciſs and ordinate, when one or other is taken in an oppoſite ſituation.

The notions of Dr. Wallis on this ſubject were not perfectly clear. For in his Arithmetic of infinites, he did not ſee that his general expreſſion for hyperbolic areas, by having a negative denominator, expreſſed the area on the other ſide of the ordinate,