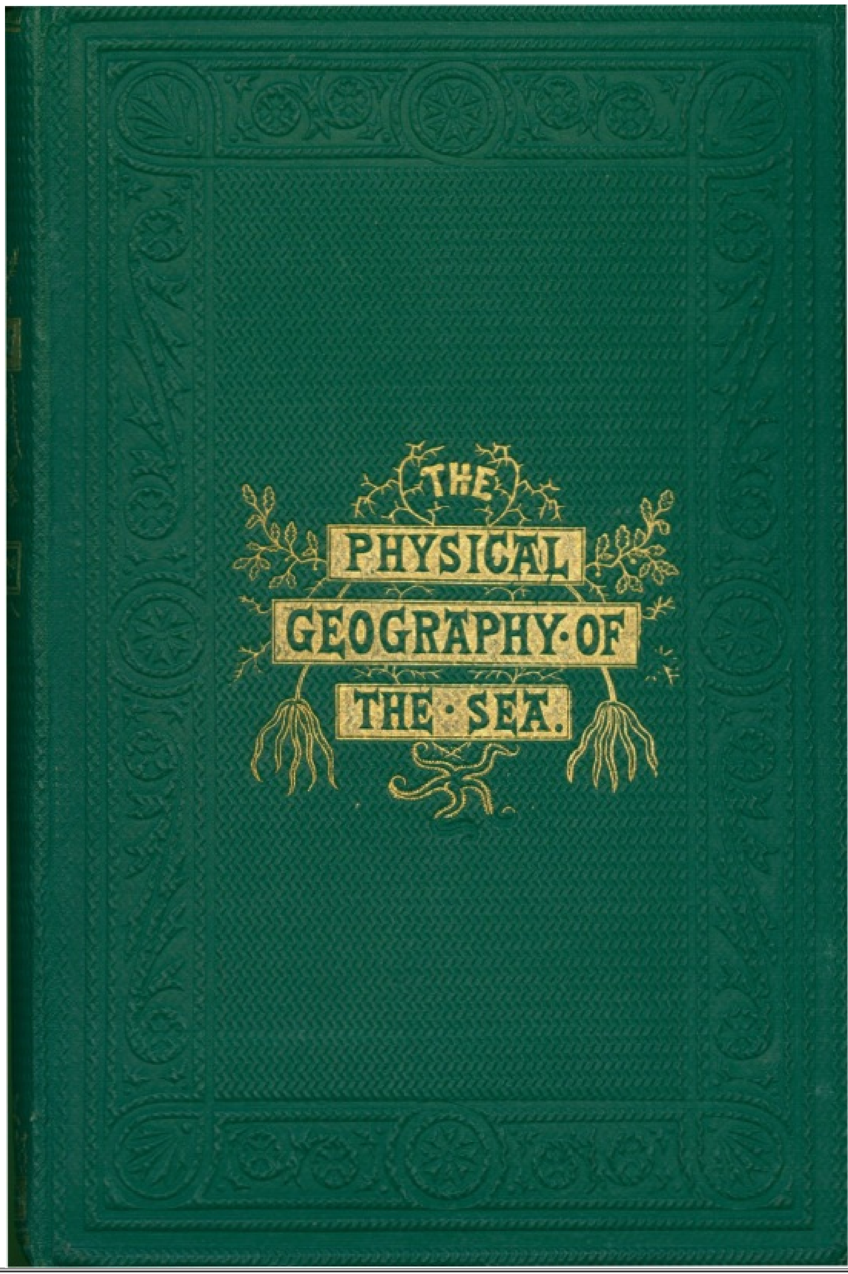
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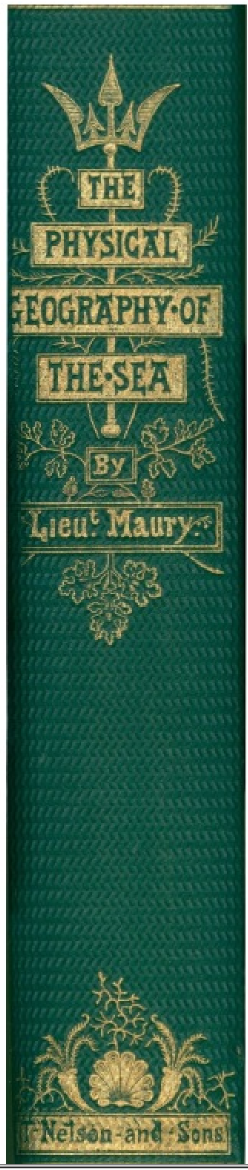
THE
PHYSICAL
GEOGRAPHY·OF
THE·SEA
By
Lieut. Maury
Nelson·and·Sons

G. E. Orr Paterson

by purchase from

Tongland Free Church.

at a Sale at Tarff Church

60th Birthday gift from
my sons, Jacob & Joshua

Yin Soong
2007

THE

PHYSICAL GEOGRAPHY

OF

THE SEA.

BY

M. F. MAURY, LL.D., U.S.N.,

SUPERINTENDENT OF THE NATIONAL OBSERVATORY, WASHINGTON.

ILLUSTRATED WITH NUMEROUS CHARTS AND DIAGRAMS.

LONDON:

T. NELSON AND SONS, PATERNOSTER ROW;

EDINBURGH; AND NEW YORK.

MDCCCLXI.

INTRODUCTION TO THE FIRST EDITION—1855.

THE primary object of "The Wind and Current Charts," out of which has grown this Treatise on the Physical Geography of the Sea, was to collect the experience of every navigator as to the winds and currents of the ocean, to discuss his observations upon them, and then to present the world with the results on charts for the improvement of commerce and navigation.

By putting down on a chart the tracks of many vessels on the same voyage, but at different times, in different years, and during all seasons, and by projecting along each track the winds and currents daily encountered, it was plain that navigators hereafter, by consulting this chart, would have for their guide the results of the combined experience of all whose tracks were thus pointed out.

Perhaps it might be the first voyage of a young navigator to the given port, when his own personal experience of the winds to be expected, the currents to be encountered by the way, would itself be blank If so, there would be the Wind and Current Chart. It would spread out before him the tracks of a thousand vessels that had preceded him on the same voyage, wherever it might be, and that, too, at the same season of the year. Such a chart, it was held, would show him not only the tracks of the vessels, but the experience also of each master as to the winds and currents by the way, the temperature of the ocean, and the variation of the needle. All this could be taken in at a glance, and thus the young mariner, instead of groping his way along until the lights of experience should come to him by the slow teachings of the dearest of all schools, would here find at once that he had already the experience of a thousand navigators to guide him on his voyage. He might, therefore, set out upon his first voyage with as much confidence in his knowledge as to the winds and currents he might expect to meet with, as though he himself had already been that way a thousand times before.

Such a chart could not fail to commend itself to intelligent shipmasters, and such a chart was constructed for them. They took it to sea, they tried it, and to their surprise and delight they found that, with the knowledge it afforded, the remote corners of the earth were brought closer together, in some instances by many days' sail. The passage hence to the equator alone was shortened ten days. Before the commencement of this undertaking, the average passage to California was 183 days; but with these charts for their guide, navigators have reduced that average, and brought it down to 135 days.

Between England and Australia, the average time going, without these charts, is ascertained to be 124 days, and coming, about the same; making the round voyage one of about 250 days on the average. These charts, and the system of research to which they have given rise, bid fair to bring that colony and the mother country nearer by many days,—reducing in no small measure the average duration of the round voyage.*

At the meeting of the British Association of 1853, it was stated by a distinguished member,—and the statement was again repeated at its meeting in 1854,—that in Bombay, whence he came, it was estimated that this system of research, if extended to the Indian Ocean, and embodied in a set of charts for that sea, such as I have been describing, would produce an annual saving to British commerce, in those waters alone, of one or two millions of dollars;† and in all seas, of ten millions.‡

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* The outward passage, it has since been ascertained, has been reduced to 97 days on the average, and the homeward passage has been made in 63.

† See Inaugural Address of the Earl of Harrowby, President of the British Association, at its twenty-fourth meeting. Liverpool, 1854.

‡ . . . "Now let us make a calculation of the annual saving to the commerce of the United States effected by those charts and sailing directions. According to Mr. Maury, the average freight from the United States to Rio Janeiro is 17.7 cts. per ton per day; to Australia, 20 cts.; to California, also, about 20 cts. The mean of this is a little over 19 cents per ton per day; but to be within the mark, we will take it at 15, and include all the ports of South America, China, and the East Indies.

"The sailing directions have shortened the passages to California 30 days, to Australia 20, to Rio Janeiro 10. The mean of this is 20, but we will take it at 15, and also include the above-named ports of South America, China, and the East Indies.

"We estimate the tonnage of the United States engaged in trade with these places at 1,000,000 tons per annum.

"With these data, we see that there has been effected a saving for each one of these tons

A system of philosophical research which is so rich with fruits and abundant with promise, could not fail to attract the attention and commend itself to the consideration of the seafaring community of the whole civilized world. It was founded on observation; it was the result of the experience of many observant men, now brought together for the first time, and patiently discussed. The results tended to increase human knowledge with regard to the sea and its wonders, and therefore the system of research could not be wanting in attractions to right-minded men.

The results of the first chart, however, though meagre and unsatisfactory, were brought to the notice of navigators; their attention was called to the blank spaces, and the importance of more and better observations than the old sea-logs generally contained was urged upon them.

They were told that if each one would agree to co-operate in a general plan of observations at sea, and would send regularly, at the end of every cruise, an abstract log of their voyage to the National Observatory at Washington, he should, for so doing, be furnished, free of cost, with a copy of the charts and sailing directions that might be founded upon those observations.

The quick, practical mind of the American shipmaster took hold of the proposition at once. To him the field was inviting, for he saw in it the promise of a rich harvest, and of many useful results.

So, in a little while, there were more than a thousand navigators engaged day and night, and in all parts of the ocean, in making and recording observations according to a uniform plan, and in furthering this attempt to increase our knowledge as to the winds and currents of the sea, and other phenomena that relate to its safe navigation and physical geography.

To enlist the service of such a large corps of observers, and to have the attention of so many clever and observant men directed to

of 15 cents per day for a period of 15 days, which will give an aggregate of 2,250,000 dollars saved per annum. This is on the outward voyage alone, and the tonnage trading with all other parts of the world is also left out of the calculation. Take these into consideration, and also the fact that there is a vast amount of foreign tonnage trading between these places and the United States, and it will be seen that the annual sum saved will swell to an enormous amount."—*Extract from Hunt's Merchant's Magazine, May,* 1854.

the same subject, was a great point gained: it was a giant stride in the advancement of knowledge, and a great step toward its spread upon the waters.

Important results soon followed, and great discoveries were made. These attracted the attention of the commercial world, and did not escape the notice of philosophers everywhere.

The field was immense, the harvest was plenteous, and there were both need and room for more labourers. Whatever the reapers should gather, or the merest gleaner collect, was to go to the benefit of commerce and navigation—the increase of knowledge—the good of all.

Therefore, all who use the sea were equally interested in the undertaking. The Government of the United States, so considering the matter, proposed a uniform system of observations at sea, and invited all the maritime states of Christendom to a conference upon the subject.

This conference, consisting of representatives from France, England, and Russia, from Sweden and Norway, Holland, Denmark, Belgium, Portugal, and the United States, met in Brussels, August 23, 1853, and recommended a plan of observations which should be followed on board the vessels of all friendly nations, and especially of those there present in the persons of their representatives.

Prussia, Spain, Sardinia, the Holy See, the free city of Hamburg, the republics of Bremen and Chili, and the empires of Austria and Brazil, have since offered their co-operation also in the same plan.

Thus the sea has been brought regularly within the domains of philosophical research, and crowded with observers.

In peace and in war these observations are to be carried on; and, in case any of the vessels on board of which they are conducted may be captured, the abstract log—as the journal which contains these observations is called—is to be held sacred.

Baron Humboldt is of opinion that the results already obtained from this system of research are sufficient to give rise to a new department of science, which he has called the PHYSICAL GEOGRAPHY OF THE SEA. If so much has already been accomplished by one nation, what may we not expect, in the course of a few years, from the joint co-operation of so many?

Rarely before has there been such a sublime spectacle presented to the scientific world: all nations agreeing to unite and co-operate in carrying out one system of philosophical research with regard to the sea. Though they may be enemies in all else, here they are to be friends. Every ship that navigates the high seas, with these charts and blank abstract logs on board, may henceforth be regarded as a floating observatory, a temple of science. The instruments used by every co-operating vessel are to be compared with standards that are common to all; so that an observation that is made anywhere, and in any ship, may be referred to and compared with all similar observations by all other ships in all parts of the world.

But these meteorological observations which this extensive and admirable system includes will relate only to the sea. This is not enough. The plan should include the land also, and be universal. Other great interests of society are to be benefited by such extension no less than commerce and navigation have been. A series of systematic observations, directed over large districts of country, nay, over continents, to the improvement of agricultural and sanitary meteorology, would, I have no doubt, tend to a development of many interesting, important, and valuable results.

The agricultural societies of many states of the Union have addressed memorials to the American Congress, asking for such extension; and it is hoped that that enlightened body will not fail favourably to respond.

This plan contemplates the co-operation of all the states of Christendom, at least so far as the form, method, subjects of observations, time of making them, and the interchange of results are concerned. I hope that my fellow-citizens will not fail to second and co-operate in such a humane, wise, and noble scheme. The Secretary of the Navy, taking the enlarged and enlightened views which do honour to great statesmen, has officially recommended the adoption of such a system, and the President has asked the favourable consideration thereof by Congress. These researches for the land look not only to the advancement of the great interests of sanitary and agricultural meteorology, but they involve also a study of the laws which regulate the atmosphere, and a careful investigation of all its phenomena.

Another beautiful feature in this system is, that it costs nothing additional. The instruments that these observations at sea call for are such as are already in use on board of every well-conditioned ship, and the observations that are required are precisely those which are necessary for her safe and proper navigation.

Great as is the value attached to what has been accomplished by these researches, in the way of shortening passages and lessening the dangers of the sea, a good of higher value is, in the opinion of many seamen, yet to come, out of the moral, the educational influence which they are calculated to exert upon the seafaring community of the world. A very clever English shipmaster, speaking recently of the advantages of educational influences among those who intend to follow the sea, remarks :—

"To the cultivated lad there is a new world spread out when he enters on his first voyage. As his education has fitted, so will he perceive, year by year, that his profession makes him acquainted with things new and instructive. His intelligence will enable him to appreciate the contrasts of each country, in its general aspect, manners, and productions, and in modes of navigation adapted to the character of coast, climate, and rivers. He will dwell with interest on the phases of the ocean,—the storm, the calm, and the breeze, and will look for traces of the laws which regulate them. All this will induce a serious earnestness in his work, and teach him to view lightly those irksome and often offensive duties incident to the beginner."*

And that these researches have such an effect, many noble-hearted mariners have testified. Captain Phinney, of the American ship Gertrude, writing from Callao, January 1855, thus expresses himself :—

"Having to proceed from this to the Chincha Islands, and remain three months, I avail myself of the present opportunity to forward to you abstracts of my two passages over your southern routes, although not required to do so until my own return to the United States next

* "The Log of a Merchant Officer, viewed with reference to the Education of Young Officers and the Youth of the Merchant Service. By Robert Methren, commander in the Peninsular and Oriental Company, and author of the 'Narrative of the Blenheim Hurricane of 1851.'" London: John Weale, 59 High Holborn; Smith, Elder, and Co., Cornhill; Ackerman and Co., Strand. 1854.

summer, knowing that you are less amply supplied with abstracts of voyages over these regions than of many other parts of the ocean; and, such as it is, I am happy to contribute my mite toward furnishing you with material to work out still farther toward perfection your great and glorious task, not only of pointing out the most speedy routes for ships to follow over the ocean, but also of teaching us sailors to look about us, and see by what wonderful manifestations of the wisdom and goodness of the great God we are continually surrounded.

"For myself, I am free to confess that for many years I commanded a ship, and, although never insensible to the beauties of nature upon the sea or land, I yet feel that, until I took up your work, I had been traversing the ocean blindfolded. I did not think; I did not know the amazing and beautiful combination of all the works of Him whom you so beautifully term 'The Great First Thought.'

"I feel that, aside from any pecuniary profit to myself from your labours, you have done me good as a man. You have taught me to look above, around, and beneath me, and recognise God's hand in every element by which I am surrounded. I am grateful for this personal benefit. Your remarks on this subject, so frequently made in your work, cause in me feelings of the greatest admiration, although my capacity to comprehend your beautiful theory is very limited.

"The man of such sentiments as you express will not be displeased with, or, at least, will know how to excuse, so much of what (in a letter of this kind) might be termed irrelevant matter. I have therefore spoken as I feel, and with sentiments of the greatest respect."

Sentiments like these cannot fail to meet with a hearty response from all good men, whether ashore or afloat.

Never before has such a corps of observers been enlisted in the cause of any department of physical science as is that which is now about to be engaged in advancing our knowledge of the Physical Geography of the Sea, and never before have men felt such an interest with regard to this knowledge.

Under this term will be included a philosophical account of the winds and currents of the sea; of the circulation of the atmosphere and ocean; of the temperature and depth of the sea; of the wonders that lie hidden in its depths; and of the phenomena that display themselves at its surface. In short, I shall treat of the economy of the sea and its adaptations—of its salts, its waters, its climates, and its inhabitants, and of whatever there may be of general interest in its commercial uses or industrial pursuits, for all such things pertain to its PHYSICAL GEOGRAPHY.

The object of this little book, moreover, is to show the present state, and from time to time the progress, of this new and beautiful system of research, as well as of this interesting department of science; and the aim of the author is to present the gleanings from this new field in a manner that may be interesting and instructive to all, whether old or young, ashore or afloat, who desire a closer look into "the wonders of the great deep," or a better knowledge as to its winds, its adaptations, or its Physical Geography.*

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* There is an old and very rare book which treats upon some of the subjects to which this little work relates: it is by Count L. F. Marsigli, a Frenchman, and is called "Natural Description of the Seas." The copy to which I refer was translated into Dutch by Boerhaave, in 1786.

The French count made his observations along the coast of Provence and Languedoc. The description only relates to that part of the Mediterranean. The book is divided into four chapters;—the first, on the bottom and shape of the sea; the second, of sea water; the third, on the movements of sea water; and the fourth, of sea plants.

He divides sea water into surface and deep-sea water; because, when he makes salt from surface water (not more than half a foot below the upper strata), this salt will give a red colour to blue paper, whereas the salt from deep-sea water will not alter the colour at all. The blue paper can only change its colour by the action of an acid. The reason why this acid (iodine?) is found in surface and not in deep-sea water is, it is derived from the air; but he supposes that the saltpetre that is found in sea water, by the action of the sun's rays and the motion of the waves, is deprived of its coarse parts, and, by evaporation, embodied in the air, to be conveyed to beasts or plants for their existence, or deposited upon the earth's crust, as it occurs on the plains of Hungary, where the earth absorbs so much of this saltpetre vapour.

Donati, also, was a valuable labourer in this field. His inquiries enabled Mr. Trembley[1] to conclude that there are, "at the bottom of the water, mountains, plains, valleys, and caverns, just as upon the land."

But by far the most interesting and valuable book touching the physical geography of the Mediterranean is Admiral Smyth's last work, entitled "The Mediterranean; a Memoir, Physical, Historical, and Nautical. By Rear-Admiral William Henry Smyth, K.S.F., D.C.L.," &c. London: John W. Parker and Son. 1854.

[1] Philosophical Transactions.

INTRODUCTION TO THE SIXTH EDITION.

THE department of the Physical Geography of the Sea is a new field of research: there is great activity in it; and it is the aim of the author of this work to keep its readers posted up with the improvements, the developments, and the contributions that are made in this interesting field from time to time.

The present edition contains much that is new; for the fifth edition has been most carefully revised,—much of it has been recast and some parts omitted.

The desire is, that this work shall keep pace with the progress of research. As it may be supposed, facts are sometimes misinterpreted or not understood when first developed. Whenever subsequent research shows such to have been the case, I have not hesitated to tear down whatever of conjecture or theory may have been built on unstable foundations, and to reconstruct according to the best lights.

It is proper to say, that, in accounting for the various phenomena that present themselves, I am wedded to no theories, and do not advocate the doctrines of any particular school. Truth is my object. Therefore, when the explanation which I may have at any time offered touching any facts fails to satisfy further developments, it is given up the moment one is suggested which will account for the new, and equally as well for the old, system of facts. In every instance that theory is preferred which is reconcilable with the greatest number of known facts. The chapter of the Gulf Stream has been enriched with the results of recent investigation, and the theory of it further developed; so, also, that on the Salts of the Sea, the Open Sea in the Arctic Ocean, the Basin of the Atlantic, and several others; but these especially have been greatly improved.

A separate chapter is now devoted to the Land and Sea Breezes, and extensive contributions have been made to that on Monsoons, Trade Winds, and Cyclones. Lieutenant Jansen. of the Dutch Navy, has helped me to enrich these with his fine thoughts. The reader will, I am sure, feel as I do, deeply indebted to him for so much instructive matter, set forth in his very delightful and pleasing manner.

NATIONAL OBSERVATORY, WASHINGTON.
April, 1856.

Since the above date, explorations have been made in this interesting department of science, and new veins of precious ore have been hit upon. We have not yet gone deep enough into them to justify a final report.[1]

In 1849 Congress passed an Act requiring the Secretary of the Navy to employ three small vessels in assisting me to perfect my discoveries. A few weeks ago, Lieutenant Berryman put to sea in the "Arctic" on this duty. His attention was especially directed to deep-sea soundings along the great telegraphic plateau stretching from Newfoundland to Ireland. The results, so far, are of the highest interest. Among them is the discovery of a line of volcanic cinders along a line a thousand miles in length, and reaching entirely across the Gulf Stream where the submarine telegraph is to cross it.

There is also Lieutenant Jansen's experiments upon Ozone, which cast unexpected light upon the circulation of the atmosphere.

Matter of more general or higher scientific importance than that contained in this new Edition is seldom gathered from any fields of research.

December, 1856.

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[1] *Vide* subsequent additions in the present Edition, Chapters xxi. xxii.

EXPLANATION OF THE PLATES.

PLATE I. is a diagram to illustrate the circulation of the atmosphere (Chap. III.). The arrows and bands within the circumference of the circle are intended to show the calm belts, and prevailing direction of the wind on each section of those belts. The arrows exterior to the periphery of the circle—which is a section of the earth supposed to be made in the plane of the meridian—are intended to show the direction of the upper and lower strata of winds in the general system of atmospherical circulation; and also to illustrate how the air brought by each stratum to the calm belts there ascends or descends, as the case may be; and then, continuing to flow on, how it crosses over in the direction in which it was travelling when it arrived at the calm zone.

PLATES II. and III. are drawings of Brooke's Deep-sea Sounding Apparatus, for bringing up specimens of the bottom (§ 701).

PLATE IV. is intended to illustrate the extreme movements of the isotherms 50°, 60°, 70°, &c., in the Atlantic Ocean during the year. The connection between the law of this motion and the climates of the sea is exceedingly interesting.

PLATE V. is a section taken from one of the manuscript charts at the Observatory. It illustrates the method adopted there for co-ordinating for the Pilot Charts the winds as reported in the abstract logs. For this purpose the ocean is divided into convenient sections,—usually five degrees of latitude by five degrees of longitude. These parallelograms are then subdivided into a system of engraved squares, the months of the year being the ordinates, and the points of the compass being the abscissæ. As the wind is reported by a vessel that passes through any part of the parallelogram, so it is assumed to have been at that time all over the parallelogram. From such investigations as this the Pilot Charts (§ 929) are constructed.

PLATE VI. illustrates the position of the channel of the Gulf Stream (Chap. I.) for summer and winter. The diagram A shows a thermometrical profile presented by cross-sections of the Gulf Stream, according to observations made by the hydrographical parties of the United States' Coast Survey. The elements for this diagram were kindly furnished me by the superintendent of that work. They are from a paper on the Gulf Stream, read by him before the American Association for the Advancement of Science, at its meeting in Washington, 1854. Imagine a vessel to sail from the Capes of Virginia straight out to sea, crossing the Gulf Stream at right angles, and taking the temperature of its waters at the surface and at various depths. The diagram shows the elevation and depression of the thermometer across this section as they were actually observed by such a vessel.

The black lines *x*, *y*, *z*, in the Gulf Stream, show the course which those threads of warm waters take (§ 57). The lines *a*, *b*, show the computed drift route that the unfortunate steamer San Francisco would take after her terrible disaster in December 1853.

PLATE VII. is intended to show how the winds may become geological agents. It shows where the winds that, in the general system of atmospherical circulation, blow over the deserts and thirsty lands in Asia and Africa (where the annual amount of precipitation is small) are supposed to get their vapour; where, as surface winds, they are supposed to condense portions of it; and whither they are supposed to transport the residue thereof through the upper regions, retaining it until they again become surface winds.

PLATE VIII. shows the prevailing direction of the wind during the year in all parts of the ocean, as derived from the series of investigations illustrated on Plate VII. It also shows the principal routes across the seas to various places. Where the cross-lines representing the yards are oblique to the keel of the vessel, they indicate that the winds are, for the most part, ahead; when perpendicular or square, that the winds are, for the most part, fair. The figures on or near the diagrams representing the vessels, show the average length of the passage in days.

The arrows denote the prevailing direction of the wind; they are supposed to fly *with* it; so that the wind is going as the arrows point. The half-bearded and half-feathered arrows represent monsoons (§ 763), and the stippled or shaded belts the calm zones.

In the regions on the polar side of the calms of Capricorn and of Cancer, where the arrows are flying both from the north-west and the south-west, the idea intended to be conveyed is, that the prevailing direction of the winds is between the north-west and the south-west, and that their frequency is from these two quarters in proportion to the number of arrows.

Plate IX. is intended to show the present state of our knowledge with regard to the drift of the ocean, or, more properly, with regard to the great flow of polar and equatorial waters, and their channels of circulation as indicated by the thermometer (§ 889). Further researches will enable us to improve this chart. The most favourite places of resort for the whale—*right* in cold, and *sperm* in warm water—are also exhibited on this chart.

Plate X. exhibits the actual path of a storm, which is a type (§ 85) of the West Indian hurricanes. Mr. Redfield, Colonel Reid, and others, have traced out the paths of a number of such storms. All of this class appear to make for the Gulf Stream: after reaching it, they turn about and follow it in their course (§ 95).

Mr. Piddington of Calcutta has made the East Indian hurricanes, which are similar to these, the object of special, patient, and laborious investigation. He calls them *cyclones*, and has elicited much valuable information concerning them, which may be found embraced in his "Sailor's Horn-book," "Conversations about Hurricanes," and numerous papers published from time to time in the Journal of the Asiatic Society.

Plates XI. and XII. speak for themselves. They are orographic for the North Atlantic Ocean, and exhibit completely the present state of our knowledge with regard to the elevations and depressions in the bed of the sea; Plate XII. exhibiting a vertical section of the Atlantic, and showing the contrasts of its bottom with the sea-level in a line from Mexico across Yucatan, Cuba, San Domingo, and the Cape de Verds, to the coast of Africa, marked A on Plate XI.

Plate XIII.—The data for this Plate are furnished by Maury's Storm and Rain Charts, including observations for 107,277 days in the North Atlantic, and 158,025 in the South; collated by Lieutenant J. J. Guthrie, at the Washington Observatory, in 1855.

The heavy vertical lines, 5°, 10°, 15°, &c., represent parallels of latitude; the other vertical lines, months; and the horizontal lines, per cents., or the number of days in a hundred.

The continuous curve line stands for phenomena in the North, and the broken curve line for phenomena in the South Atlantic. Thus the Gales' Curve shows that in every hundred days, and on the average, in the month of January of different years, there have been observed, in the northern hemisphere, 36 gales (36 per cent.) between the parallels of 50° and 55°; whereas during the same time and between the same parallels in the southern hemisphere, only 10 gales on the average (10 per cent.) have been reported.

The fact is here developed that the atmosphere is in a more unstable condition in the North than in the South Atlantic; that we have more calms, more rains, more fogs, more gales, and more thunder in the northern than in the southern hemisphere, particularly between the equator and the 55th parallel. Beyond that the influence of Cape Horn becomes manifest.

CONTENTS.

THE

PHYSICAL GEOGRAPHY OF THE SEA.

CHAPTER I.

THE GULF STREAM.

CHAPTER I. — § 1 Gulf Stream.

THERE is a river in the ocean. In the severest droughts it never fails, and in the mightiest floods it never overflows. Its banks and its bottoms are of cold water, while its current is of warm. The Gulf of Mexico is its fountain, and its mouth is in the Arctic Seas. It is the Gulf Stream. There is in the world no other such majestic flow of waters. Its current is more rapid than the Mississippi or the Amazon, and its volume more than a thousand times greater.

§ 2 Colour of its waters.

Its waters, as far out from the Gulf as the Carolina coasts, are of an indigo blue. They are so distinctly marked, that their line of junction with the common sea

CHAPTER I. water may be traced by the eye. Often one half of the vessel may be perceived floating in Gulf Stream water, while the other half is in common water of the sea; so sharp is the line, and such the want of affinity between those waters, and such, too, the reluctance, so to speak, on the part of those of the Gulf Stream to mingle with the common water of the sea.

Saltness.

§ 3 At the salt-works in France, and along the shores of the Adriatic, where the "*salines*" are carried on by the process of solar evaporation, there is a series of vats or pools through which the water is passed as it comes from the sea, and is reduced to the briny state. The longer it is exposed to evaporation the salter it grows, and the deeper is the hue of its blue, until crystallization is about to commence, when the now deep blue water puts on a reddish tint. Now the waters of the Gulf Stream are salter[1] than the waters of the sea through which they flow, and hence we can account for the deep indigo blue which all navigators observe off the Carolina coasts.

Contrast with other waters.

§ 4 These salt-makers are in the habit of judging of the richness of the sea water in salt by its colour—the greener the hue, the fresher the water. We have in this, perhaps, an explanation of the contrasts which the waters of the Gulf Stream present with those of the Atlantic, as well as of the light green of the North Sea and other Polar waters; also of the dark blue of the trade-wind regions, and especially of the Indian Ocean, which poets have described as the "black waters."

§ 5 What is the cause of the Gulf Stream has always puzzled philosophers. Many are the theories and numer-

[1] § 29.

ous the speculations that have been advanced with regard to it. Modern investigations and examinations are beginning to throw some light upon the subject, though all is not yet clear. CHAPTER I.

Early writers maintained that the Mississippi River was the father of the Gulf Stream. Its floods, they said, produce it; for its velocity, it was held, could be computed by the rate of the current of the river. Theories as to its cause.

Captain Livingston overturned this hypothesis by showing that the volume of water which the Mississippi River empties into the Gulf of Mexico is not equal to the three-thousandth part of that which escapes from it through the Gulf Stream. § 6 Captain Livingston

Moreover, the water of the Gulf Stream is salt—that of the Mississippi fresh; and those philosophers[1] forgot that just as much salt as escapes from the Gulf of Mexico through this stream, must enter the Gulf through some other channel from the main ocean; for, if it did not, the Gulf of Mexico, in process of time, unless it had a salt bed at the bottom, or was fed with salt springs from below—neither of which is probable—would become a fresh water basin.

The above quoted argument of Captain Livingston, however, was held to be conclusive; and upon the remains of the hypothesis which he had so completely overturned he set up another, which, in turn, has been upset. In it he ascribed the velocity of the Gulf Stream as depending "on the motion of the sun in the ecliptic, and the influence he has on the waters of the Atlantic."

But the opinion that came to be the most generally received and deep rooted in the mind of seafaring people § 7

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[1] § 5.

CHAPTER I.

Dr. Franklin's opinion about the trade-winds.

was the one repeated by Dr. Franklin, and which held that the Gulf Stream is the escaping of the waters that have been *forced* into the Caribbean Sea by the trade-winds, and that it is the pressure of those winds upon the water which forces up into that sea a head, as it were, for this stream.

Not conclusive.

We know of instances in which waters have been accumulated on one side of a lake, or in one end of a canal, at the expense of the other. The pressure of the trade-winds may *assist* to give the Gulf Stream its initial velocity, but are they of themselves adequate to such an effect? To my mind, the laws of Hydrostatics, as at present expounded, appear by no means to warrant the conclusion that it is, unless the aid of other agents also be brought to bear.

Strait of Bonifaccio

§ 8 Admiral Smyth, in his valuable memoir on the Mediterranean (p. 162), mentions that a continuance in the Sea of Tuscany of "*gusty gales*" from the south-west has been known to raise its surface no less than twelve feet above its ordinary level. This, he says, occasions a strong surface drift through the Strait of Bonifaccio. But in this we have nothing like the Gulf Stream; no deep and narrow channel-way to conduct these waters off like a miniature river even in that sea, but a mere surface flow, such as usually follows the piling up of water in any pond or gulf above the ordinary level.

Its difference from the Gulf Stream.

The Bonifaccio current does not flow like a "river in the sea" across the Mediterranean, but it spreads itself out as soon as it passes the Straits, and, like a circle on the water, loses itself by broad spreading as soon as it finds sea-room.

CHAPTER I. — § 9

Supposing the pressure of the waters that are *forced* into the Caribbean Sea by the trade-winds to be the *sole* cause of the Gulf Stream, that Sea and the Mexican Gulf should have a much higher level than the Atlantic. Accordingly, the advocates of this theory require for its support "a great degree of elevation." Major Rennell likens the stream to "an immense river descending from a higher level into a plain." Now, we know very nearly the average breadth and velocity of the Gulf Stream in the Florida Pass. We also know, with a like degree of approximation, the velocity and breadth of the same waters off Cape Hatteras. Their breadth here is about seventy-five miles against thirty-two in the "Narrows" of the Straits, and their mean velocity is three knots off Hatteras against four in the "Narrows." This being the case, it is easy to show that the depth of the Gulf Stream off Hatteras is not so great as it is in the "Narrows" of Bemini by nearly 50 per cent., and that, consequently, instead of *descending*, its bed represents the surface of an inclined plane, with its descent inclined from the north toward the south, *up* which plane the lower depths of the stream *must* ascend. If we assume its depth off Bemini* to be two hundred fathoms, which are thought to be within limits, the above rates of breadth and velocity will give one hundred and fourteen fathoms for its depth off Hatteras. The waters, therefore, which in the Straits are below the level of the Hatteras depth, so far from *descending*, are actually forced up an inclined plane,

Breadth and velocity in the Florida Pass.

Off Cape Hatteras.

Its depth off Bemini.

Its waters ascend.

* Professor Bache reports that the officers of the Coast Survey have sounded with the deep sea lead, and ascertained its depth here to be 370 fathoms (January, 1856).

CHAPTER I. whose submarine ascent is not less than ten inches to the mile.

§ 10 The Niagara contrasted with the Gulf Stream. The Niagara is an "immense river descending into a plain." But instead of preserving its character in Lake Ontario as a distinct and well-defined stream for several hundred miles, it spreads itself out, and its waters are immediately lost in those of the lake. Why should not the Gulf Stream do the same? It gradually enlarges itself, it is true; but, instead of mingling with the ocean by broad spreading, as the "immense rivers" descending into the northern lakes do, its waters, like a stream of oil in the ocean, preserve a distinctive character for more than three thousand miles.

§ 11 Moreover, while the Gulf Stream is running to the north from its supposed elevated level at the south, there is a cold current coming down from the north; Currents meeting it. meeting the warm waters of the Gulf midway the ocean, it divides itself, and runs by the side of them right back into those very reservoirs at the south, to which theory gives an elevation sufficient to send out entirely across the Atlantic a jet of warm water said to be more than three thousand times greater in volume than the Mississippi River. This current from Baffin's Bay has not only no trade-winds to give it a head, but the prevailing winds are unfavourable to it, and for a great part of the way it is below the surface, and far beyond the propelling reach of any wind. And there is every reason to believe that this, with other polar currents, is quite equal in volume to the Gulf Stream. Are they not the effects of like causes? If so, what have the trade winds to do with the one more than the other?

CHAPTER I.

§ 12 Information derived from bottles.

It is a custom often practised by seafaring people to throw a bottle overboard, with a paper, stating the time and place at which it is done. In the absence of other information as to currents, that afforded by these mute little navigators is of great value. They leave no tracks behind them, it is true, and their routes can not be ascertained. But knowing where they were cast, and seeing where they are found, some idea may be formed as to their course. Straight lines may at least be drawn, showing the shortest distance from the beginning to the end of their voyage, with the time elapsed. Admiral Beechey, R.N., has prepared a chart, representing, in this way, the tracks of more than one hundred bottles. From it, it appears that the waters from every quarter of the Atlantic tend toward the Gulf of Mexico and its stream. Bottles cast into the sea midway between the Old and the New Worlds, near the coasts of Europe, Africa, and America, at the extreme north or farthest south, have been found either in the West Indies, or the British Isles, or within the well-known range of Gulf Stream waters.

Admiral Beechey's chart.

Of two cast out together in south latitude on the coast of Africa, one was found on the island of Trinidad; the other on Guernsey, in the English Channel. In the absence of positive information on the subject, the circumstantial evidence that the latter performed the tour of the Gulf is all but conclusive. And there is reason to suppose that some of the bottles of the admiral's chart have also performed the tour of the Gulf Stream; then, without being cast ashore, have returned with the drift along the coast of Africa into the inter-tropical region;

CHAPTER I. thence through the Caribbean Sea, and so on with the Gulf Stream again. (Plate VI.)

Another bottle, thrown over off Cape Horn by an American master, in 1837, has been recently picked up on the coast of Ireland. An inspection of the chart, and of the drift of the other bottles, seems to *force* the conclusion, that this bottle too went even from that remote region to the so-called *higher* level of the Gulf Stream reservoir.

§ 13 Midway the Atlantic, in the triangular space between the Azores, Canaries, and the Cape de Verd Islands, is the Sargasso Sea. (Plate VI.) Covering an area equal in extent to the Mississippi Valley, it is so thickly matted over with Gulf Weeds *(fucus natans)*, that the speed of vessels passing through it is often much retarded. When the companions of Columbus saw it, they thought it marked the limits of navigation, and became alarmed. To the eye, at a little distance, it seems substantial enough to walk upon. Patches of the weed are always to be seen floating along the outer edge of the Gulf Stream. Now, if bits of cork or chaff, or any floating substance, be put into a basin, and a circular motion be given to to the water, all the light substances will be found crowding together near the centre of the pool, where there is the least motion. Just such a basin is the Atlantic Ocean to the Gulf Stream; and the Sargasso Sea is the centre of the whirl. Columbus first found this weedy sea in his voyage of discovery; there it has remained to this day, moving up and down, and changing its position like the calms of Cancer, according to the seasons, the storms, and the winds. Exact observations

Sargasso Sea.

Discovered by Columbus.

as to its limits and their range, extending back for fifty years, assure us that its mean position has not been altered since that time. This indication of a circular motion by the Gulf Stream is corroborated by the bottle chart, by Plate VI., and other sources of information. If, therefore, this be so, why give the endless current a higher level in one part of its course than another?

Its limits and position.

§ 14 Nay, more; at the very season of the year when the Gulf Stream is rushing in greatest volume through the Straits of Florida, and hastening to the north with the greatest rapidity, there is a cold stream from Baffin's Bay, Labrador, and the coasts of the north, running to the south with equal velocity. Where is the trade-wind that gives the higher level to Baffin's Bay, or that even presses upon, or assists to put this current in motion? The agency of winds in producing currents in the deep sea must be very partial. These two currents meet off the Grand Banks, where the latter is divided. One part of it underruns the Gulf Stream, as is shown by the icebergs, which are carried in a direction tending across its course. The probability is, that this "fork" flows on toward the south, and runs into the Caribbean Sea, for the temperature of the water at a little depth there has been found far below the mean temperature of the earth's crust, and quite as cold as at a corresponding depth off the Arctic shores of Spitzbergen.

Cold stream from Baffin's Bay.

Its direction.

§ 15 More water can not run from the equator or the pole than to it. If we make the trade-winds to cause the Gulf Stream, we ought to have some other wind to produce the Polar flow; but these currents, for the most part, and for great distances, are *submarine*, and there-

Currents not influenced by winds.

CHAPTER I. fore beyond the influence of winds. Hence it should appear that *winds* have little to do with the general system of aqueous circulation in the ocean.

The other "fork" runs between us and the Gulf Stream to the south, as already described. As far as it has been traced, it warrants the belief that it, too, runs *up* to seek the so-called *higher* level of the Mexican Gulf.

§ 16 The power necessary to overcome the resistance opposed to such a body of water as that of the Gulf Stream, running several thousand miles without any renewal of impulse from the forces of gravitation or any other known cause, is truly surprising. It so happens that we have an argument for determining, with considerable accuracy, the resistance which the waters of this stream meet with in their motion toward the east. Owing to the diurnal rotation, they are carried around with the earth on its axis *toward the east* with an hourly velocity of one hundred and fifty-seven* miles greater when they enter the Atlantic than when they arrive off the Banks of Newfoundland; for, in consequence of the difference of latitude between the parallels of these two places, their rate of motion around the axis of the earth is reduced from nine hundred and fifteen† to seven hundred and fifty-eight miles the hour.

Resistance to the Gulf Stream.

§ 17 Therefore this immense volume of water would, if we suppose it to pass from the Bahamas to the Grand Banks in an hour, meet with an opposing force in the

* In this calculation the earth is treated as a perfect sphere, with a diameter of 7925·56 miles.

† Or 915·26 to 758·60. On the latter parallel, the current has an east set of about one and a half miles the hour, making the true velocity to the east; and on the axis of the earth, about seven hundred and sixty miles an hour at the Grand Banks.

shape of resistance sufficient, in the aggregate, to retard it two miles and a half the minute in its eastwardly rate. If the actual resistance be calculated according to received laws, it will be found equal to several atmospheres. And by analogy, how inadequate must the pressure of the gentle trade-winds be to such resistance, and to the effect assigned them? If, therefore, in the proposed inquiry, we search for a propelling power nowhere but in the higher level of the Gulf, we must admit, in the head of water there, the existence of a force capable of putting in motion, and of driving over a plain at the rate of four miles the hour, all the waters, as fast as they can be brought down by three thousand[1] such streams as the Mississippi River,—a power at least sufficient to overcome the resistance required to reduce from two miles and a half to a few feet per minute the velocity of a stream that keeps in perpetual motion one fourth of all the waters in the Atlantic Ocean.

§ 18 No certainty as to the cause of the Gulf Stream.

The facts, from observation on this interesting subject, afford us at best but a mere glimmer of light, by no means sufficient to make any mind clear as to a *higher level* of the Gulf, or as to the sufficiency of any other of the causes generally assigned for this wonderful stream. If it be necessary to resort to a higher level in the Gulf to account for the velocity off Hatteras, I cannot perceive why we should not, with like reasoning, resort to a higher level off Hatteras also to account for the velocity off the Grand Banks, and thus make the Gulf Stream, throughout its circuit, a *descending* current, and, by the *reductio ad absurdum*, show that the trade-winds are not adequate to the effect ascribed. Moreover, the top

[1] § 6.

CHAPTER I. of the Gulf Stream runs on a level with the ocean, therefore *we know* it is not a descending current.

§ 19 When facts are wanting, it often happens that hypothesis will serve, in their stead, the purposes of illustration. Let us, therefore, suppose a globe of the earth's size, having a solid nucleus, and covered all over with water two hundred fathoms deep, and that every source of heat and cause of radiation be removed, so that its fluid temperature becomes constant and uniform throughout. On such a globe, the equilibrium remaining undisturbed, there would be neither wind nor current.

Hypothesis.

§ 20 Let us now suppose that all the water within the tropics, to the depth of one hundred fathoms, suddenly becomes oil. The aqueous equilibrium of the planet would thereby be disturbed, and a general system of currents and counter currents would be immediately commenced—the oil, in an unbroken sheet on the surface, running toward the poles, and the water, in an under current, toward the equator. The oil is supposed, as it reaches the polar basin, to be reconverted into water, and the water to become oil as it crosses Cancer and Capricorn, rising to the surface in the intertropical regions, and returning as before.

§ 21 Thus, *without wind*, we should have a perpetual and uniform system of tropical and polar currents. In consequence of diurnal rotation of the planet on its axis, each particle of oil, were resistance small, would approach the poles on a spiral turning to the east, with a relative velocity greater and greater, until finally it would reach the pole, and whirl about it at the rate of nearly a thousand miles the hour. Becoming water and losing its velocity, it would approach the tropics by a similar but inverted spiral, turning toward the west. Owing to the principle here alluded to, all currents from the equator to the poles should have an eastward tendency, and all from the poles toward the equator a westward. CHAPTER I.

§ 22 Let us now suppose the solid nucleus of this hypothetical globe to assume the exact form and shape of the bottom of our seas, and in all respects, as to figure and size, to represent the shoals and islands of the sea, as well as the coast lines and continents of the earth. The uniform system of currents just described would now be interrupted by obstructions and local causes of various kinds, such as unequal depth of water, contour of shore-lines, &c.; and we should have at certain places currents greater in volume and velocity than at others. But still there would be a system of currents and counter currents to and from either pole and the equator. Now, do not the cold waters of the north, and the warm waters of the Gulf, made specifically lighter by tropical heat, and which we see actually preserving such a system of counter currents, hold, at least in some degree, the relation of the supposed water and oil? Results of hypothesis

§ 23 In obedience to the laws here hinted at, there is a constant tendency[1] of polar waters toward the tropics, and of tropical waters toward the poles. Captain Wilkes, of the United States Exploring Expedition, crossed one of these hyperborean under-currents two hundred miles in breadth at the equator. Tendency of polar and tropical waters.

§ 24 Assuming the maximum velocity of the Gulf Stream at five knots, and its depth and breadth in the Narrows Assumed velocity.

[1] Plate IX.

CHAPTER I. of Bemini as before,[1] the vertical section across would present an area of two hundred millions of square feet moving at the rate of seven feet three inches per second.

Difference of specific gravity. The difference of specific gravity between the volume of Gulf water that crosses this sectional line in one second, and an equal volume of water at the ocean temperature of the latitude, supposing the two volumes to be equally salt, is fifteen millions of pounds. If these estimated dimensions (assumed merely for the purposes of illustration) be within limits, then the force per second operating here to propel the waters of the Gulf toward the pole is the equilibrating tendency due to fifteen millions of pounds of water in the latitude of Bemini. This is in one scale of the balance. In the other, the polar scale, there is the difference of specific gravity due an equal volume of water in the polar basin, on account of its degree of temperature as well as of saltness.

§ 25 Author's opinion. In investigating the currents of the seas, such agencies should be taken into account. As a cause, I doubt whether this one is sufficient of itself to produce a stream of such velocity and compactness as that of the Gulf; for, assuming its estimated discharge to be correct, the proposition is almost susceptible of mathematical demonstration, that to overcome the resistance opposed in consequence of its velocity would require a force at least sufficient to drive, at the rate of three miles the hour, ninety thousand millions of tons up an inclined plane having an ascent of three inches to the mile.* Yet heat, the very principle from which one of these agents is de-

* Supposing there be no resistance from friction.

[1] § 9.

rived, is admitted to be one of the chief causes of those winds which are said to be the sole cause of this current. CHAPTER I.

§ 26 Chemical properties of its waters. The chemical properties, or, if the expression be admissible, the *galvanic* properties of the Gulf Stream waters, as they come from their fountains, are different, or rather more intense, than they are in sea water generally. If so, they may have a peculiar molecular arrangement or viscosity that resists the admixture of other sea waters differing in temperature and saltness. It is a well known fact, that waters of different temperatures, when put in the same vessel, do not readily mix of themselves, but require the process of agitation. Nor do large volumes of water in motion readily admit of the admixture of water at rest.

Experiments on sea water. In 1843 the Secretary of the Navy took measures for procuring a series of observations and experiments with regard to the corrosive effects of sea water upon the copper sheathing of ships. With patience, care, and labour, these researches were carried on for a period of ten years; and it is said the fact has been established, that the copper on the bottom of ships cruising in the Caribbean Sea and Gulf of Mexico suffers more from the action of sea water upon it, than does the copper of ships cruising in any other part of the ocean. Galvanic properties. In other words, the salts of these waters create the most powerful galvanic battery that is found in the ocean.

§ 27 Now, it may be supposed—other things being equal—that the strength of this galvanic battery in the sea depends in some measure upon the proportion of salts that the sea waters hold in solution, and also upon temperature.

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§ 28 If, therefore, in the absence of better information, this suggestion be taken as a probability as to the origin of these galvanic properties, we may go a step farther, and draw the inference that the waters of the Gulf Stream, as they rush out in such volume and with such velocity into the Atlantic, have not only chemical affinities peculiar to themselves, but, having more salts, higher temperature, and a high velocity, they are not so permeable to water differing from them in all these respects, and, consequently, the line of meeting between them and the other water of the ocean becomes marked. This is the case with almost all waters in rapid motion. Where the Mississippi and Missouri rivers come together, there is a similar reluctance on the part of their waters to mingle, for the line of meeting between them can be traced for miles below the junction of the two rivers.

Chemical affinities.

§ 29 The story told by the copper[1] and the blue colour[2] indicates a higher point of saturation with salts than sea water generally, and the salometer confirms it. Dr. Thomassy, a French *savant*, who has been extensively engaged in the manufacture of salt by solar evaporation, informs me that on his passage to the United States he tried the saltness of the water with a most delicate instrument: he found it in the Bay of Biscay to contain $3\frac{1}{2}$ per cent. of salt; in the trade-wind region, $4\frac{1}{10}$ per cent.; and in the Gulf Stream, off Charleston, 4 per cent., notwithstanding the Amazon and the Mississippi, with all the intermediate rivers, and the clouds of the West Indies, had lent their fresh water to dilute the saltness of this basin.

Dr. Thomassy's experiments.

§ 30 Now, the question may be asked, What should make

[1] § 26. [2] § 3.

the waters of the Mexican Gulf and Caribbean Sea salter than the waters of like temperature in those parts of the ocean through which the Gulf Stream flows? CHAPTER I.

§ 31 Physical agencies. There are physical agents that are known to be at work in different parts of the ocean, the tendency of which is to make the waters in one part of the ocean salter and heavier, and in another part lighter and less salt than the average of sea water. These agents are those employed by sea-shells in secreting solid matter for their structures; they are also heat* and radiation, evaporation and precipitation.

§ 32 Evaporation. In the trade-wind regions at sea,[1] evaporation is generally in excess of precipitation, while in the extra-tropical regions the reverse is the case; that is, the clouds let down more water there than the winds take up again; and these are the regions in which the Gulf Stream enters the Atlantic.

§ 33 Along the shores of India, where experiments have been carefully made, the evaporation from the sea amounts to three-fourths of an inch daily. Suppose it in the trade-wind region of the Atlantic to amount to only half an inch, that would give an annual evaporation of fifteen feet. In the process of evaporation from the sea, fresh water only is taken up, the salts are left behind.

Now, a layer of sea water fifteen feet deep, and as broad as the trade-wind belts of the Atlantic, and reaching across the ocean, contains an immense amount of salts.

§ 34 The great equatorial current (Plate VI.) which sweeps from the shores of Africa across the Atlantic into the Caribbean Sea is a surface current; and may it not bear

* According to Dr. Marcet, sea water contracts down to 28°.

[1] Plate VIII.

CHAPTER I. into that sea a large portion of those waters that have satisfied the thirsty trade-winds with saltless vapour? If so—and it probably does—have we not detected here the foot-prints of an agent that does tend to make the waters of the Caribbean Sea salter, and therefore heavier than the average of sea water at a given temperature?

Reason for saltness of Caribbean Sea.

It is immaterial, so far as the correctness of the principle upon which this reasoning depends is concerned, whether the annual evaporation from the trade-wind regions of the Atlantic be fifteen, ten, or five feet. The layer of water, whatever be its thickness, that is evaporated from this part of the ocean, is not all poured back by the clouds in the same place whence it came. But they take it and pour it down in showers upon the extra-tropical regions of the earth—on the land as well as in the sea—and on the land more water is let down than is taken up into the clouds again. The rest sinks down through the soil to feed the springs, and return through the rivers to the sea. Suppose the excess of precipitation in these extra-tropical regions of the sea to amount to but twelve inches, or even to but two—it is twelve inches or two inches, as the case may be, of fresh water added to the sea in those parts, and which therefore tends to lessen the specific gravity of sea water there to that extent, and to produce a double effect, for the simple reason that what is taken from one scale, by being put into the other, doubles the difference.

Effects of evaporation.

§ 35 Now that we may form some idea as to the influence which the salts left by the vapour that the trade-winds, north-east and south-east, take up from sea water, is calculated to exert in creating currents, let us make a partial calculation to show how much salt this vapour held in solution before it was taken up, and, of course, while it was yet in the state of sea water. The north-east trade-wind regions of the Atlantic embrace an area of at least three million square miles; and the yearly evaporation from it is,[1] we will suppose, fifteen feet. The salt that is contained in a mass of sea water covering to the depth of fifteen feet an area of three million square miles in superficial extent, would be sufficient to cover the British islands to the depth of fourteen feet. As this water supplies the trade-winds with vapour, it therefore becomes salter, and as it becomes salter the forces of aggregation among its particles are increased, as we may infer from the fact,[2] that the waters of the Gulf Stream are reluctant to mix with those of the ocean.

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Supposed evaporation in the trade-wind regions.

§ 36 Whatever be the cause that enables these trade-wind waters to remain on the surface, whether it be from the fact just stated, and in consequence of which the waters of the Gulf Stream are held together in their channel; or whether it be from the fact that the expansion from the heat of the torrid zone is sufficient to compensate for this increased saltness; or whether it be from the low temperature and high saturation of the submarine waters of the inter-tropical ocean; or whether it be owing to all of these influences together that these waters are kept on the surface, suffice it to say, we do know that they go into the Caribbean Sea[3] as a surface current. On their passage to and through it, they intermingle with the fresh waters that are emptied into the sea from the Amazon, the Oronoco, and the Mississippi, and from the clouds, and the rivers of the

Trade-wind waters form a surface current.

[1] § 33. [2] § 27. [3] § 34.

CHAPTER I.

Mixture of fresh water.

coasts round about. An immense volume of fresh water is supplied from these sources. It tends to make the sea water, that the trade-winds have been playing upon and driving along, less briny, warmer, and lighter; for the waters of these large inter-tropical streams are warmer than sea water. This admixture of fresh water still leaves the Gulf Stream a brine stronger than that of the extra-tropical sea generally, but not quite so strong as that of the trade-wind regions.[1]

Effect of the trade-winds.

It is safe to assume that the trade-winds, by their constant force, do assist to skim the Atlantic of the water that has supplied them with vapour, driving it into the Caribbean Sea, whence, for causes unknown, it escapes by the channel of the Gulf Stream in preference to any other.*

§ 37 In the present state of our knowledge concerning this wonderful phenomenon—for the Gulf Stream is one of the most marvellous things in the ocean—we can do little more than conjecture. But we have two causes in operation which we may safely assume are among those concerned in producing the Gulf Stream. One of these is in the increased saltness of its water after the trade-winds have been supplied with vapour from it, be it much or little; and the other is in the diminished quantum of salt which the Baltic and the Northern Seas contain. The waters of the Baltic are nearly fresh; they are said to contain only about half as much salt as sea water does generally.

Saltness of Baltic and North Seas.

§ 38 Now here we have, on one side, the Caribbean Sea

* The fact is familiar to all concerned in the manufacture of salt by solar evaporation, that the first show of crystallization commences at the surface.

[1] § 29.

and Gulf of Mexico, with their waters of brine; on the other, the great Polar basin, the Baltic and the North Sea, the two latter with waters that are but little more than brackish.† In one set of these sea-basins the water is heavy; in the other it is light. Between them the ocean intervenes; but water is bound to seek and to maintain its level; and here, therefore, we unmask one of the agents concerned in causing the Gulf Stream. What is the influence of this agent—that is, how great is it, and to what extent does it go—we can not say; only it is at least one of the agents concerned. Moreover, speculate as we may as to all the agencies concerned in collecting these waters, that have supplied the trade-winds with vapour, into the Caribbean Sea, and then in driving them across the Atlantic—of this we may be sure, that the salt which the trade-wind vapour leaves behind in the tropics has to be conveyed away from the trade-wind region, to be mixed up again in due proportion with the other water of the sea—the Baltic Sea and the Arctic Ocean included—and that these are some of the waters at least which we see running off through the Gulf Stream. To convey them away is doubtless one of the offices which, in the economy of the ocean, has been assigned to it.

One agent concerned in causing the Gulf Stream.

Temperature.

As to the temperature of the Gulf Stream, there is, in a winter's day, off Hatteras, and even as high up as the Grand Banks of Newfoundland in mid ocean, a difference

† The Polar basin has a known water area of 3,000,000 square miles, and an unexplored area, including land and water, of 1,500,000 square miles. Whether the water in this basin be more or less salt than that of the inter-tropical seas, we know it is quite different in temperature, and difference of temperature will beget currents quite as readily as difference in saltness, for change in specific gravity follows either.

CHAPTER I. between its waters and those of the ocean near by of 20°, and even 30°. Water, we know, expands by heat, and here the difference of temperature may more than compensate for the difference in saltness, and leave, therefore, the waters of the Gulf Stream lighter by reason of their warmth.

§ 39 If they be lighter, they should therefore occupy a higher level than those through which they flow. Assuming the depth off Hatteras to be one hundred and fourteen fathoms, and allowing the usual rates of expansion for sea water, figures show that the middle or axis of the Gulf Stream there should be nearly two feet higher than the contiguous waters of the Atlantic. Hence the surface of the stream should present a double inclined plane, from which the water would be running down on either side as from the roof of a house. As this runs off at the top, the same weight of colder water runs in at the bottom, and so raises up the cold water bed of the Gulf Stream, and causes it to become shallower and shallower as it goes north. That the Gulf Stream is therefore roof-shaped, causing the waters on its surface to flow off to either side from the middle, we have not only circumstantial evidence to show, but observations to prove.

Expansion

Form.

§ 40 Navigators, while drifting along with the Gulf Stream, have lowered a boat to try the surface current. In such cases, the boat would drift either to the east or to the west, as it happened to be on one side or the other of the axis of the stream, while the vessel herself would drift along with the stream in the direction of its course; thus showing the existence of a shallow roof-current from the middle toward either edge, which would carry the

Surface current.

boat along, but which, being superficial, does not extend deep enough to affect the drift of the vessel. CHAPTER I.

§ 41 That such is the case[1] is also indicated by the circumstance that the sea-weed and drift-wood which are found in such large quantities along the outer edge[2] of the Gulf Stream, are never, even with the prevalence of easterly winds, found along its inner edge—and for the simple reason that to cross the Gulf Stream, and to pass over from that side to this, they would have to drift up an inclined plane, as it were; that is, they would have to stem this roof-current until they reached the middle of the stream. We rarely hear of planks, or wrecks, or of any floating substance which is cast into the sea on the other side of the Gulf Stream being found along the coast of the United States. Drift-wood, trees, and seeds from the West India islands, are said to have been cast up on the shores of Europe, but never, that I ever heard, on the Atlantic shores of this country.

Direction of drift-wood, &c.

We are treating now of the effects of physical causes. The question to which I ask attention is, Why does the Gulf Stream slough off and cast upon its outer edge, sea-weed, drift-wood, and all other solid bodies that are found floating upon it?

Causes of the direction of drift-wood.

§ 42 One cause has been shown to be in its roof-shaped current; but there is another which tends to produce the same effect; and because it is a physical agent, it should not, in a treatise of this kind, be overlooked, be its action never so slight. I allude now to the effects produced upon the drift matter of the stream by the diurnal rotation of the earth.

§ 43 Take, for illustration, a railroad that runs north and

[1] § 39. [2] § 13.

CHAPTER I. south. It is well known to engineers that when the cars are going north on such a road, their tendency is to run off on the east side; but when the train is going south, their tendency is to run off on the west side of the track—*i. e.*, always on the right-hand side in our hemisphere. Illustration. Whether the road be one mile or one hundred miles in length, the effect of diurnal rotation is the same, and the tendency to run off, as you cross a given parallel at a stated rate of speed, is the same; whether the road be long or short, the tendency to fly off the track being in proportion to the speed of the trains, and not at all in proportion to the length of the road.

§ 44 Diurnal rotation. Now, *vis inertiæ* and velocity being taken into the account, the tendency to obey the force of this diurnal rotation, and to trend to the right, is proportionably as great in the case of a patch of sea-weed as it drifts along the Gulf Stream, as it is in the case of the train of cars as they speed to the north along the iron track of the Hudson River railway, or any other railway that lies north and south. The rails restrain the cars and prevent them from flying off; but there are no rails to restrain the sea-weed, and nothing to prevent the drift-matter of the Gulf Stream from going off in obedience to this force. The slightest impulse tending to turn aside bodies moving freely in water is immediately felt and implicitly obeyed.

§ 45 It is in consequence of this diurnal rotation that drift-wood coming down the Mississippi is so very apt to be cast upon the west or right bank. This is the reverse of what obtains upon the Gulf Stream, for it flows to the north; it therefore sloughs off[1] to the east.

[1] § 43.

CHAPTER I.

Its effects on the winds and currents.

The effect of diurnal rotation upon the winds and upon the currents of the sea is admitted by all—the trade-winds derive their *easting* from it—it must, therefore, extend to all the matter which these currents bear with them, to the largest iceberg as well as to the merest spire of grass that floats upon the waters, or the minutest organism that the most powerful microscope can detect among the impalpable particles of sea-dust. This effect of diurnal rotation upon drift will be frequently alluded to in the pages of this work.

Banks of Newfoundland.

In its course to the north, the Gulf Stream gradually trends more and more to the eastward, until it arrives off the Banks of Newfoundland, where its course becomes nearly due east. These banks, it has been thought, deflect it from its proper course, and cause it to take this turn. Examination will prove, I think, that they are an effect, certainly not the cause. It is here that the frigid current already spoken of,[1] with its icebergs from the north, are met and melted by the warm waters of the Gulf. Of course the loads of earth, stones, and gravel brought down upon them are here deposited. Captain Scoresby, far away in the north, counted five hundred icebergs setting out from the same vicinity upon this cold current for the south. Many of them, loaded with earth, have been seen aground on the Banks. This process of transferring deposits from the north for these shoals, and of snowing down upon them the infusoria and the corpses of "living creatures" that are spawned so abundantly in the warm waters of the Gulf Stream, and sloughed off in myriads for burial where the conflict between it and the great Polar current[2] takes place, § 46

[1] § 11. [2] § 14.

CHAPTER I.

is everlastingly going on. These agencies, with time, seem altogether adequate to the formation of extensive bars or banks.

Their formation.

The deep sea soundings that have been made by vessels of the navy[1] tend to confirm this view as to the formation of these Banks. The greatest contrast in the bottom of the Atlantic is just to the south of these Banks. Nowhere in the open sea has the water been found to deepen so suddenly as here. Coming from the north, the bottom of the sea is shelving; but suddenly, after passing these Banks, its depth increases by almost a precipitous descent for many thousand feet, thus indicating that the debris which forms the Grand Banks comes from the north.

§ 47 From the Straits of Bemini the course of the Gulf Stream (Plate VI.) describes (as far as it can be traced over toward the British Islands which are in the midst of its waters) the arc of a great circle as nearly as may be. Such a course as the Gulf Stream takes is very nearly the course that a cannon ball, could it be shot from these straits to those islands, would describe.

Course of the Gulf Stream.

If it were possible to see Ireland from Bemini, and to get a cannon that would reach that far, the person standing on Bemini and taking aim, intending to shoot at Ireland as a target, would, if the earth were at rest, sight direct, and make no allowance for difference of motion between marksman and target.

§ 48 But there *is* diurnal rotation; the earth *does* revolve on its axis; and since Bemini is nearer to the equator than Ireland is, the gun would be moving in diurnal rotation[2] faster than the target, and therefore

Diurnal rotation affects its course.

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[1] Plate XI. [2] § 16.

CHAPTER I.

the marksman, taking aim point blank at his target, would miss. He would find, on examination, that he had shot south—that is, to the *right*[1] of his mark. In other words, that the path actually described by the ball would be the resultant of this difference in the rate of rotation and the trajectile force; the former, impelling to the east, would cause the ball to describe a great circle, but one with too much obliquity to pass through the target. Like a ray of light from the stars, the ball would be affected by aberration.

§ 49 Illustration.

It is the case of the passenger in the railroad car throwing an apple, as the train sweeps by, to a boy standing by the wayside. If he throw straight at the boy, he will miss, for the apple, partaking of the motion of the cars, will go ahead of the boy, and for the very reason that the shot will pass in advance of the target, for both the marksman and the passenger are going faster than the object at which they aim.

§ 50 Natural tendency of currents to describe curves.

Hence we may assume it as a law, that the natural tendency of all currents in the sea, like the natural tendency of all projectiles through the air, is to describe their curves of flight in the planes of great circles. The natural tendency of all matter, when put in motion, is to go from point to point by the shortest distance, and it requires force to overcome this tendency. Light, heat, and electricity, running water, and all substances, whether ponderable or imponderable, seek, when in motion, to obey this law. Electricity may be turned aside from its course, and so may the cannon ball or running water; but remove every obstruction, and leave the current or the shot free to continue on in the direction of the first

[1] § 43.

CHAPTER I. impulse, or to turn aside of its own volition, so to speak, and straight it will go, and continue to go—if on a plane, in a straight line; if on a sphere, in the arc of a great circle—thus showing that it has no volition except to obey impulse, and the physical requirements to take the shortest way to its point of destination.

§ 51 The waters of the Gulf Stream, as they escape from the Gulf,[1] are bound for the British Islands, to the North Sea, and Frozen Ocean.[2] Accordingly, they take,[3] in obedience to this physical law, the most direct course by which nature will permit them to reach their destination. And this course, as already remarked, is nearly that of the great circle, and exactly that of the supposed cannon ball.

Course of the Gulf Stream the same as a cannon ball.

§ 52 Many philosophers have expressed the opinion—indeed, the belief[4] is common among mariners—that the coasts of the United States and the Shoals of Nantucket turn the Gulf Stream toward the east; but if the view I have been endeavouring to make clear be correct—and I think it is—it appears that the course of the Gulf Stream is fixed and prescribed by exactly the same laws that require the planets to revolve in orbits, the planes of which shall pass through the centre of the sun; and that, were the Nantucket Shoals not in existence, the course of the Gulf Stream, in the main, would be exactly as it is and where it is. The Gulf Stream is bound over to the North Sea and Bay of Biscay partly for the reason, perhaps, that the waters there are lighter than those of the Mexican Gulf;[5] and if the Shoals of Nantucket were not in existence, it could not pursue a more direct route. The Grand Banks,

Common belief that Shoals of Nantucket turn it eastward.

[1] § 37. [2] Plate IX. [3] § 47. [4] § 46. [5] § 37.

however, are encroaching,[1] and cold currents from the north come down upon it: they may, and probably do, assist now and then to turn it aside. CHAPTER I.

§ 53 Facts against this belief. Now if this explanation as to the *course* of the Gulf Stream and its eastward tendency hold good, a current setting from the north toward the south should[2] have a westward tendency. It should also move in a circle of trajection, or such as would be described by a trajectile moving through the air without resistance and for a great distance. Accordingly, and in obedience to the propelling powers, derived from the rate at which different parallels are whirled around in diurnal motion,[3] we find the current from the north, which meets the Gulf Stream, on the Grand Banks,[4] taking a south-*westwardly* direction, as already described.[5] It runs down to the tropics by the side of the Gulf Stream, and stretches as far to the west as our own shores will allow. Yet, in the face of these facts, and in spite of this force, both Major Rennel and M. Arago make the coasts of the United States and the Shoals of Nantucket to turn the Gulf Stream toward the east. Opinion of Major Rennel and M. Arago.

§ 54 Operation of other forces. But there are other forces operating upon the Gulf Stream. They are derived from the effect of changes in the waters of the whole ocean, as produced by changes in their temperature from time to time. As the Gulf Stream leaves the coasts of the United States, it begins to vary its position according to the seasons; the limit of its northern edge, as it passes the meridian of Cape Race (Plate VI.), being in winter about latitude 40-41°, and in September, when the sea is hottest, about latitude 45-46°. The trough of the Gulf Stream, therefore, may

[1] § 46. [2] § 21. [3] § 16. [4] Plate IX. [5] § 45.

CHAPTER I. be supposed to waver about in the ocean not unlike a pennon in the breeze. Its head is confined between the shoals of the Bahamahs and the Carolinas; but that part of it which stretches over toward the Grand Banks of Newfoundland is, as the temperature of the waters of the ocean changes, first pressed down toward the south, and then again up toward the north, according to the season of the year.

§ 55 To appreciate the extent of the force by which it is so pressed, let us imagine the waters of the Gulf Stream to extend all the way to the bottom of the sea, so as completely to separate, by an impenetrable liquid wall, if you please, the waters of the ocean on the right from the waters in the ocean on the left of the stream. Changes in the temperature of the ocean. It is the height of summer: the waters of the sea on either hand are for the most part in a liquid state, and the Gulf Stream, let it be supposed, has assumed a normal condition between the two divisions, adjusting itself to the pressure on either side, so as to balance them exactly and be in equilibrium. Now, again, it is the dead of winter, and the temperature of the waters over an area of millions of square miles in the North Atlantic has been changed many degrees, and this change of temperature has been followed by a change in the specific gravity of those waters, amounting, no doubt, in the aggregate, to many hundred millions of tons, over the whole ocean; for sea water, unlike fresh,[1] contracts to freezing. Now, is it probable that, in passing from their summer to their winter temperature, the sea waters to the right of the Gulf Stream should change their specific gravity exactly as much in the aggregate as do the

[1] § 31.

waters in the whole ocean to the left of it? If not, the difference must be compensated by some means. Sparks are not more prone to fly upward, nor water to seek its level, than Nature is sure with her efforts to restore equilibrium in both sea and air whenever, wherever, and by whatever it be disturbed. Therefore, though the waters of the Gulf Stream do not extend to the bottom, and though they be not impenetrable to the waters on either hand, yet, seeing that they have a waste of waters on the right, and a waste of waters on the left, to which[1] they offer a sort of resisting permeability, we are enabled to comprehend how the waters on either hand, as their specific gravity is increased or diminished, will impart to the trough of this stream a vibratory motion, pressing it now to the right, now to the left, according to the seasons and the consequent changes of temperature in the sea.

Vibratory motion.

§ 56 Its limits in March and September.

Plate VI. shows the limits of the Gulf Stream for March and September. The reason for this change of position is obvious. The banks of the Gulf Stream are cold water. In winter, the volume of cold water on the American, or left side of the stream, is greatly increased. It must have room, and gains it by pressing the warmer waters of the stream farther to the south, or right. In September, the temperature of these cold waters is modified; there is not such an extent of them, and then the warmer waters, in turn, press them back, and so the pendulum-like motion is preserved.

§ 57 Streaks of warm and cold water.

The observations made by the United States Coast Survey indicate that there are in the Gulf Stream threads of warmer, separated by streaks of cooler water. See Plate VI., in which these are shown; they are marked

[1] § 2.

CHAPTER I. *x, y, z.* Figure A may be taken to represent a thermometrical cross section of the stream opposite the Capes of Virginia, for instance; the top of the curve representing the thermometer in the threads of the warmer water, and the depressions the height of the same instrument in the streaks of cooler water between; thus exhibiting, as one sails from America across the Gulf Stream, a remarkable series of thermometrical elevations and depressions in the surface temperature of this mighty river in the sea.

§ 58 These streaks, *x, y, z,* are not found in the Gulf Stream as it issues from its fountain, and I have thought them to be an incident of the process by which the waters of the Stream gradually grow cool. Suppose a perfect calm over this stream, and that all the water on the top of it to the depth of ten feet were suddenly, as it runs along in a winter's day, to be stricken by the wand of some magician, and reduced from the temperature of 75° to that of 32°, the water below the depth of ten feet remaining at 75° as before. How would this cold and heavy water sink? Like a great water-tight floor or field of ice as broad as the Gulf Stream, and loaded to sinking? And how would the warm water rise to the top? By running out under this floor or field, rising up over the edges, and flowing back to the middle? I think not; on the contrary, I suppose the warm water would rise up here and there in streaks, and that the cold would go down in streaks or seams. The process would be not unlike what we see going on in a fountain which is fed by one or more bubbling springs from below. We can see the warm water rising up in a column from the orifice below, and in winter the water

Supposed cause.

on the top first grows cool and then sinks. Now, imagine the fountain to be a long and narrow stream, and this orifice to be a fissure running along at the bottom in the middle of it, and feeding it with warm water. We can well imagine that there would be a seam of water rising up all the way in the middle of the stream, and that a delicate thermometer would, in cold weather, show a marked difference of temperature between the water as it rises up in this seam, and that going down on either side after it has been cooled. Now, if we make our imaginary stream broader, and place at a little distance another fissure parallel with the first, and also supplying warm water, there would be between the two a streak of cooler water descending after having parted with a certain degree of heat at the surface, and thus we would have repeated the ribbons of cold and warm water which the Coast Survey has found in the Gulf Stream. CHAPTER I.

The hottest water in the Gulf Stream is also the lightest; as it rises to the top, it is cooled both by evaporation and exposure, when the surface is replenished by fresh supplies of hot water from below. Thus, in a winter's day, the waters at the surface of the Gulf Stream off Cape Hatteras may be at 80°, and at the depth of five hundred fathoms—three thousand feet—as actual observations show, the thermometer will stand at 57°. Following the stream thence off the Capes of Virginia, one hundred and twenty miles, it will be found—the water-thermometer having been carefully noted all the way—that it now stands a degree or two less at the surface, while all below is cooler. In other words, the stratum of water at 57°, which was three thousand feet § 59

Temperature of Gulf Stream.

3

CHAPTER I. below the surface off Hatteras, has, in a course of one hundred and twenty or one hundred and thirty miles in a horizontal direction, ascended, vertically, six hundred feet; that is, this stratum has run up hill with an ascent of five or six feet to the mile.

§ 60 As a rule, the hottest water of the Gulf Stream is at or near the surface; and as the deep-sea thermometer is sent down, it shows that these waters, though still far warmer than the water on either side at corresponding depths, gradually become less and less warm until the bottom of the current is reached. There is reason to believe that the warm waters of the Gulf Stream are nowhere permitted, in the oceanic economy, to touch the bottom of the sea. There is everywhere a cushion of cool water between them and the solid parts of the earth's crust. This arrangement is suggestive, and strikingly beautiful. One of the benign offices of the Gulf Stream is to convey heat from the Gulf of Mexico, where otherwise it would become excessive, and to dispense it in regions beyond the Atlantic, for the amelioration of the climates of the British Islands and of all Western Europe. Now, cold water is one of the best non-conductors of heat, and if the warm water of the Gulf Stream was sent across the Atlantic in contact with the solid crust of the earth—comparatively a good conductor of heat—instead of being sent across, as it is, in contact with a cool, non-conducting cushion of cool water to fend it from the bottom, all its heat would be lost in the first part of the way, and the soft climates of both France and England would be as that of Labrador, severe in the extreme, and ice-bound.

Its effect on the climate of Western Europe.

CHAPTER II.

INFLUENCE OF THE GULF STREAM UPON CLIMATES.

CHAPTER II. — § 61 Principle of heating apparatus.

MODERN ingenuity has suggested a beautiful mode of warming houses in winter. It is done by means of hot water. The furnace and the caldron are sometimes placed at a distance from the apartments to be warmed. It is so at the Observatory. In this case, pipes are used to conduct the heated water from the caldron under the superintendent's dwelling over into one of the basement rooms of the Observatory, a distance of one hundred feet. These pipes are then flared out so as to present a large cooling surface; after which they are united into one again, through which the water, being now cooled, returns of its own accord to the caldron. Thus cool water is returning all the time and flowing in at the bottom of the caldron, while hot water is continually flowing out at the top.

The ventilation of the Observatory is so arranged that the circulation of the atmosphere through it is led from this basement room, where the pipes are, to all other parts of the building; and in the process of this circulation, CHAPTER II. the warmth conveyed by the water to the basement is taken thence by the air and distributed over all the rooms. Now, to compare small things with great, we have, in the warm waters which are confined in the Gulf of Mexico, just such a heating apparatus for Great Britain, the North Atlantic, and Western Europe.

§ 62 Similarity to the Gulf Stream. The furnace is the torrid zone; the Mexican Gulf and Caribbean Sea are the caldrons; the Gulf Stream is the conducting pipe. From the Grand Banks of Newfoundland to the shores of Europe is the basement—the hot-air chamber—in which this pipe is flared out so as to present a large cooling surface. Here the circulation of the atmosphere is arranged by nature; and it is such, that the warmth thus conveyed into this warm-air chamber of mid-ocean is taken up by the genial west winds, and dispensed, in the most benign manner, throughout Great Britain and the west of Europe.

§ 63 The maximum temperature of the water-heated air-chamber of the Observatory is about 90°. The maximum temperature of the Gulf Stream is 86°, or about 9° above the ocean temperature due the latitude. Increasing its latitude 10°, it loses but 2° of temperature; and, after having run three thousand miles toward the north, it still preserves, even in winter, the heat of summer. With this temperature, it crosses the 40th degree of north latitude, and there, overflowing its liquid banks, it spreads itself out for thousands of square leagues over the cold waters around, and covers the ocean with a mantle of warmth that serves so much to mitigate in Europe the rigours of winter. Moving now more slowly, but dispensing its genial influences more freely, it finally meets

Effect on European climate.

CHAPTER II.

Its effect on the climate of the British Islands.

the British Islands. By these it is divided,[1] one part going into the polar basin of Spitzbergen, the other entering the Bay of Biscay, but each with a warmth considerably above the ocean temperature. Such an immense volume of heated water cannot fail to carry with it beyond the seas a mild and moist atmosphere. And this it is which so much softens climate there.

Calculation.

We know not, except approximately in one or two places, what the depth or the under temperature of the Gulf Stream may be; but *assuming* the temperature and velocity at the depth of two hundred fathoms to be those of the surface, and taking the well-known difference between the capacity of air and of water for specific heat as the argument, a simple calculation will show that the quantity of heat discharged over the Atlantic from the waters of the Gulf Stream in a winter's day, would be sufficient to raise the whole column of atmosphere that rests upon France and the British Islands from the freezing point to summer heat. § 64

West winds affected by it.

Every west wind that blows crosses the stream on its way to Europe, and carries with it a portion of this heat to temper there the northern winds of winter. It is the influence of this stream upon climate that makes Erin the "Emerald Isle of the Sea," and that clothes the shores of Albion in evergreen robes; while in the same latitude, on this side, the coasts of Labrador are fast bound in fetters of ice. In a valuable paper on currents,* Mr. Redfield states that in 1831 the harbour of St. John's, Newfoundland, was closed with ice as late as the month of June; yet who ever heard of the port of Liverpool, on the other

Mr. Redfield's paper on currents.

* American Journal of Science, vol. xiv., p. 293.

[1] Plate IX.

CHAPTER II side, though 2° farther north, being closed with ice even in the dead of winter?

§ 65 Isothermal lines of the Atlantic. The Thermal Chart (Plate IV.) shows this. The isothermal lines of 60°, 50°, &c., starting off from the parallel of 40° near the coasts of the United States, run off in a north-eastwardly direction, showing the same oceanic temperature on the European side of the Atlantic in latitude 55° or 60°, that we have on the western side in latitude 40°. Scott, in one of his beautiful novels, tells us that the ponds in the Orkneys (latitude near 60°) are not frozen in winter. The people there owe their soft climate to this grand heating apparatus, for driftwood from the West Indies is occasionally cast ashore there by the Gulf Stream.

§ 66 Beneficial influence of the Stream on South American climate. Nor do the beneficial influences of this stream upon climate end here. The West Indian Archipelago is encompassed on one side by its chain of islands, and on the other by the Cordilleras of the Andes, contracting with the Isthmus of Darien, and stretching themselves out over the plains of Central America and Mexico. Beginning on the summit of this range, we leave the regions of perpetual snow, and descend first into the *tierra templada,* and then into the *tierra caliente,* or burning land. Descending still lower, we reach both the level and the surface of the Mexican seas, where, were it not for this beautiful and benign system of aqueous circulation, the peculiar features of the surrounding country assure us we should have the hottest, if not the most pestilential climate in the world. As the waters in these two caldrons become heated, they are borne off by the Gulf Stream, and are replaced by cooler currents through the

Caribbean Sea; the surface water, as it enters here, being CHAPTER II.
3° or 4°, and that in depth 40°* cooler than when it escapes from the Gulf. Taking only this difference in surface temperature as an index of the heat accumulated there, a simple calculation will show that the quantity of heat daily carried off by the Gulf Stream from those regions, and discharged over the Atlantic, is sufficient to raise mountains of iron from zero to the melting point, and to keep in flow from them a molten stream of metal greater in volume than the waters daily discharged from the Mississippi River. Who, therefore can calculate the benign influence of this wonderful current upon the climate of the South? In the pursuit of this subject, the mind is led from nature up to the great Architect of nature; and what mind will the study of this subject not fill with profitable emotions? Unchanged and unchanging alone, of all created things, the ocean is the great emblem of its everlasting Creator. "He treadeth upon the waves of the sea," and is seen in the wonders of the deep. Yea, "He calleth for its waters, and poureth them out upon the face of the earth."

In obedience to this call, the aqueous portion of our § 67
planet preserves its beautiful system of circulation. By it heat and warmth are dispensed to the extra-tropical regions; clouds and rain are sent to refresh the dry land; and by it cooling streams are brought from Polar Seas to temper the heat of the torrid zone. At the depth of two hundred and forty fathoms, the temperature

* Temperature of the Caribbean Sea (from the journals of Mr. Dunsterville): Surface temperature: 83°, September; 84°, July; 83°–86½°, Mosquito Coast. Temperature in depth: 48°, 240 fathoms; 43°, 386 fathoms; 42°, 450 fathoms; 43°, 500 fathoms.

CHAPTER II.

Temperature of currents in the Caribbean Sea.

of the currents setting into the Caribbean Sea has been found as low as 48°, while that of the surface was 85°. Another cast with three hundred and eighty-six fathoms gave 43° below against 83° at the surface. The hurricanes of those regions agitate the sea to great depths; that of 1780 tore rocks up from the bottom seven fathoms deep, and cast them ashore. They therefore cannot fail to bring to the surface portions of the cooler water below.

At the bottom of Gulf Stream.

§ 68 At the very bottom of the Gulf Stream, when its surface temperature was 80°, the deep-sea thermometer of the Coast Survey has recorded a temperature as low as 35° Fahrenheit.

Within the Arctic Circle.

§ 69 These cold waters doubtless come down from the north to replace the warm water sent through the Gulf Stream to moderate the cold of Spitzbergen; for within the Arctic Circle the temperature at corresponding depths off the shores of that island is said to be only one degree colder than in the Caribbean Sea, while on the coasts of Labrador, and in the Polar Seas, the temperature of the water beneath the ice was invariably found by Lieutenant De Haven at 28°, or 4° below the melting point of fresh-water ice. Captain Scoresby relates, that on the coast of Greenland, in latitude 72°, the temperature of the air was 42°; of the water, 34°; and 29° at the depth of one hundred and eighteen fathoms. He there found a surface current setting to the south, and bearing with it this extremely cold water, with vast numbers of icebergs, whose centres, perhaps, were far below zero. It would be curious to ascertain the routes of these under currents on their way to the tropical regions, which they are intended to cool. One has been found at the equator[1] two

Labrador and Polar Seas.

Off coast of Greenland.

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[1] § 23.

hundred miles broad, and 23° colder than the surface water. Unless the land or shoals intervene, it no doubt comes down in a spiral curve, approaching in its course the great circle route. CHAPTER II.

§ 70 Currents indicated by fish.

Perhaps the best indication as to these cold currents may be derived from the fish of the sea. The whales first pointed out the existence of the Gulf Stream by avoiding its warm waters. Along our own coasts, all those delicate animals and marine productions which delight in warmer waters are wanting; thus indicating, by their absence, the cold current from the north now known to exist there. In the genial warmth of the sea about the Bermudas on one hand, and Africa on the other, we find in great abundance those delicate shell-fish and coral formations which are altogether wanting in the same latitudes along the shores of South Carolina. The same obtains in the west coast of South America; for there the cold current almost reaches the line before the first sprig of coral is found to grow.

§ 71

A few years ago, great numbers of bonita and albercore—tropical fish—following the Gulf Stream, entered the English Channel, and alarmed the fishermen of Cornwall and Devonshire by the havoc which they created among the pilchards there.

§ 72

It may well be questioned if our Atlantic cities and towns do not owe their excellent fish-markets, as well as our watering-places their refreshing sea-bathing in summer, to this stream of cold water. The temperature of the Mediterranean is 4° or 5° above the ocean temperature of the same latitude, and the fish there are, for the most part, very indifferent. On the other hand, the tem-

CHAPTER II.

perature along our coast is several degrees below that of the ocean, and from Maine to Florida our tables are supplied with the most excellent of fish. The sheep's-head, so much esteemed in Virginia and the Carolinas, when taken on the warm coral banks of the Bahamas, loses its flavour, and is held in no esteem. The same is the case with other fish: when taken in the cold water of that coast, they have a delicious flavour, and are highly esteemed; but when taken in the warm water on the other edge of the Gulf Stream, though but a few miles distant, their flesh is soft, and unfit for the table. The temperature of the water at the Balize reaches 90°. The fish taken there are not to be compared with those of the same latitude in this cold stream. New Orleans, therefore, resorts to the cool waters on the Florida coasts for her choicest fish. The same is the case in the Pacific. A current of cold water[1] from the south sweeps the shores of Chili, Peru, and Columbia, and reaches the Gallipagos Islands under the line. Throughout this whole distance, the world does not afford a more abundant or excellent supply of fish. Yet out in the Pacific, at the Society Islands, where coral abounds, and the water preserves a higher temperature, the fish, though they vie in gorgeousness of colouring with the birds, and plants, and insects of the tropics, are held in no esteem as an article of food. I have known sailors, even after long voyages, still to prefer their salt beef and pork to a mess of fish taken there. The few facts which we have bearing upon this subject seem to suggest it as a point of the inquiry to be made, whether the habitat of certain fish does not indicate the temperature of the water, and whether these

Effects of temperature on fish.

[1] § 455.

cold and warm currents of the ocean do not constitute the great highways through which migratory fishes travel from one region to another. Why should not fish be as much the creatures of climate as plants, or as birds, and other animals of land, sea, and air? Indeed, we know that some kinds of fish are found only in certain climates. In other words, they live where the temperature of the water ranges between certain degrees.

CHAPTER II.

Navigators have often met with vast numbers of young sea-nettles (*medusæ*) drifting along with the Gulf Stream. They are known to constitute the principal food for the whale; but whither bound by this route has caused much speculation, for it is well known that the habits of the right whale are averse to the warm waters of this stream. An intelligent sea-captain informs me that, several years ago, in the Gulf Stream on the coast of Florida, he fell in with such a "school of young sea-nettles as had never before been heard of." The sea was covered with them for many leagues. He likened them, in appearance on the water, to acorns floating on a stream; but they were so thick as to completely cover the sea. He was bound to England, and was five or six days in sailing through them. In about sixty days afterward, on his return, he fell in with the same school off the Western Islands, and here he was three or four days in passing them again. He recognized them as the same, for he had never before seen any like them; and on both occasions he frequently hauled up bucketfuls and examined them. § 73

Sea-nettles

Anecdote

Now, the Western Islands is the great place of resort for whales: and at first there is something curious to us § 74

CHAPTER II. in the idea that the Gulf of Mexico is the harvest-field, and the Gulf Stream the gleaner which collects the fruitage planted there, and conveys it thousands of miles off to the hungry whale at sea. But how perfectly in unison is it with the kind and providential care of that great and good Being which feeds the young ravens when they cry, and caters for the sparrow!

§ 75 Climates of the sea. The sea has its climates as well as the land. They both change with the latitude; but one varies with the elevation above, the other with the depression below the sea level. The climates in each are regulated by circulation; but the regulators are, on the one hand, winds; on the other, currents.

§ 76 The inhabitants of the ocean are as much the creatures of climate as are those of the dry land; for the same Almighty hand which decked the lily and cares for the sparrow, fashioned also the pearl and feeds the great whale, and adapted each to the physical conditions by which his providence has surrounded it. Whether of the land or the sea, the inhabitants are all his creatures, Offices of the sea. subjects of his laws, and agents in his economy. The sea, therefore, we may safely infer, has its offices and duties to perform; so, may we infer, have its currents, and so, too, its inhabitants; consequently, he who undertakes to study its phenomena must cease to regard it as a waste of waters. He must look upon it as a part of that exquisite machinery by which the harmonies of nature are preserved, and then he will begin to perceive the developments of order and the evidences of design; these make it a most beautiful and interesting subject for contemplation.

§ 77 To one who has never studied the mechanism of a watch, its main-spring or the balance-wheel is a mere piece of metal. He may have looked at the face of the watch, and, while he admires the motion of its hands, and the time it keeps, or the tune it plays, he may have wondered in idle amazement as to the character of the machinery which is concealed within. Take it to pieces, and show him each part separately, he will recognize neither design, nor adaptation, nor relation between them; but put them together, set them to work, point out the offices of each spring, wheel, and cog, explain their movements, and then show him the result; now he perceives that it is all *one* design; that, notwithstanding the number of parts, their diverse forms and various offices, and the agents concerned, the whole piece is of *one* thought, the expression of *one* idea. He now rightly concludes that when the main-spring was fashioned and tempered, its relation to all the other parts must have been considered; that the cogs on this wheel are cut and regulated—*adapted*—to the rachets on that, &c.; and his final conclusion will be, that such a piece of mechanism could not have been produced by chance; for the adaptation of the parts is such as to show it to be according to design, and obedient to the will of *one* intelligence. So, too, when one looks out upon the face of this beautiful world, he may admire its lovely scenery, but his admiration can never grow into adoration unless he will take the trouble to look behind and study, in some of its details at least, the exquisite system of machinery by which such beautiful results are brought about. To him who does this, the sea, with its physical geography, becomes as the main-

Reflections.

CHAPTER II. spring of a watch; its waters, and its currents, and its salts, and its inhabitants, with their adaptations, as balance-wheels, cogs and pinions, and jewels. Thus he perceives that they, too, are according to design; that they are the expression of One Thought, a unity with harmonies which One Intelligence, and One Intelligence alone, could utter. And when he has arrived at this point, then he feels that the study of the sea, in its physical aspect, is truly sublime. It elevates the mind and ennobles the man. The Gulf Stream is now no longer, therefore, to be regarded by such an one merely as an immense current of warm water running across the ocean, but as a balance-wheel—a part of that grand machinery by which air and water are adapted to each other, and by which this earth itself is adapted to the well-being of its inhabitants—of the flora which decks, and the fauna which enlivens its surface.

§ 78 Let us now consider the influence of the Gulf Stream upon the meteorology of the ocean.

Influence of the Gulf Stream on the meteorology of the sea.

To use a sailor expression, the Gulf Stream is the great "weather breeder" of the North Atlantic Ocean. The most furious gales of wind sweep along with it; and the fogs of Newfoundland, which so much endanger navigation in winter, doubtless owe their existence to the presence, in that cold sea, of immense volumes of warm water brought by the Gulf Stream. Sir Philip Brooke found the air on each side of it at the freezing point, while that of its waters was 80°. "The heavy, warm, damp air over the current produced great irregularities in his chronometers." The excess of heat daily brought into such a region by the waters of the Gulf Stream would, if suddenly stricken from them, be sufficient to make the column of superincumbent atmosphere hotter than melted iron. CHAPTER II.

§ 79 Its liability to storms.

With such an element of atmospherical disturbance in its bosom, we might expect storms of the most violent kind to accompany it in its course. Accordingly, the most terrific that rage on the ocean have been known to spend their fury within or near its borders.

§ 80

Our nautical works tell us of a storm which forced this stream back to its sources, and piled up the water in the Gulf to the height of thirty feet. The Ledbury Snow attempted to ride it out. When it abated, she found herself high up on the dry land, and discovered that she had let go her anchor among the tree-tops on Elliott's Key. The Florida Keys were inundated many feet; and, it is said, the scene presented in the Gulf Stream was never surpassed in awful sublimity on the ocean. The water thus dammed up is said to have rushed out with wonderful velocity against the fury of the gale, producing a sea that beggared description.

§ 81 Great hurricane of 1780.

The "great hurricane" of 1780 commenced at Barbadoes. In it the bark was blown from the trees, and the fruits of the earth destroyed; the very bottom and depths of the sea were uprooted, and the waves rose to such a height that forts and castles were washed away, and their great guns carried about in the air like chaff; nouses were razed, ships were wrecked, and the bodies of men and beasts lifted up in the air and dashed to pieces in the storm. At the different islands, not less than twenty thousand persons lost their lives on shore; while farther to the north, the "Stirling Castle" and the "Dover

CHAPTER II. Castle" men-of-war went down at sea, and fifty sail were driven on shore at the Bermudas.

§ 82 British Admiralty investigation. Several years ago, the British Admiralty set on foot inquiries as to the cause of the storms in certain parts of the Atlantic, which so often rage with diastrous effects to navigation. The result may be summed up in the conclusion to which the investigation led: that they are occasioned by the irregularity between the temperature of the Gulf Stream and of the neighbouring regions, both in the air and water.

§ 83 Dampness of English climate due to the Gulf Stream. The habitual dampness of the climate of the British Islands, as well as the occasional dampness of that along the Atlantic coasts of the United States when easterly winds prevail, is attributable also to the Gulf Stream. These winds come to us loaded with vapours gathered from its warm and smoking waters. The Gulf Stream carries the temperature of summer, even in the dead of winter, as far north as the Grand Banks of Newfoundland.

§ 84 One of the poles of maximum cold is, according to theory, situated in latitude 80° north, longitude 100° west. It is distant but little more than two thousand miles, in a north-westwardly direction, from the summer-heated waters of this stream. This proximity of extremes of greatest cold and summer heat will, as observations are multiplied and discussed, be probably found to have much to do with the storms that rage with such fury on the left side of the Gulf Stream.

§ 85 I am not prepared to maintain that the Gulf Stream is really the "Storm King" of the Atlantic, which has power to control the march of every gale that is raised there; but the course of many gales has been traced from the place of their origin directly to the Gulf Stream. Gales that take their rise on the coast of Africa, and even as far down on that side as the parallel of 10° or 15° north latitude, have, it has been shown by an examination of log-books, made straight for the Gulf Stream; joining it, they have then been known to turn about, and, travelling with this stream, to recross the Atlantic, and so reach the shores of Europe. In this way the tracks of storms have been traced out and followed for a week or ten days. Their path is marked by wreck and disaster.

CHAPTER II.

Its influence on storms.

Plate X. was prepared by Lieutenant B. S. Porter, from data furnished by the log-books at the Observatory. It represents one of these storms that commenced in August 1848. It commenced more than a thousand miles from the Gulf Stream, made a straight course for it, and travelled with it for many days. § 86

The dark shading shows the space covered by the gale, and the white line in the middle shows the axis of the gale, or the line of minimum barometric pressure. There are many other instances of similar gales. Professor Espy informs us that he also has traced many a gale from the land out toward the Gulf Stream.

Now, what should attract these terrific storms to the Gulf Stream? Sailors dread storms in the Gulf Stream more than they do in any other part of the ocean. It is not the fury of the storm alone that they dread, but it is the "ugly sea" which these storms raise. The current of the stream running in one direction, and the wind blowing in another, creates a sea that is often frightful. § 87

In the month of December 1853, the fine new steam ship San Francisco sailed from New York with a regiment of United States troops on board, bound around Cape Horn for California. She was overtaken, while crossing the Gulf Stream, by a gale of wind, in which § 88

Wreck of the San Francisco.

CHAPTER II. she was dreadfully crippled. Her decks were swept, and by one single blow of those terrible seas that the storms there raise, one hundred and seventy-nine souls, officers and soldiers, were washed overboard and drowned.

The day after this disaster she was seen by one vessel, and again the next day, December 26th, by another, but neither of them could render her any assistance.

Apprehensions for those on board.

When these two vessels arrived in the United States, and reported what they had seen, the most painful apprehensions were entertained by friends for the safety of those on board the steamer. Vessels were sent out to search for and relieve her. But which way should these vessels go? Where should they look?

An appeal was made to know what light the system of researches carried on at the National Observatory concerning winds and currents could throw upon the subject.

§ 89 The materials that had been discussed were examined, and a chart was prepared to show the course of the Gulf Stream at that season of the year. (See the limits of the Gulf Stream for March, Plate VI.) Upon the supposition that the steamer had been completely disabled, the lines *a b* were drawn to define the limits of her drift. Between these two lines, it was said, the steamer, if she could neither steam nor sail after the gale, had drifted.

§ 90 By request, I prepared instructions for two revenue cutters that were sent to search for her. One of them being at New London, was told to go along the dotted track leading to *c*, expecting thereby to keep inside of the line along which the steamer had drifted, with the view of intercepting and speaking homeward-bound vessels that might have seen the wreck.

Search made for her.

CHAPTER II. § 91

The cutter was to proceed to *c*, where she might expect to fall in with the line of drift taken by the steamer. The last that was seen of that ill-fated vessel was when she was at *o*, but a few miles from *c*. So, if the cutter had been in time, she had instructions that would have taken her in sight of the object of her search.

§ 92 It is true that, before the cutter sailed, the Kilby, the Three Bells, and the Antarctic, unknown to anxious friends at home, had fallen in with and relieved the wreck; but that does not detract from the system of observations, of the results of which, and their practical application, it is the object of this work to treat.

§ 93 A beautiful illustration of their usefulness is the fact that, though the bark Kilby lost sight of the wreck at night, and the next morning did not know which way to look for it, and could not find it, yet, by a system of philosophical deduction, we on shore could point out the whereabouts of the disabled steamer so closely, that vessels could be directed to look for her exactly where she was to be seen.

§ 94 Whirlwinds.

These storms, for which the Gulf Stream has such attraction, and over which it seems to exercise so much control, are said to be, for the most part, whirlwinds. All boys are familiar with miniature whirlwinds on shore. They are seen, especially in the autumn, sweeping along the roads and streets, raising columns of dust, leaves, &c., which rise up like inverted cones in the air, and gyrate about the centre or axis of the storm. Thus, while the axis, and the dust, and the leaves, and all those things which mark the course of the whirlwind, are travelling in one direction, it may be seen that the wind is blowing around this axis in all directions.

CHAPTER II.

Cyclones.

Just so with some of these Gulf Stream storms. That represented on Plate X. is such a one. It was a rotary storm. Mr. Piddington, an eminent meteorologist of Calcutta, calls them *Cyclones.*

§ 95 Now, what should make these storms travel toward the Gulf Stream, and then, joining it, travel along with its current? It is the high temperature of its waters, say mariners. But why, or wherefore, should the spirits of the storm obey in this manner the influence of these high temperatures, philosophers have not been able to explain.

§ 96 *The influence of the Gulf Stream upon commerce and navigation.*

Influence of Gulf Stream on commerce and navigation.

Formerly the Gulf Stream controlled commerce across the Atlantic by governing vessels in their routes through this ocean to a greater extent than it does now, and simply for the reason that ships are faster, nautical instruments better, and navigators are more skilful now than formerly they were.

§ 97

Improvements in navigation

Up to the close of the last century, the navigator *guessed* as much as he *calculated* the place of his ship: vessels from Europe to Boston frequently made New York, and thought the landfall by no means bad. Chronometers, now so accurate, were then an experiment. The Nautical Ephemeris itself was faulty, and gave tables which involved errors of thirty miles in the longitude. The instruments of navigation erred by *degrees* quite as much as they now do by *minutes;* for the rude "cross staff" and "back staff," the "sea-ring" and "mariner's bow," had not yet given place to the nicer sextant and circle of reflection of the present day. Instances are numerous of vessels navigating the Atlantic in those times being 6°, 8°, and even 10° of longitude out of their reckoning in as many days from port. CHAPTER II.

§ 98 Gulf Stream a means of finding longitude

Though navigators had been in the habit of crossing and recrossing the Gulf Stream almost daily for three centuries, it never occurred to them to make use of it as a means of giving them their longitude, and of warning them of their approach to the shores of this continent.

§ 99 Dr. Franklin the first to suggest this.

Dr. Franklin was the first to suggest this use of it. The contrast afforded by the temperature of its waters and that of the sea between the Stream and the shores of America was striking. The dividing line between the warm and the cool waters was sharp;[1] and this dividing line, especially that on the western side of the stream, never changed its position as much in longitude as mariners erred in their reckoning.

§ 100

When he was in London in 1770, he happened to be consulted as to a memorial which the Board of Customs at Boston sent to the Lcrds of the Treasury, stating that the Falmouth packets were generally a fortnight longer to Boston than common traders were from London to Providence, Rhode Island. They therefore asked that the Falmouth packets might be sent to Providence instead of to Boston. This appeared strange to the doctor, for London was much farther than Falmouth, and from Falmouth the routes were the same, and the difference should have been the other way. He, however, consulted Captain Folger, a Nantucket whaler, who chanced to be in London also; the fisherman explained to him that the difference arose from the circumstance that the Rhode Island captains were acquainted with the Gulf Stream, while those of the English packets were

Results of a knowledge of the Gulf Stream.

[1] § 2.

CHAPTER II.

not. The latter kept in it, and were set back sixty or seventy miles a day, while the former avoided it altogether. He had been made acquainted with it by the whales which were found on either side of it, but never in it.[1] At the request of the doctor, he then traced on a chart the course of this stream from the Straits of Florida. The doctor had it engraved at Tower Hill, and sent copies of it to the Falmouth captains, who paid no attention to it. The course of the Gulf Stream, as laid down by that fisherman from his general recollection of it, has been retained and quoted on the charts for navigation, we may say, until the present day.

Chart of its course by a fisherman.

But the investigations of which we are treating are beginning to throw more light upon this subject; they are giving us more correct knowledge in every respect with regard to it, and to many other new and striking features in the physical geography of the sea.

§ 101 No part of the world affords a more difficult or dangerous navigation than the approaches of our northern coast in winter. Before the warmth of the Gulf Stream was known, a voyage at this season from Europe to New England, New York, and even to the Capes of the Delaware or Chesapeake, was many times more trying, difficult, and dangerous than it now is. In making this part of the coast, vessels are frequently met by snow-storms and gales which mock the seaman's strength, and set at naught his skill. In a little while his bark becomes a mass of ice; with her crew frosted and helpless, she remains obedient only to her helm, and is kept away for the Gulf Stream. After a few hours' run, she reaches its edge, and almost at the next bound passes from the

Dangerous navigation of our north coasts.

Snow-storms

[1] § 70.

midst of winter into a sea at summer heat. Now the ice disappears from her apparel; the sailor bathes his stiffened limbs in tepid waters; feeling himself invigorated and refreshed with the genial warmth about him, he realizes, out there at sea, the fable of Antæus and his mother Earth. He rises up and attempts to make his port again, and is again, perhaps, as rudely met and beat back from the north-west; but each time that he is driven off from the contest, he comes forth from this stream, like the ancient son of Neptune, stronger and stronger, until, after many days, his freshened strength prevails, and he at last triumphs and enters his haven in safety, though in this contest he sometimes falls to rise no more, for it is often terrible. Many ships annually founder in these gales; and I might name instances, for they are not uncommon, in which vessels bound to Norfolk or Baltimore, with their crews enervated in tropical climates, have encountered, as far down as the Capes of Virginia, snow-storms that have driven them back into the Gulf Stream time and again, and have kept them out for forty, fifty, and even for sixty days, trying to make an anchorage.

CHAPTER II. — Sudden change.

§ 102 — The warm waters of the Stream a boon to navigation

Nevertheless, the presence of the warm waters of the Gulf Stream, with their summer heat in mid-winter, off the shores of New England, is a great boon to navigation. At this season of the year especially, the number of wrecks and the loss of life along the Atlantic sea-front are frightful. The month's average of wrecks has been as high as three a day. How many escape by seeking refuge from the cold in the warm waters of the Gulf Stream is matter of conjecture. Suffice it to say, that before their temperature

CHAPTER II. was known, vessels thus distressed knew of no place of refuge short of the West Indies; and the newspapers of that day—Franklin's Pennsylvania Gazette among them—inform us that it was no uncommon occurrence for vessels, bound for the Capes of the Delaware in winter, to be blown off and to go to the West Indies, and there wait for the return of spring before they would attempt another approach to this part of the coast.

§ 103 Importance of Dr. Franklin's discovery. Accordingly, Dr. Franklin's discovery with regard to the Gulf Stream temperature was looked upon as one of great importance, not only on account of its affording to the frosted mariner in winter a convenient refuge from the snow-storm, but because of its serving the navigator with an excellent land-mark or beacon for our coast in all weathers. And so viewing it, the doctor, through political considerations, concealed his discovery for a while. It was then not uncommon for vessels to be as much as 10° out in their reckoning. He himself was 5°. The prize of £20,000, which had been offered, and partly paid to Harrison, the chronometer maker, for improving the means of finding longitude at sea, was fresh in the minds of navigators. And here it was thought a solution of the grand problem—for longitude at sea was a grand problem—had been stumbled upon by chance; for, on approaching the coast, the current of warm water in the Gulf Stream, and of cold water on this side of it, if tried with the thermometer, would enable the mariner to judge with great certainty, and in the worst of weather, as to his position. Jonathan Williams afterward, in speaking of the importance which the discovery of these warm and cold currents would prove to navigation, pertinently asked the question, "If these stripes of water had been distinguished by the colours of red, white, and blue, could they be more distinctly discovered than they are by the constant use of the thermometer?" And he might have added, could they have marked the position of the ship more clearly?

§ 104

Commodore Truxton's opinion of the thermometer.

When his work on Thermometrical Navigation appeared, Commodore Truxton wrote to him: "Your publication will be of use to navigation, by rendering sea voyages secure far beyond what even you yourself will immediately calculate, for I have proved the utility of the thermometer very often since we sailed together.

"It will be found a most valuable instrument in the hands of mariners, and particularly as to those who are unacquainted with astronomical observations; . . . . . these particularly stand in need of a simple method of ascertaining the approach to or distance from the coast, especially in the winter season; for it is then that passages are often prolonged, and ships blown off the coast by hard westerly winds, and vessels get into the Gulf Stream without its being known; on which account they are often hove to by the captains' supposing themselves near the coast when they are very far off (having been drifted by the currents). On the other hand, ships are often cast on the coast by sailing in the eddy of the Stream, which causes them to outrun their common reckoning. Every year produces new proofs of these facts, and of the calamities incident thereto."

§ 105

Though Dr. Franklin's discovery was made in 1775, yet, for political reasons, it was not generally made known till 1790. Its immediate effect in navigation was to

CHAPTER II.

Effect of Dr. Franklin's discovery on navigation

make the ports of the North as accessible in winter as in summer. What agency this circumstance had in the decline of the direct trade of the South, which followed this discovery, would be, at least to the political economist, a subject for much curious and interesting speculation. I have referred to the commercial tables of the time, and have compared the trade of Charleston with that of the northern cities for several years, both before and after the discovery of Dr. Franklin became generally known to navigators. The comparison shows an immediate decline in the Southern trade, and a wonderful increase in that of the North. But whether this discovery in navigation, and this revolution in trade, stand in the relation of cause and effect, or be merely a coincidence, let others judge.

Decline of the Southern trade.

§ 106 In 1769, the commerce of the two Carolinas equalled that of all the New England States together; it was more than double that of New York, and exceeded that of Pennsylvania by one-third.* In 1792, the exports from New York amounted in value to two millions and

* *From M'Pherson's Annals of Commerce.—Exports and Imports in* 1769, *valued in Sterling Money.*

EXPORTS.

	To Gr. Britain.			So. of Europe.			West Indies.			Africa.			Total.		
	£	*s.*	*d.*	£	*s.*	*d.*	£	*s.*	*d.*	£	*s.*	*d.*	£	*s.*	*d.*
New England.....	142,775	12	9	81,173	16	2	308,427	9	6	17,713	0	9	550,089	19	2
New York.........	113,382	8	8	50,885	13	0	66,324	17	5	1,313	2	6	231,906	1	7
Pennsylvania.....	28,112	6	9	203,762	11	11	178,331	7	8	560	9	9	410,756	16	1
North and South Carolina.........	405,014	13	1	76,119	12	10	87,758	19	3	691	12	1	569,584	17	3
IMPORTS.															
New England.....	223,695	11	6	25,408	17	9	314,749	14	5	180	0	0	564,034	3	8
New York.........	75,930	19	7	14,927	7	0	897,420	4	0	697	10	0	188,976	1	3
Pennsylvania.....	204,979	17	4	14,249	8	4	180,591	12	4				399,830	18	0
North and South Carolina.........	327,084	8	6	7,099	5	10	76,269	17	11	137,620	10	0	535,714	2	3

a half; from Pennsylvania to 3,820,000 dollars; and from Charleston alone to 3,834,000 dollars. CHAPTER II.

§ 107 Increase of the Northern trade. But in 1795—by which time the Gulf Stream began to be as well understood by navigators as it now is, and the average passages from Europe to the North were shortened nearly one-half, while those to the South remained about the same—the customs at Philadelphia alone amounted to 2,941,000 dollars,* or more than one-half of those collected in all the states together.

§ 108 Further effects of the discovery. Nor did the effect of the doctor's discovery end here. Before it was made, the Gulf Stream was altogether insidious in its effects. By it vessels were often drifted many miles out of their course without knowing it; and in bad and cloudy weather, when many days would intervene from one observation to another, the set of the current, though really felt for but a few hours during the interval, could only be proportioned out equally among the whole number of days. Therefore navigators could have only very vague ideas either as to the strength or the actual limits of the Gulf Stream, until they were marked out to

* *Value of Exports in Dollars.*[1]

	1791.	1792.	1793.	1794.	1795.	1796.
Massachusetts	2,519,651	2,888,104	3,755,347	5,292,441	7,117,907	9,949,345
New York	2,505,465	2,535,790	2,932,370	5,442,000	10,304,000	12,208,027
Pennsylvania	3,436,000	3,820,000	6,958,000	6,643,000	11,518,000	17,513,866
South Carolina	2,693,000	2,428,000	3,191,000	3,868,000	5,998,000	7,620,000

Duties on Imports in Dollars.

	1791.	1792.	1793.	1794.	1795.	1796.	1833.
Massachusetts	1,006,000	723,000	1,044,000	1,121,000	1,520,000	1,460,000	3,055,000
New York	1,334,000	1,173,000	1,204,000	1,878,000	2,028,000	2,187,000	10,713,000
Pennsylvania	1,466,000	1,100,000	1,823,000	1,498,000	2,300,000	2,050,000	2,207,000
South Carolina	523,000	359,000	360,000	661,000	722,000	66,000	389,000

[1] Doc. No. 330, H. R., 2d Session, 25th Congress. Some of its statements do not agree with those taken from M'Pherson, and previously quoted.

CHAPTER II. the Nantucket fishermen by the whales, or made known by Captain Folger to Dr. Franklin. The discovery, therefore, of its high temperature assured the navigator of the presence of a current of surprising velocity, and which, now turned to certain account, would hasten, as it had retarded his voyage in a wonderful degree.

§ 109 Improvement of nautical tables and instruments. Such, at the present day, is the degree of perfection to which nautical tables and instruments have been brought, that the navigator may now detect, and with great certainty, every current that thwarts his way. He makes great use of them. Colonel Sabine, in his passage, a few years ago, from Sierra Leone to New York, was drifted one thousand six hundred miles of his way by the force of currents alone; and, since the application of the thermometer to the Gulf Stream, the average passage from England has been reduced from upwards of eight weeks to a little more than four.

§ 110 Decline of Southern commerce ascribed to legislation. Some political economists of America have ascribed the great decline of Southern commerce which followed the adoption of the Constitution of the United States to the protection given by legislation to Northern interests. Author's opinion. But I think these statements and figures show that this decline was in no small degree owing to the Gulf Stream and the water thermometer; for they changed the relations of Charleston—the great Southern emporium of the times—removing it from its position as a half-way house, and placing it in the category of an outside station.

§ 111 Necessity for a knowledge of the winds. The plan of our work takes us necessarily into the air, for the sea derives from the winds some of the most striking features in its physical geography. Without a knowledge of the winds, we can neither understand the navigation of the ocean, nor make ourselves intelligently acquainted with the great highways across it. As with the land, so with the sea; some parts of it are as untravelled and as unknown as the great Amazonian wilderness of Brazil, or the inland basins of Central Africa. To the south of a line extending from Cape Horn to the Cape of Good Hope[1] is an immense waste of waters. None of the commercial thoroughfares of the ocean lead through it; only the adventurous whaleman finds his way there now and then in pursuit of his game; but for all the purposes of science and navigation, it is a vast unknown region. Now, were the prevailing winds of the South Atlantic northerly or southerly, instead of easterly or westerly, this unploughed sea would be an oft-used thoroughfare.

Nay, more, the sea supplies the winds with food for the rain which these busy messengers convey away from the ocean to "the springs in the valleys which run among the hills." To the philosopher the places which supply the vapours are as suggestive and as interesting for the instruction they afford, as the places are upon which the vapours are showered down. Therefore, as he who studies the physical geography of the land is expected to make himself acquainted with the regions of precipitation, so he who looks into the physical geography of the sea should search for the regions of evaporation, and for those springs in the ocean which supply the reservoirs among the mountains with water to feed the rivers; and, in order to conduct this search properly, he must consult the winds, and make himself acquainted with their "circuits." Hence, in a work on the Physical Geography of the Sea, we treat also of the ATMOSPHERE. § 112

How this subject ought to be studied

[1] Plate VIII.

CHAPTER III.

THE ATMOSPHERE.

CHAPTER III. — § 113 The Atmosphere.

A PHILOSOPHER of the East,* with a richness of imagery truly Oriental, describes the atmosphere as "a spherical shell which surrounds our planet to a depth which is unknown to us, by reason of its growing tenuity, as it is released from the pressure of its own superincumbent mass. Its upper surface cannot be nearer to us than fifty, and can scarcely be more remote than five hundred miles. It surrounds us on all sides, yet we see it not; it presses on us with a load of fifteen pounds on every square inch of surface of our bodies, or from seventy to one hundred tons on us in all, yet we do not so much as feel its weight. Softer than the softest down—more impalpable than the finest gossamer—it leaves the cobweb undisturbed, and scarcely stirs the lightest flower that feeds on the dew it supplies; yet it bears the fleets of nations on its wings around the world, and crushes

* Dr. Buist, of Bombay.

CHAPTER III.

Beautifully described.

the most refractory substances with its weight. When in motion, its force is sufficient to level the most stately forests and stable buildings with the earth—to raise the waters of the ocean into ridges like mountains, and dash the strongest ships to pieces like toys. It warms and cools by turns the earth and the living creatures that inhabit it. It draws up vapours from the sea and land, retains them dissolved in itself, or suspended in cisterns of clouds, and throws them down again as rain or dew when they are required. It bends the rays of the sun from their path, to give us the twilight of evening and of dawn; it disperses and refracts their various tints to beautify the approach and the retreat of the orb of day. But for the atmosphere, sunshine would burst on us and fail us at once, and at once remove us from midnight darkness to the blaze of noon. We should have no twilight to soften and beautify the landscape; no clouds to shade us from the scorching heat, but the bald earth, as it revolved on its axis, would turn its tanned and weakened front to the full and unmitigated rays of the lord of day. It affords the gas which vivifies and warms our frames, and receives into itself that which has been polluted by use, and is thrown off as noxious. It feeds the flame of life exactly as it does that of the fire—it is in both cases consumed, and affords the food of consumption—in both cases it becomes combined with charcoal, which requires it for combustion, and is removed by it when this is over."

"It is only the girdling encircling air," says another philosopher,* "that flows above and around all, that § 114

* *Vide* North British Review.

CHAPTER III.

Its use to the whole world.

makes the whole world kin. The carbonic acid with which to-day our breathing fills the air, to-morrow seeks its way round the world. The date-trees that grow round the falls of the Nile will drink it in by their leaves; the cedars of Lebanon will take of it to add to their stature; the cocoa-nuts of Tahiti will grow rapidly upon it, and the palms and bananas of Japan will change it into flowers. The oxygen we are breathing was distilled for us some short time ago by the magnolias of the Susquehanna, and the great trees that skirt the Orinoco and the Amazon—the giant rhododendrons of the Himalayas contributed to it, and the roses and myrtles of Cashmere, the cinnamon-tree of Ceylon, and the forest older than the flood, buried deep in the heart of Africa, far behind the Mountains of the Moon. The rain we see descending was thawed for us out of the icebergs which have watched the polar star for ages, and the lotus lilies have soaked up from the Nile, and exhaled as vapour, snows that rested on the summits of the Alps."

As food of animals.

§ 115 "The atmosphere," continues Maun, "which forms the outer surface of the habitable world, is a vast reservoir, into which the supply of food designed for living creatures is thrown; or, in one word, it is itself the food, in its simpie form, of all living creatures. The animal grinds down the fibre and the tissue of the plant, or the nutritious store that has been laid up within its cells, and converts these into the substance of which its own organs are composed. The plant acquires the organs and nutritious store thus yielded up as food to the animal, from the invulnerable air surrounding it."

§ 116 "But animals are furnished with the means of locomotion and of seizure—they can approach their food, and lay hold of and swallow it; plants must wait till their food comes to them. No solid particles find access to their frames; the restless ambient air which rushes past them loaded with the carbon, the hydrogen, the oxygen, the water—everything they need in the shape of supplies, is constantly at hand to minister to their wants, not only to afford them food in due season, but in the shape and fashion in which alone it can avail them." CHAPTER III. Of plants.

There is no employment more ennobling to man and his intellect than to trace the evidences of design and purpose in the Creator, which are visible in many parts of the creation. Hence, to the right-minded mariner, and to him who studies the physical relations of earth, sea, and air, the atmosphere is something more than a shoreless ocean, at the bottom of which he creeps along. It is an envelope or covering for the dispersion of light and heat over the surface of the earth; it is a sewer into which, with every breath we draw, we cast vast quantities of dead animal matter; it is a laboratory for purification, in which that matter is recompounded, and wrought again into wholesome and healthful shapes; it is a machine[1] for pumping up all the rivers from the sea, and conveying the waters for their fountains on the ocean to their sources in the mountains; it is an inexhaustible magazine, marvellously adapted for many benign and beneficent purposes. § 117 General uses.

Upon the proper working of this machine depends the well-being of every plant and animal that inhabits the earth; therefore the management of it, its movements, and the performance of its offices, cannot be left to § 118

[1] § 112.

CHAPTER III. chance. They are, we may rely upon it, guided by laws that make all parts, functions, and movements of the machinery as obedient to order and as harmonious as are the planets in their orbits.

§ 119 *Order in sea and air* An examination into the economy of the universe will be sufficient to satisfy the well-balanced minds of observant men, that the laws which govern the atmosphere and the laws which govern the ocean[1] are laws which were put in force by the Creator when the foundations of the earth were laid, and that therefore they are laws of order; else, why should the Gulf Stream, for instance, be always where it is, and running from the Gulf of Mexico, and not somewhere else, and sometimes running into it? Why should there be a perpetual drought in one part of the world, and continual showers in another? Or why should the winds and "waves of the sea ever clap their hands with joy," or obey the voice of rebuke?

§ 120 *Language of Nature.* To one who looks abroad to contemplate the agents of nature, as he sees them at work upon our planet, no expression uttered nor act performed by them is without meaning. By such an one, the wind and rain, the vapour and the cloud, the tide, the current, the saltness, and depth, and warmth, and colour of the sea, the shade of the sky, the temperature of the air, the tint and shape of the clouds, the height of the tree on the shore, the size of its leaves, the brilliancy of its flowers—each and all may be regarded as the exponent of certain physical combinations, and therefore as the expression in which Nature chooses to announce her own doings, or, if we please, as the language in which she writes down or chooses to make known her own laws. To understand

[1] § 76.

that language and to interpret aright those laws is the object of the undertaking which we now have in hand. No fact gathered in such a field as the one before us can therefore come amiss to those who tread the walks of inductive philosophy; for, in the hand-book of nature, every such fact is a syllable; and it is by patiently collecting fact after fact, and by joining together syllable after syllable, that we may finally seek to read aright from the great volume which the mariner at sea as well as the philosopher on the mountain each sees spread out before him.

CHAPTER III.

OF ITS CIRCULATION.—We have seen[1] that there are constant currents in the ocean; we shall now see that there are also regular currents in the atmosphere. § 121

From the parallel of about 30° north and south, nearly to the equator, we have, extending entirely around the earth, two zones of perpetual winds, namely, the zone of north-east trades on this side, and of south-east on that. With slight interruptions, they blow perpetually, and are as steady and as constant as the currents of the Mississippi River, always moving in the same direction (Plate I.) except when they are turned aside by a desert here and there to blow as monsoons, or as land and sea breezes. As these two main currents of air are constantly flowing from the poles toward the equator, we are safe in assuming that the air which they keep in motion must return by some channel to the place toward the poles whence it came in order to supply the trades. If this were not so, these winds would soon exhaust the Polar regions of atmosphere, and pile it up about the equator, and then cease to blow for the want of air to make more wind of. § 122

The trade winds.

[1] § 31.

CHAPTER III.

§ 123 This return current, therefore, must be in the upper regions of the atmosphere, at least until it passes over those parallels between which the trade-winds are always blowing on the surface. The return current must also move in the direction opposite to that wind the place of which it is intended to supply. These direct and counter currents are also made to move in a sort of spiral or loxodromic curve, turning to the west as they go from the poles to the equator, and in the opposite direction as they move from the equator toward the poles. This turning is caused by the rotation of the earth on its axis.

Their currents.

§ 124 The earth, we know, moves from west to east. Now, if we imagine a particle of atmosphere at the north pole, where it is at rest, to be put in motion in a straight line toward the equator, we can easily see how this particle of air, coming from the very axis of diurnal rotation, where it did not partake of the diurnal motion of the earth, would, in consequence of its *vis inertiæ*, find, as it travels south, the earth slipping from under it, as it were, and thus it would appear to be coming from the north-east and going toward the south-west; in other words, it would be a north-east wind.

Cause of north-east wind.

§ 125 The better to explain, let us take a common terrestrial globe for the illustration. Bring the island of Madeira, or any other place about the same parallel, under the brazen meridian; put a finger of the left hand on the place; then, moving the finger down along the meridian to the south, to represent the particle of air, turn the globe on its axis from west to east, to represent the diurnal rotation of the earth, and when the finger reaches the equator, stop. It will now be seen that the place on the

Illustration.

globe under the finger is to the southward and westward of the place from which the finger started; in other words, the track of the finger over the surface of the globe, like the track of the particle of air upon the earth, has been from the northward and eastward. CHAPTER III.

On the other hand, we can perceive how a like particle of atmosphere that starts from the equator, to take the place of the other at the pole, would, as it travels north, in consequence of its *vis inertiæ*, be going toward the east faster than the earth. It would therefore appear to be blowing from the south-west, and going toward the north-east, and exactly in the opposite direction to the other. Writing south for north, the same takes place between the south pole and the equator. § 126 Cause of south-west wind.

Such is the process which is actually going on in nature; and if we take the motions of these two particles as the type of the motion of all, we shall have an illustration of the great currents in the air, the equator being near one of the nodes, and there being at least two systems of currents, an upper and an under, between it and each pole. § 127 Two systems of currents.

Halley, in his theory of the trade-winds, pointed out the key to the explanation so far, of the atmospherical circulation; but, were the explanation to rest here, a north-east trade-wind extending from the pole to the equator would satisfy it; and were this so, we should have, on the surface, no winds but the north-east trade-winds on this side, and none but south-east trade-winds on the other side, of the equator. § 128 Halley's theory not conclusive.

Let us return now to our northern particle (Plate I.), and follow it in a round from the north pole across the § 129 Theory.

CHAPTER III. equator to the south pole, and back again. Setting off from the polar regions, this particle of air, for some reason which does not appear to have been very satisfactorily explained by philosophers, instead of travelling[1] on the surface all the way from the pole to the equator, travels in the upper regions of the atmosphere until it gets near the parallel of 30°. Here it meets, also in the clouds, the hypothetical particle that is coming from the south, and going north to take its place.

§ 130 Cause of calm. About this parallel of 30° north, then, these two particles press against each other with the whole amount of their motive power, and produce a calm and an accumulation of atmosphere: this accumulation is sufficient to balance the pressure of the two winds from the north and south.

§ 131 Calms of Cancer. From under this bank of calms, which seamen call the "horse lattitudes" (I have called them the calms of Cancer), two surface currents of wind are ejected; one toward the equator, as the north-east trades, the other toward the pole, as the south-west passage-winds.

§ 132 Downward currents. These winds come out at the lower surface of the calm region, and consequently the place of the air borne away in this manner must be supplied, we may infer, by downward currents from the superincumbent air of the calm region. Like the case of a vessel of water which has two streams from opposite directions running in at the top, and two of equal capacity discharging in opposite directions at the bottom, the motion of the water would be downward, so is the motion of the air in this calm zone.

§ 133 The barometer, in this calm region, is said to stand

[1] § 128

CHAPTER III.

higher than it does either to the north or to the south of it; and this is another proof as to the banking up here of the atmosphere, and pressure from its downward motion. We can understand why there should be an uprising of the air which the two systems of trade-winds pour into the equatorial calms. But when this air commences to flow toward the poles as an upper current, we cannot understand why it should not continue gradually to descend and turn back[1] all the way from the equator to the poles, nor as far as investigation has gone, has any explanation been suggested for the calm belts of the tropics; nor can we tell why the upper currents should meet at one parallel in preference to another. But the fact of a meeting and a preference is certain.

Effect of calm region on barometer.

Causes not understood.

Following our imaginary particle of air, however, from the north across this calm belt of Cancer, we now feel it moving on the surface of the earth as the north-east trade-wind; and as such it continues, till it arrives near the equator, where it meets a like hypothetical particle, which, starting from the south at the same time the other started from the north pole, has blown as the south-east trade-wind. § 134

Theory continued.

Here, at this equatorial place of meeting, there is another conflict of winds, and another calm region, for a north-east and south-east wind cannot blow at the same time in the same place. The two particles have been put in motion by the same power; they meet with equal force; and, therefore, at their place of meeting, are stopped in their course. Here, therefore, there is a calm belt. § 135

Cause of calm.

Warmed now by the heat of the sun, and pressed on § 136

[1] § 144.

CHAPTER III. Ascending currents. each side by the whole force of the north-east and south-east trades, these two hypothetical particles, taken as the type of the whole, cease to move onward and ascend. This operation is the reverse of that which took place at the meeting[1] near the parallel of 30°.

§ 137 Calm of Capricorn. This imaginary particle, then, having ascended to the upper regions of the atmosphere again, travels there counter to the south-east trades, until it meets, near the calm belt of Capricorn, another particle from the south pole; here there is a descent as before; it then[3] flows on toward the south pole as a surface wind from the north-west.

§ 138 Conclusion of theory. Entering the polar regions obliquely, it is pressed upon by similar particles flowing in oblique currents across every meridian; and here again is a calm place or node; for, as our imaginary particle approaches the parallels near the polar calms more and more obliquely, it, with all the rest, is whirled about the pole in a continued circular gale; finally, reaching the vortex or the calm place, it is carried upward to the regions of atmosphere above, whence it commences again its circuit to the north as an upper current, as far as the calm belt of Capricorn; here it encounters[4] its fellow from the north;[5] they stop, descend, and flow out as surface currents,[6] the one with which the imagination is travelling, to the equatorial calm as the south-east trade-wind; here[7] it ascends, travelling thence to the calm belt of Cancer as an upper current counter to the north-east trades. Here[8] it ceases to be an upper current, but, descending,[9] travels on with the south-west passage-winds toward the pole.

§ 139 Now the course we have imagined an atom of air to take is this (Plate I.): an ascent in a place of calms

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[1] § 130. [3] § 126. [5] § 126. [7] § 135. [9] § 131.
[2] § 131. [4] § 137. [6] § 132. [8] § 130 and § 129.

about the north pole at P; an efflux thence as an upper current[1] until it meets G (also an upper current) over the calms of Cancer. Here[2] there is supposed to be a descent, as shown by the arrows along the wavy lines which envelop the circle. This upper current from the pole[3] now becomes the north-east trade-wind, B,[4] on the surface, until it meets the south-east trades in the equatorial calms, when it ascends and travels as C with the upper current to the calms of Capricorn, then as D with the prevailing north-west surface current to the south pole, thence up with the arrow P, and around with the hands of a watch, and back, as indicated by the arrows along E, F, G, and H.

CHAPTER III. — Course of the imaginary atom of air.

§ 140 — Bible allusions to laws of nature.

The Bible frequently makes allusions to the laws of nature, their operation and effects. But such allusions are often so wrapped in the folds of the peculiar and graceful drapery with which its language is occasionally clothed, that the meaning, though peeping out from its thin covering all the while, yet lies in some sense concealed, until the lights and revelations of science are thrown upon it; then it bursts out and strikes us with exquisite force and beauty.

§ 141 — Light thrown on the Bible by our knowledge of nature.

As our knowledge of nature and her laws has increased, so has our understanding of many passages in the Bible been improved. The Psalmist called the earth "the round world;" yet for ages it was the most damnable heresy for Christian men to say the world is round; and, finally, sailors circumnavigated the globe, proved the Bible to be right, and saved Christian men of science from the stake.

§ 142

"Canst thou tell the sweet influences of the Pleiades?"

[1] § 129. [2] § 130. [3] § 124. [4] § 134.

CHAPTER III.

Remarks on the Pleiades.

Astronomers of the present day, if they have not answered this question, have thrown so much light upon it as to show that, if ever it be answered by man, he must consult the science of astronomy. It has been recently all but proved, that the earth and sun, with their splendid retinue of comets, satellites, and planets, are all in motion around some point or centre of attraction inconceivably remote, and that that point is in the direction of the star Alcyon, one of the Pleiades! Who but the astronomer, then, could tell their "sweet influences?"

The Bible in reference to winds.

§ 143 And as for the general system of atmospherical circulation which I have been so long endeavouring to describe, the Bible tells it all in a single sentence: "The wind goeth toward the south, and turneth about unto the north; it whirleth about continually, and the wind returneth again according to his circuits."—Eccl. i. 6.

"Sloughing off" of winds on approaching the poles.

§ 144 Of course, as the surface winds H and D (Plate I.) approach the poles, there must be a sloughing off, if I may be allowed the expression, of air from the surface winds, in consequence of their approaching the poles; for as they near the poles, the parallels become smaller and smaller, and the surface current must either extend much higher up, and blow with greater rapidity as it approaches the poles, or else a part of it must be sloughed off above, and so turn back before reaching the calms about the poles. The latter is probably the case.

Trade-winds on the Atlantic.

§ 145 Our investigations show that the south-east trade-wind region is much larger than the north-east (I speak now of its extent over the Atlantic Ocean only); that the south-east trades are the fresher, and that they often push themselves up to 10° or 15° of north latitude;

whereas the north-east trade-wind seldom gets south of the equator. CHAPTER III.

§ 146 Clouds of the trade-winds. The peculiar clouds of the trade-winds are formed between the upper and lower currents of air. They are probably formed of vapour condensed from the upper current, and evaporated as it descends by the lower and dry current from the poles. It is the same phenomenon up there which is so often observed here below; when a cool and dry current of air meets a warm and wet one, an evolution of vapour or fog ensues.

§ 147 General course of winds. We now see the general course of the "wind in his circuits," as we see the general course of the water in a river. There are many abrading surfaces, irregularities, &c., which produce a thousand eddies in the main stream; yet, nevertheless, the general direction of the whole is not disturbed nor affected by those counter currents; so with the atmosphere and the variable winds which we find here in this latitude.

§ 148 Obedient to law. Have I not, therefore, very good grounds for the opinion[1] that the "wind in his circuits," though apparently to us never so wayward, is as obedient to law and as subservient to order as were the morning stars when they "sang together?"

§ 149 Two forces concerned in driving the winds. There are at least two forces concerned in driving the wind through its circuits. We have seen[2] whence that force is derived which gives easting to the winds as they approach the equator, and westing as they approach the poles, and allusion, without explanation, has been made[3] to the source whence they derive their northing and their southing. Cause of trade winds considered. The trade-winds are caused, it is said, by the inter-tropical heat of the sun, which, expanding the air,

[1] § 118. [2] § 124. [3] § 136.

causes it to rise up near the equator; it then flows off in the upper currents north and south, and there is a rush of air at the surface both from the north and the south to restore the equilibrium—hence the trade-winds. But to the north side of the trade-wind belt in the northern, and on the south side in the southern hemisphere, the prevailing direction of the winds is not toward the source of heat about the equator, but exactly in the opposite direction. In the extra-tropical region of each hemisphere the prevailing winds blow from the equator toward the poles. It therefore at first appears paradoxical to say that heat makes the easterly winds of the torrid zone blow toward the equator, and the westerly winds of the temperate zones to blow toward the poles. Let us illustrate:

§ 150 The *primum mobile* of the extra-tropical winds toward the equator is, as just intimated, generally ascribed to heat, and in this wise, namely: Suppose, for the moment, the earth to have no diurnal rotation; that it is at rest; that the rays of the sun have been cut off from it; that the atmosphere has assumed a mean uniformity of temperature, the thermometer at the equator and the thermometer at the poles giving the same reading; that the winds are still, and that the whole aerial ocean is in equilibrium and at rest. Now imagine the screen which is supposed to have shut off the influence of the sun to be removed, and the whole atmosphere to assume the various temperatures in the various parts of the world that it actually has at this moment, what would take place, supposing the uniform temperature to be a mean between that at the equator and that at the poles?

Illustration.

Why, this would take place: a swelling up of the atmosphere about the equator by the expansive force of intertropical heat, and a contraction of it about the poles in consequence of the cold. These two forces, considering them under their most obvious effects, would disturb the supposed atmospherical equilibrium by altering the level of the great aerial ocean; the expansive force of heat elevating it about the equator, and the contracting powers of cold depressing it about the poles. And forthwith two systems of winds would commence to blow, namely, one in the upper regions from the equator toward the poles, and as this warm and expanded air should flow toward either pole, seeking its level, a wind would blow on the surface from either pole to restore the air to the equator which the upper current had carried off.

These two winds would blow due north and south; § 151
the effects of heat at the equator, and cold at the poles, would cause them so to do. Now suppose the earth to commence its diurnal rotation; then, instead of having these winds north and south winds, they will, for reasons already explained,[1] approach the equator on both sides with *easting* in them, and each pole with westing.

Illustration continued.

The circumference of the earth measured on the § 152
parallel of 60° is only half what it is when measured on the equator. Therefore, supposing velocity to be the same, only half the volume of atmosphere[2] that sets off from the equator as an upper current toward the poles can cross the parallel of 60° north or south. The other moiety has been gradually drawn in and carried back[3] by the current which is moving in the opposite direction.

Such, and such only, would be the extent of the power § 153

[1] § 124. [2] § 149. [3] § 144.

CHAPTER III.

Power of sun on the air under supposed circumstances.

of the sun to create a polar and equatorial flow of air, were its power confined simply to a change of level. But the atmosphere has been invested with another property which increases its mobility, and gives the heat of the sun still more power to put it in motion, and it is this: as heat changes the atmospherical level, it changes also the specific gravity of the air acted upon. If, therefore, the level of the great aerial ocean were undisturbed by the sun's rays, and if the air were adapted to a change of specific gravity alone, without any change in volume, this quality would also be the source of at least two systems of currents in the air, namely, an upper and a lower. The two agents combined, namely, that which changes level or volume, and that which changes specific gravity, give us the general currents under consideration. Hence we say that the *primum mobile* of the air is derived from change of specific gravity induced by the freezing temperature of the polar regions, as well as from change of specific gravity due the expanding force of the sun's rays within the tropics.

Specific gravity of air.

§ 154 Therefore, fairly to appreciate the extent of the influence due the heat of the sun in causing the winds, it should be recollected that we may with as much reason ascribe to the inter-tropical heat of the sun the north-west winds, which are the prevailing winds of the extra-tropical regions of the southern hemisphere, or the south-west winds, which are the prevailing winds of the extra-tropical regions of the northern hemisphere, as we may the trade-winds, which blow in the opposite directions. Paradoxical, therefore, as it seems for us to say that the heat of the sun causes the winds between the parallels of 25° or

Conclusions.

30° north and south to blow toward the equator, and that it also causes the prevailing winds on the polar sides of these same parallels to blow toward the poles, yet the paradox ceases when we come to recollect that by the process of equatorial heating and polar cooling which is going on in the atmosphere, the specific gravity of the air is changed as well as its level. Nevertheless, as Halley said, in his paper read before the Royal Society in London in 1686, and as we also have said,[1] "it is likewise very hard to conceive why the limits of the trade-wind should be fixed about the parallel of latitude 30° all around the globe, and that they should so seldom exceed or fall short of those bounds."

Halley's remarks.

Operated upon by the equilibrating tendency of the atmosphere and by diurnal rotation, the wind approaches the north pole, for example, by a series of spirals from the south-west. If we draw a circle about this pole on a common terrestrial globe, and intersect it by spirals to represent the direction of the wind, we shall see that the wind enters all parts of this circle from the south-west, and that, consequently, there should be about the poles a disc or circular space of calms, in which the air ceases to move forward as wind, and ascends as in a calm; about this calm disc, therefore, there should be a whirl, in which the ascending column of air revolves from right to left, or *against* the hands of a watch. At the south pole the winds come from the north-west,[2] and consequently there they revolve about it *with* the hands of a watch. § 155

How wind approaches north pole.

South pole

That this should be so will be obvious to any one who will look at the arrows on the polar sides of the calms Cancer and Capricorn (Plate I.) These arrows are

[1] § 133. [2] § 137.

CHAPTER III. intended to represent the prevailing direction of the wind at the surface of the earth on the polar side of these calms.

§ 156 Singular coincidence regarding rotatory storms and whirlwinds. It is a singular coincidence between these two facts thus deduced, and other facts which have been observed and which have been set forth by Redfield, Reid, Piddington, and others, namely, that many of the rotatory storms in the northern hemisphere revolve as do the whirlwinds about the north pole, namely, from right to left, and that all circular gales in the southern hemisphere revolve in the opposite direction, as does the whirl about the south pole.

§ 157 How can there be any connection between the rotary motion of the wind about the pole, and the rotary motion of it in a gale caused here by local agents?

§ 158 That there is probably such a connection has been suggested by other facts and circumstances, and perhaps I shall be enabled to make myself clearer when we come to treat of these facts and circumstances, and to inquire farther[1] into the relations between magnetism and the circulation of the atmosphere; for, although the theory of heat satisfies the conditions of the problem, and though heat, doubtless, is one of the chief agents in keeping up the circulation of the atmosphere, yet it can be made to appear that it is not the *sole* agent.

Heat not the sole agent of winds.

§ 159 Offices of the atmosphere SOME OF ITS METEOROLOGICAL AGENCIES.—So far, we see how the atmosphere moves; but the atmosphere, like every other department in the economy of nature, has its offices to perform, and they are many. I have already alluded to some of them; but I only propose, at this time, to consider some of the meteorological agencies at sea, which, in the grand design of creation, have probably been assigned to this wonderful machine.

[1] As at § 299.

CHAPTER III.

§ 160 On moisture and climate.

To distribute moisture over the surface of the earth, and to temper the climate of different latitudes, it would seem, are two great offices assigned by their Creator to the ocean and the air.

§ 161 Constant precipitation in calm belts.

When the north-east and south-east trades meet and produce the equatorial calms,[1] the air, by the time it reaches this calm belt, is heavily laden with moisture, for in each hemisphere it has travelled obliquely over a large space of the ocean. It has no room for escape but in the upward direction.[2] It expands as it ascends, and becomes cooler; a portion of its vapour is thus condensed, and comes down in the shape of rain. Therefore it is that, under these calms, we have a region of constant precipitation. Old sailors tell us of such dead calms of long continuance here, of such heavy and constant rains, that they have scooped up fresh water from the surface of the sea. Singular fact.

§ 162

The conditions to which this air is exposed here under the equator are probably not such as to cause it to precipitate all the moisture that it has taken up in its long sweep across the waters. Let us see what becomes of the rest; for Nature, in her economy, permits nothing to be taken away from the earth which is not to be restored to it again in some form, and at some time or other.

§ 163 Amazon and Mississippi.

Consider the great rivers—the Amazon and the Mississippi, for example. We see them day after day, and year after year, discharging immense volumes of water into the ocean.

Whence are their sources supplied.

"All the rivers run into the sea, yet the sea is not full" (Eccl. i. 7). Where do the waters so discharged go, and where do they come from? They come from their sources, you will say. But whence are their sources supplied? for,

[1] § 135. [2] § 136.

CHAPTER III. unless what the fountain sends forth be returned to it again, it will fail and be dry.

§ 164 Precipitation exceeds evaporation. We see simply, in the waters that are discharged by these rivers, the amount by which the precipitation exceeds the evaporation throughout the whole extent of valley drained by them; and by precipitation I mean the total amount of water that falls from, or is deposited by the atmosphere, whether as dew, rain, hail, or snow.

§ 165 The springs of these rivers[1] are supplied from the rains of heaven, and these rains are formed of vapours which are taken up from the sea, that "it be not full," and carried up to the mountains through the air.

"Note the place whence the rivers come, thither they return again."

§ 166 Waters of rivers carried back to their sources. Behold how the waters of the Amazon, of the Mississippi, the St. Lawrence, and all the great rivers of America, Europe, and Asia, lifted up by the atmosphere, and flowing in invisible streams back through the air to their sources among the hills,[2] and that through channels so regular, certain, and well defined, that the quantity thus conveyed one year with the other is nearly the same: for that is the quantity which we see running down to the ocean through these rivers; and the quantity discharged annually by each river is, as far as we can judge, nearly a constant.

§ 167 Order and arrangement in the offices of atmosphere. We now begin to conceive what a powerful machine the atmosphere must be; and, though it is apparently so capricious and wayward in its movements, here is evidence of order and arrangement which we must admit, and proof which we cannot deny, that it performs this mighty office with regularity and certainty, and is, therefore, as

[1] § 112. [2] § 112.

obedient to law as is the steam-engine to the will of its builder. CHAPTER III.

It, too, is an engine. The South Seas themselves, in all their vast inter-tropical extent, are the boiler for it, and the northern hemisphere is its condenser. The mechanical power exerted by the air and the sun in lifting water from the earth, in transporting it from one place to another, and in letting it down again, is inconceivably great. The utilitarian who compares the water-power that the Falls of Niagara would afford if applied to machinery, is astonished at the number of figures which are required to express its equivalent in horse-power. Yet what is the horse-power of the Niagara, falling a few steps, in comparison with the horse-power that is required to lift up as high as the clouds and let down again all the water that is discharged into the sea, not only by this river, but by all other rivers in the world. The calculation has been made by engineers, and, according to it, the force for making and lifting vapour from each area of one acre that is included on the surface of the earth is equal to the power of 30 horses, and for the whole area of the earth it is 800 times greater than all the water-power in Europe. § 168

Comparison with the steam engine.

Calculation of force required for lifting vapour from the earth.

Where does the vapour that makes the rains which feed the rivers of the northern hemisphere come from? § 169

The proportion between the land and water in the northern hemisphere is very different from the proportion that obtains between them in the southern. In the northern hemisphere, the land and water are nearly equally divided. In the southern, there is several times more water than land. All the great rivers in the world are

Difference of proportion between land and water in northern and southern hemispheres.

CHAPTER III.

River Amazon.

in the northern hemisphere, where there is less ocean to supply them. Whence, then, are their sources replenished? Those of the Amazon are supplied with rains from the equatorial calms and trade-winds of the Atlantic. That river runs east, its branches come from the north and south; it is always the rainy season on one side or the other of it; consequently, it is a river without periodic stages of a very marked character. It is always near its high-water mark. For one half of the year its northern tributaries are flooded, and its southern for the other half. It discharges under the line, and as its tributaries come from both hemispheres, it cannot be said to belong exclusively to either. It is supplied with water made of vapour that is taken up from the Atlantic Ocean. Taking the

Rio de la Plata the only great river of the southern hemisphere.

Amazon, therefore, out of the count, the Rio de la Plata is the only great river of the southern hemisphere. There is no large river in New Holland. The South Sea Islands give rise to none, nor is there one in South Africa entitled to be called great that we know of.

§ 170 The great rivers of North America and North Africa, and all the rivers of Europe and Asia, lie wholly within the northern hemisphere. How is it, then, considering that the evaporating surface lies mainly in the southern hemisphere—how is it, I say, that we should have the evaporation to take place in one hemisphere and the con-

Greater amount of rain falls in northern hemispere than southern.

densation in the other? The total amount of rain which falls in the northern hemisphere is much greater, meteorologists tell us, than that which falls in the southern. The annual amount of rain in the north temperate zone is half as much again as that of the south temperate.

§ 171 How is it, then, that this vapour gets, as stated[1] from the

[1] § 170.

southern into the northern hemisphere, and comes with such regularity that our rivers never go dry and our springs fail not? It is because of the beautiful operations and the exquisite *compensation* of this grand machine, the atmosphere. It is exquisitely and wonderfully counterpoised. Late in the autumn of the north, throughout its winter, and in early spring, the sun is pouring his rays with the greatest intensity down upon the seas of the southern hemisphere, and this powerful engine which we are contemplating is pumping up the water there[1] for our rivers with the greatest activity. At this time, the mean temperature of the entire southern hemisphere is said to be about 10° higher than the northern.

How the atmosphere supplies the northern rivers from the southern seas.

§ 172

The heat which this heavy evaporation absorbs becomes latent, and, with the moisture, is carried through the upper regions of the atmosphere until it reaches our climates. Here the vapour is formed into clouds, condensed, and precipitated. The heat which held this water in the state of vapour is set free, it becomes sensible heat, and it is that which contributes so much to temper our winter climate. It clouds up in winter, turns warm, and we say we are going to have falling weather. That is because the process of condensation has already commenced, though no rain or snow may have fallen: thus we feel this southern heat that has been collected from the rays of the sun by the sea, been bottled away by the winds in the clouds of a southern summer, and set free in the process of condensation in our northern winter.

Process of condensation.

§ 173

South-east trade-winds bear their moisture into northern hemisphere.

If Plate I. fairly represent the course of the winds, the south-east trade-winds would enter the northern hemisphere, and, as an upper current, bear into it all their

[1] § 169.

CHAPTER III. moisture, except that which is precipitated in the region of equatorial calms.

§ 174 Hypothesis. The South Seas, then,[1] should supply mainly the water for this engine, while the northern hemisphere condenses it; we should, therefore, have more rain in the northern hemisphere. The rivers tell us that we have—at least on the land: for the great water-courses of the globe, and half the fresh water in the world, are found on our side of the equator. This fact alone is strongly corroborative of this hypothesis.

§ 175 Confirmed by rain gauge. The rain gauge tells us also the same story. The yearly average of rain in the north temperate zone is, according to Johnston, thirty-seven inches. He gives but twenty-six in the south temperate. The observations of mariners are also corroborative of the same. Log-books, containing altogether the records for upward of 260,000 days in the Atlantic Ocean north and south,[2] have been carefully examined for the purpose of ascertaining, for comparison, the number of calms, rains, and gales, therein recorded for each hemisphere. Result of examination of log-books. Proportionally the number of each is given as decidedly greater for the north than it is for the south. The result of this examination is very instructive, for it shows the status of the atmosphere to be much more unstable in the northern hemisphere, with its excess of land, than in the southern, with its excess of water. Rains, and fogs, and thunder, and calms, and storms, all occur much more frequently, and are more irregular also as to the time and place of their occurrence on this side, than they are on the other side of the equator.

§ 176 Moisture is never extracted from the air by subjecting

[1] According to § 168. [2] Plate XIII.

it from a low to a higher temperature, but the reverse. Thus all the air which comes loaded with moisture from the other hemisphere, and is borne into this with the south-east trade-winds, travels in the upper regions of the atmosphere[1] until it reaches the calms of Cancer; here it becomes the surface wind that prevails from the southward and westward. As it goes north it grows cooler, and the process of condensation commences.

CHAPTER III. — Moisture never extracted by subjecting the air from a low to a higher temperature.

§ 177 We may now liken it to the wet sponge, and the decrease of temperature to the hand that squeezes that sponge. Finally reaching the cold latitudes, all the moisture that a dew-point of zero, and even far below, can extract, is wrung from it; and this air then commences "to return according to his circuits" as dry atmosphere. And here we can quote Scripture again: "The north wind driveth away rain." This is a meteorological fact of high authority and great importance in the study of the circulation of the atmosphere.

Important meteorological fact

§ 178 By reasoning in this manner and from such facts, we are led to the conclusion that our rivers are supplied with their waters principally from the trade-wind regions, the extra-tropical northern rivers from the southern trades, and the extra-tropical southern rivers from the northern trade-winds, for the trade-winds are the evaporating winds.

Conclusion drawn.

§ 179 Taking for our guide such faint glimmerings of light as we can catch from these facts, and supposing these views to be correct, then the saltest portion of the sea should be in the trade-wind regions, where the water for all the rivers is evaporated; and there the saltest portions are found. There, too, the rains fall less frequently.[2]

Saltest portion of the sea found in trade-wind regions.

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[1] § 130. [2] Plate XIII.

CHAPTER III.

§ 180 Dr. Ruschenberger's observations on specific gravity of sea-water.

Dr. Ruschenberger, of the navy, on his last voyage to India, was kind enough to conduct a series of observations on the specific gravity of sea water. In about the parallel of 17° north and south—midway of the trade-wind regions—he found the heaviest water. Though so warm, the water there was heavier than the cold water to the south of the Cape of Good Hope. Lieutenant D. D. Porter, in the steam-ship Golden Age, found the heaviest water about the parallels of 20° north and 17° south.

§ 181 How it is that there are smaller rivers and less rain in southern hemisphere.

In summing up the evidence in favour of this view of the general system of atmospherical circulation, it remains to be shown how it is, if the view be correct, there should be smaller rivers and less rain in the southern hemisphere. The winds that are to blow as the north-east trade-winds, returning from the polar regions, where the moisture[1] has been compressed out of them, remain, as we have seen, dry winds until they cross the calm zone of Cancer, and are felt on the surface as the north-east trades. About two-thirds of them only can then blow over the ocean; the rest blow over the land—over Asia, Africa, and North America, where there is but comparatively a small portion of evaporating surface exposed to their action.

§ 182 Zone of north-east trade-wind

The zone of the north-east trades extends, on an average, from about 29° north to 7° north. Now, if we examine the globe, to see how much of this zone is land and how much water, we shall find, commencing with China and coming over Asia, the broad part of Africa, and so on, across the continent of America to the Pacific, land enough to fill up, as nearly as may be, just one third of it. This land, if thrown into one body between these

[1] § 176.

parallels, would make a belt equal to 120° of longitude by 22° of latitude, and comprise an area of about twelve and a half millions of square miles, thus leaving an evaporating surface of about twenty-five millions of square miles in the northern against about seventy-five millions in the southern hemisphere.

According to the hypothesis, illustrated by Plate I., as to the circulation of the atmosphere, it is these north-east trade-winds that take up and carry over, after they rise up in the belt of equatorial calms, the vapours which make the rains that feed the rivers in the extra-tropical regions of the southern hemisphere. § 183

Only two-thirds fully charged with moisture.

Upon this supposition, then, two-thirds only of the north-east trade-winds are fully charged with moisture, and only two-thirds of the amount of rain that falls in the northern hemisphere should fall in the southern, and this is just about the proportion[1] that observation gives. § 184

South-east trade-winds prevail to a greater extent at sea.

In like manner, the south-east trade-winds take up the vapours which make our rivers, and as they prevail to a much greater extent at sea, and have exposed to their action about three times as much ocean as the north-east trade-winds have, we might expect, according to this hypothesis, more rains in the northern—and consequently more and larger rivers—than in the southern hemisphere. That part of the ocean over which the south-east trades prevail is very much larger than that portion where the north-east trades blow. § 185

Difficulty of estimating the quantity of rain in the two hemispheres.

This estimate as to the quantity of rain in the two hemispheres is one which is not capable of verification by any more than the rudest approximations; for the greater extent of south-east trades on one side, and of high moun- § 186

[1] § 173.

CHAPTER III. tains on the other, must each of necessity, and independent of other agents, have their effects. Nevertheless, this estimate gives as close an approximation as we can make out from our data.

§ 187 *The rainy seasons, how caused.*—The calm and trade-wind regions or belts move up and down the earth annually, in latitude nearly a thousand miles. In July and August, the zone of equatorial calms is found between 7° north and 12° north, sometimes higher; in March and April, between latitude 5° south and 2° north.

§ 188 Rainy seasons. With this fact, and these points of view before us, it is easy to perceive why it is that we have a rainy season in Oregon, a rainy and dry season in California, another at Panama, two at Bogotá, none in Peru, and one in Chili.

§ 189 In Oregon it rains every month, but about five times more in the winter than in the summer months.

n Oregon. The winter there is the summer of the southern hemisphere, when this steam-engine[1] is working with the greatest pressure. The vapour that is taken up by the south-east trades is borne along over the region of north-east trades to latitude 35° or 40° north, where it descends and appears on the surface with the south-west winds of those latitudes. Driving upon the highlands of the continent, this vapour is condensed and precipitated, during this part of the year, almost in constant showers, and to the depth of about thirty inches in three months.

§ 190 System of zones follows the sun. In the winter, the calm belt of Cancer approaches the equator. This whole system of zones, namely, of trades, calms, and westerly winds, follows the sun; and they of our hemisphere are nearer the equator in the winter and spring months than at any other season.

[1] § 168.

§ 191 The south-west winds commence at this season to prevail as far down as the lower part of California. In winter and spring, the land in California is cooler than the sea air, and is quite cold enough to extract moisture from it. But in summer and autumn the land is the warmer, and cannot condense the vapours of water held by the air. So the same cause which made it rain in Oregon now makes it rain in California. As the sun returns to the north, he brings the calm belt of Cancer and the north-east trades along with him; and now, at places where, six months before, the south-west winds were the prevailing winds, the north-east trades are found to blow. This is the case in the latitude of California. The prevailing winds, then, instead of going from a warmer to a cooler climate, as before, are going the opposite way. Consequently, if, under these circumstances, they have the moisture in them to make rains of, they cannot precipitate it.

Rainy season in California.

Cause

§ 192 Proof, if proof were wanting, that the prevailing winds in the latitude of California are from the westward, is obvious to all who cross the Rocky Mountains or ascend the Sierra Madre. In the pass south of the Great Salt Lake basin those west winds have worn away the hills and polished the rock by their ceaseless abrasion and the scouring effects of the driving sand. Those who have crossed this pass are astonished at the force of the wind and the marks there exhibited of its GEOLOGICAL AGENCIES.

Proof that west winds prevail in California.

§ 193 Panama is in the region of equatorial calms. This belt of calms travels during the year, back and forth, over about 17° of latitude, coming farther north in the summer, where it tarries for several months, and then returning

Equatorial calms.

so as to reach its extreme southern latitude some time in March or April. Where these calms are it is always raining, and the chart* shows that they hang over the latitude of Panama from June to November, consequently from June to November is the rainy season at Panama. The rest of the year that place is in the region of the north-east trades, which, before they arrive there, have to cross the mountains of the isthmus, on the cool tops of which they deposit their moisture, and leave Panama rainless and pleasant until the sun returns north with the belt of equatorial calms after him. They then push the belt of north-east trades farther to the north, occupy a part of the winter zone, and refresh that part of the earth with summer rains. This belt of calms moves over more than double of its breadth, and nearly the entire motion from south to north is accomplished generally in two months, May and June. Take the parallel of 4° north as an illustration: during these two months the entire belt of calms crosses this parallel, and then leaves it in the region of the south-east trades. During these two months it was pouring down rain on that parallel. After the calm belt passes it, the rains cease, and the people in that latitude have no more wet weather till the fall, when the belt of calms recrosses this parallel on its way to the south. By examining the "Trade-wind Chart," it may be seen what the latitudes are that have two rainy seasons, and that Bogotá is within the bi-rainy latitudes.

Rainy season at Panama.

Movements of the belt of calms.

§ 194 *The Rainless Regions.*—The coast of Peru is within the region of perpetual south-east trade-winds. Though

Rainless regions.

* Vide *Trade-wind Chart* (Maury's Wind and Current).

the Peruvian shores are on the verge of the great South Sea boiler, yet it never rains there. The reason is plain. CHAPTER III.

§ 195 South-east trade-winds.

The south-east trade-winds in the Atlantic Ocean first strike the water on the coast of Africa. Travelling to the north-west, they blow obliquely across the ocean until they reach the coast of Brazil. By this time they are heavily laden with vapour, which they continue to bear along across the continent, depositing it as they go, and supplying with it the sources of the Rio de la Plata and the southern tributaries of the Amazon. Finally, they reach the snow-capped Andes, and here is wrung from them the last particle of moisture that that very low temperature can extract.

Peruvian climate cannot extract vapour from them

Reaching the summit of that range, they now tumble down as cool and dry winds on the Pacific slopes beyond. Meeting with no evaporating surface, and with no temperature *colder* than that to which they were subjected on the mountain-tops, they reach the ocean before they again become charged with fresh vapour, and before, therefore, they have any which the Peruvian climate can extract. The last they had to spare was deposited as snow on the tops of the Cordilleras, to feed mountain streams under the heat of the sun, and irrigate the valleys on the western slopes. Thus we see how the top of the Andes becomes the reservoir from which are supplied the rivers of Chili and Peru.

§ 196 Other rainless regions.

The other rainless or almost rainless regions are the western coasts of Mexico, the deserts of Africa, Asia, North America, and Australia.

§ 197

We have a rainless region about the Red Sea, because

CHAPTER III. the Red Sea, for the most part, lies within the north-east trade-wind region, and these winds, when they reach that region, are dry winds, for they have as yet, in their course, crossed no wide sheets of water from which they could take up a supply of vapour.

§ 198 Most of New Holland lies within the south-east trade-wind region; so does most of inter-tropical South America. But inter-tropical South America is the land of showers. The largest rivers, and most copiously watered country in the world are to be found there, whereas almost exactly the reverse is the case in Australia. Whence this difference? Examine the direction of the winds with regard to the shore-line of these two regions, and the explanation will at once be suggested. In Australia—east coast—the shore-line is stretched out in the direction of the trades; in South America—east coast—it is perpendicular to their direction. In Australia, they fringe this shore only with their vapour, and so stint that thirsty land with showers that the trees cannot afford to spread their leaves out to the sun, for it evaporates all the moisture from them; their instincts, therefore, teach them to turn their edges to his rays. In inter-tropical South America, the trade-winds blow perpendicularly upon the shore, penetrating the very heart of the country with their moisture. Here the leaves, measuring many feet square—as the plantain, &c.—turn their broad sides up to the sun, and court his rays.

Difference between Australia and South America.

§ 199 *Why there is more rain on one side of a mountain than on the other.*

We may now, from what has been said, see why the Andes, and all other mountains which lie athwart the course of the winds, have a dry and a rainy side, and how the prevailing winds of the latitude determine which is the rainy and which the dry side. CHAPTER III.

Thus, let us take the southern coast of Chili for illustration. In our summer time, when the sun comes north, and drags after him his belts of perpetual winds and calms, that coast is left within the regions of the north-west winds—the winds that are counter to the south-east trades—which, cooled by the winter temperature of the highlands of Chili, deposit their moisture copiously. During the rest of the year, the most of Chili is in the region of the south-east trades, and the same causes which operate in California to prevent rain there, operate in Chili; only the dry season in one place is the rainy season of the other.

Reason why one side of a mountain is wet and the other dry.

Hence we see that the weather side of all such mountains as the Andes is the wet side, and the lee side the dry.

The same phenomenon, from a like cause, is repeated in inter-tropical India, only in that country each side of the mountain is made alternately the wet and the dry side by a change in the prevailing direction of the wind. India is in one of the monsoon regions:[1] it is the most famous of them all. From October to April the north-east trades prevail. They evaporate from the Bay of Bengal water enough to feed with rains, during this season, the western shores of this bay and the Ghauts range of mountains. This range holds the relation to these winds that the Andes of Peru[2] hold to the south-east trades; it first cools and then relieves them of their moisture, and they tumble down on the western slopes § 200

India the most famous of the monsoon regions.

[1] Plate VIII. [2] § 194.

CHAPTER III.

of the Ghauts, Peruvian-like,[1] cool, rainless, and dry; wherefore that narrow strip of country between the Ghauts and the Arabian Sea would, like that in Peru between the Andes and the Pacific, remain without rain for ever, were it not for other agents which are at work about India, and not about Peru. The work of the agents to which I allude is felt in the monsoons, and these prevail in India, and not in Peru.

§ 201 After the north-east trades have blown out their season, which in India ends in April,[2] the great arid plains of Central Asia, of Tartary, Thibet, and Mongolia, become heated up; they rarefy the air of the north-east trades, and cause it to ascend. This rarefaction and ascent, by their demand for an indraught, are felt by the air which the south-east trade-winds bring to the equatorial Doldrums of the Indian Ocean; it rushes over into the northern hemisphere to supply the upward draught from the heated plains as the south-west monsoons. The forces of diurnal rotation assist[3] to give these winds their westing. Thus the south-east trades, in certain parts of the Indian Ocean, are converted, during the summer and early autumn, into south-west monsoons. These, then, come from the Indian Ocean and Sea of Arabia loaded with moisture, and striking with it perpendicularly upon the Ghauts, precipitate upon that narrow strip of land between this range and the Arabian Sea an amount of water that is truly astonishing. Here, then, are not only the conditions for causing more rain, now on the west, now on the east side of this mountain range, but the conditions also for the most copious precipitation. Accordingly, when we come to consult rain gauges, and

How the south-east trades in certain parts of the Indian Ocean become south-west monsoons.

[1] § 199. [2] § 200. [3] § 44.

to ask meteorological observers in India about the fall of rain, they tell us that on the western slopes of the Ghauts it sometimes reaches the enormous depth of twelve or fifteen inches in one day.* Were the Andes stretched along the eastern instead of the western coast of America, we should have an amount of precipitation on their eastern slopes that would be truly astonishing; for the water which the Amazon and the other majestic streams of South America return to the ocean would still be precipitated between the sea-shore and the crest of these mountains.

CHAPTER III.

Enormous depth of rain on the Ghauts.

These winds of India then continue their course to the Himalaya range as dry winds. In crossing this range, they are subjected to a lower temperature than that to which they were exposed in crossing the Ghauts. Here they drop more of their moisture in the shape of snow and rain, and then pass over into the thirsty lands beyond with scarcely enough vapour in them to make even a cloud. Thence they ascend into the upper air, there to become counter-currents in the general system of atmospherical circulation. § 202

Dry winds on the Himalayas

The Regions of Greatest Precipitation.—We shall now be enabled to determine, if the views which I have been endeavouring to present be correct, what parts of the earth are subject to the greatest fall of rain. They should be on the slopes of those mountains which the trade-winds first strike, after having blown across the greatest tract of ocean. The more abrupt the elevation, and the shorter the distance between the mountain top and the ocean,[1] the greater the amount of precipitation. § 203

The regions of greatest precipitation.

* Keith Johnston.

1 § 199.

CHAPTER III. If, therefore, we commence at the parallel of about 30° north in the Pacific, where the north-east trade-winds first strike that ocean, and trace them through their circuits till they first strike high land, we ought to find such a place of heavy rains.

§ 204 Course of north-east trade-wind. Commencing at this parallel of 30°, therefore, in the North Pacific, and tracing thence the course of the north-east trade-winds, we shall find that they blow thence, and reach the region of equatorial calms near the Caroline Islands. Here they rise up; but, instead of pursuing the same course in the upper stratum of winds through the southern hemisphere, they, in consequence of the rotation of the earth,[1] are made to take a south-east course. They keep in this upper stratum until they reach the calms of Capricorn, between the parallels of 30° and 40°, after which they become the prevailing north-west winds of the southern hemisphere, which correspond to the south-west of the northern. Continuing on to the south-east, they are now the surface winds; they are going from warmer to cooler latitudes; they become as the wet sponge,[2] and are abruptly intercepted by the Andes of Patagonia, whose cold summit compresses them, and with its low dew-point squeezes the water out of them. Captain King found the astonishing fall of water here of nearly thirteen feet (one hundred and fifty-one inches) in forty-one days; and Mr. Darwin reports that the sea-water along this part of the South American coast is sometimes quite fresh, from the vast quantity of rain that falls.

Astonishing fall of water in Patagonia.

§ 205 We ought to expect a corresponding rainy region to be found to the north of Oregon; but there the moun-

[1] § 126. [2] § 177.

tains are not so high, the obstruction to the south-west winds is not so abrupt, the highlands are farther from the coast, and the air which these winds carry in their circulation to that part of the coast, though it be as heavily charged with moisture as at Patagonia, has a greater extent of country over which to deposit its rain, and consequently, the fall to the square inch will not be as great.* CHAPTER III. — Why greater than Oregon.

In like manner, we should be enabled to say in what part of the world the most equable climates are to be found. They are to be found in the equatorial calms, where the north-east and south-east trades meet fresh from the ocean, and keep the temperature uniform under a canopy of perpetual clouds. § 206 Most equable climates.

Amount of Evaporation.—The mean annual fall of rain on the entire surface of the earth is estimated at about five feet. § 207

To evaporate water enough annually from the ocean to cover the earth, on the average, five feet deep with rain; to transport it from one zone to another; and to precipitate it in the right places, at suitable times, and in the proportions due, is one of the offices of the grand atmospherical machine. This water is evaporated principally from the torrid zone. Supposing it all to come thence, we shall have, encircling the earth, a belt of ocean three thousand miles in breadth, from which this atmosphere evaporates a layer of water anually sixteen § 208 Evaporation.

* I have, through the kindness of A. Holbrook, Esq., United States Attorney for Oregon, received the *Oregon Spectator* of February 13, 1851, containing the Rev. G. H. Atkinson's Meteorological Journal, kept in Oregon city during the month of January 1851. The quantity of rain and snow for that month is 13.63 inches, or about one third the average quantity that falls at Washington during the year.

CHAPTER III. Exquisite machinery of the atmosphere.

feet in depth. And to hoist up as high as the clouds, and lower down again all the water in a lake sixteen feet deep, and three thousand miles broad, and twenty-four thousand long, is the yearly business of this invisible machinery. What a powerful engine is the atmosphere! and how nicely adjusted must be all the cogs, and wheels, and springs, and *compensations* of this exquisite piece of machinery, that it never wears out nor breaks down, nor fails to do its work at the right time, and in the right way!

§ 209 Dr. Buist's report on evaporation.

In his annual report to the Society (*Transactions of the Bombay Geographical Society* from May, 1849, to August, 1850, vol. ix.), Dr. Buist, the secretary, states, on the authority of Mr. Laidly, the evaporation at Calcutta to be "about fifteen feet annually; that between the Cape and Calcutta it averages, in October and November, nearly three-fourths of an inch daily; between 10° and 20° in the Bay of Bengal, it was found to exceed an inch daily. Supposing this to be double the average throughout the year, we should," continues the doctor, "have eighteen feet of evaporation annually."

§ 210 Evaporation in Indian Ocean.

If, in considering the direct observations upon the daily rate of evaporation in India, it be remembered that the seasons there are divided into wet and dry; that in the dry season, evaporation in the Indian Ocean, because of its high temperature, and also of the high temperature and dry state of the wind, probably goes on as rapidly as it does any where else in the world; if, moreover, we remember that the regular trade-wind regions proper at sea are regions of small precipitation;[1] that evaporation is going on from them all the year round, we shall have

Estimate for trade-wind surface.

[1] § 179.

reason to consider the estimate of sixteen feet annually for the trade-wind surface of the ocean not too high. CHAPTER III.

§ 211 Why the proportions of land and water are as we find them.

We see the light beginning to break upon us, for we now begin to perceive why it is that the proportions between the land and water were made as we find them in nature. If there had been more water and less land, we should have had more rain, and *vice versa;* and then climates would have been different from what they now are, and the inhabitants, animal or vegetable, would not have been as they are. And as they are, that wise Being who, in his kind providence, so watches over and regards the things of this world that he takes notice of the sparrow's fall, and numbers the very hairs of our head, doubtless designed them to be.

§ 212 Beauty of physical arrangements of the earth.

The mind is delighted, and the imagination charmed, by contemplating the physical arrangements of the earth from such points of view as this is which we now have before us; from it the sea, and the air, and the land, appear each as a part of that grand machinery upon which the well-being of all the inhabitants of earth, sea, and air depends; and which, in the beautiful adaptations that we are pointing out, affords new and striking evidence that they all have their origin in ONE omniscient idea, just as the different parts of a watch may be considered to have been constructed and arranged according to *one* human design.

§ 213 Precipitation sometimes greater than evaporation.

In some parts of the earth, the precipitation is greater than the evaporation; thus the amount of water borne down by every river that runs into the sea may be considered as the excess of the precipitation over the evaporation that takes place in the valley drained by that river.

CHAPTER III.

§ 214 This excess comes from the sea; the winds convey it to the interior; and the forces of gravity, dashing it along in mountain torrents or gentle streams, hurry it back to the sea again.

§ 215 *In other parts exactly equal.* In other parts of the earth, the evaporation and precipitation are exactly equal, as in those inland basins such as that in which the city of Mexico, Lake Titicaca, the Caspian Sea, &c., are situated, which basins have no ocean drainage.

§ 216 *Valley of Caspian Sea.* If more rain fell in the valley of the Caspian Sea than is evaporated from it, that sea would finally get full and overflow the whole of that great basin. If less fell than is evaporated from it again, then that sea, in the course of time, would dry up, and plants and animals there would all perish for the want of water.

§ 217 In the sheets of water which we find distributed over that and every other inhabitable inland basin, we see reservoirs, or evaporating surfaces, just sufficient for the supply of that degree of moisture which is best adapted to the well-being of the plants and animals that people such basins.

§ 218 *In others neither evaporation nor precipitation takes place* In other parts of the earth still, we find places, as the Desert of Sahara, in which neither evaporation nor precipitation takes place, and in which we find neither plant nor animal.

§ 219 *Terrestrial adaptations.* ADAPTATIONS.—In contemplating the system of terrestrial adaptations, these researches teach one to regard the mountain ranges and the great deserts of the earth as the astronomer does the counterpoises to his telescope—though they be mere dead weights, they are, nevertheless, necessary to make the balance complete, the adjustments of his machine perfect. These counterpoises give ease to the motions, stability to the performance, and accuracy to the workings of the instrument. They are "*compensations.*" CHAPTER III.

Whenever I turn to contemplate the works of nature, I am struck with the admirable system of compensation, with the beauty and nicety with which every department is poised by the others; things and principles are meted out in directions apparently the most opposite, but in proportions so exactly balanced and nicely adjusted that results the most harmonious are produced. § 220 System of compensation.

It is by the action of opposite and compensating forces that the earth is kept in its orbit, and the stars are held suspended in the azure vault of heaven; and these forces are so exquisitely adjusted, that, at the end of a thousand years, the earth, the sun, and moon, and every star in the firmament, is found to come and stand in its proper place at the proper moment. § 221 By it the earth is kept in its orbit.

Nay, philosophy teaches us that when the little snow-drop, which in our garden-walks we see raising its beautiful head at "the singing of birds," to remind us that "the winter is passed and gone," was created, the whole mass of the earth, from pole to pole, and from circumference to centre, must have been taken into account and weighed, in order that the proper degree of strength might be given to its tiny fibres. § 222 What philosophy teaches by the snow-drop.

Botanists tell us that the constitution of this plant is such as to require that, at a certain stage of its growth, the stalk should bend, and the flower should bow its head, that an operation may take place which is necessary in order that the herb should produce seed after its kind; § 223

CHAPTER III. Its constitution.

and that, after this fecundation, its vegetable health requires that it should lift its head again and stand erect. Now, if the mass of the earth had been greater or less, the force of gravity would have been different; in that case, the strength of fibre in the snow-drop, as it is, would have been too much or too little; the plant could not bow or raise its head at the right time, fecundation could not take place, and its family would have become extinct with the first individual that was planted, because its "seed" would not have been "in itself," and therefore it could not have reproduced itself, and its creation would have been a failure.

§ 224 Perfect adaptation

Now, if we see such perfect adaptation, such exquisite adjustment, in the case of one of the smallest flowers of the field, how much more may we not expect "compensation" in the atmosphere and the ocean, upon the right adjustment and due performance of which depends not only the life of that plant, but the well-being of every individual that is found in the entire vegetable and animal kingdoms of the world?

§ 225 Effects of east wind.

When the east winds blow along the Atlantic coast for a little while, they bring us air saturated with moisture from the Gulf Stream, and we complain of the sultry, oppressive, heavy atmosphere; the invalid grows worse, and the well man feels ill, because, when he takes this atmosphere into his lungs, it is already so charged with moisture that it cannot take up and carry off that which encumbers his lungs, and which nature has caused his blood to bring and leave there, that respiration may take up and carry off. At other times the air is dry and hot; he feels that it is conveying off matter from the lungs too fast; he realizes the idea that it is consuming him, and he calls the sensation burning. CHAPTER III.

§ 226 Assumption. Therefore, in considering the general laws which govern the physical agents of the universe, and regulate them in the due performance of their offices, I have felt myself constrained to set out with the assumption that, if the atmosphere had had a greater or less capacity for moisture, or if the proportion of land and water had been different—if the earth, air, and water had not been in exact counterpoise—the whole arrangement of the animal and vegetable kingdoms would have varied from their present state. But God, for reasons which man may never know, chose to make those kingdoms what they are; for this purpose it was necessary, in his judgment, to establish the proportions between the land and water and the desert just as they are, and to make the capacity of the air to circulate heat and moisture just what it is, and to have it to do all its work in obedience to law and in subservience to order. If it were not so, why was power given to the winds to lift up and transport moisture, and to feed the plants with nourishment? or why was the property given to the sea by which its waters may become first vapour, and then fruitful showers or gentle dews? If the proportions and properties of land, sea, and air were not adjusted according to the reciprocal capacities of all to perform the functions required by each, why should we be told that HE "measured the waters in the hollow of his hand, and comprehended the dust in a measure, and weighed the mountains in scales, and the hills in a balance?" Why did he span the heavens, but that he might mete out the atmosphere in exact propor-

CHAPTER III. tion to all the rest, and impart to it those properties and powers which it was necessary for it to have, in order that it might perform all those offices and duties for which he designed it?

§ 227 Lessons taught by sea and air. Harmonious in their action, the air and sea are obedient to law and subject to order in all their movements; when we consult them in the performance of their manifold and marvellous offices, they teach us lessons concerning the wonders of the deep, the mysteries of the sky, the greatness, and the wisdom, and goodness of the Creator, which make us wiser and better men. The investigations into the broad-spreading circle of phenomena connected with the winds of heaven and the waves of the sea are second to none for the good which they do and the lessons which they teach. The astronomer is said to see the hand of God in the sky; but does not the right-minded mariner, who looks aloft as he ponders over these things, hear his voice in every wave of the sea that "claps its hands," and feel his presence in every breeze that blows?

CHAPTER IV.

LAND AND SEA BREEZES.

Lieutenant Jansen, § 228.—His Contributions, 229.—The Sea-breeze, 230.—An Illustration, 231.—The Land-breeze, 232.—Jansen's Account of the Land and Sea Breeze in the East Indies, 234.—A Morning Scene, 235.—The Calm, 237. The Inhabitants of the Sea going to Work, 239.—Noon, 240.—The Sea-breeze dies, 245.—The Land-breeze, 247.—A Discussion, 248.—Why Land and Sea Breezes are not of equal Freshness on the Sea-shore of all Countries, 252.—The Sea-breeze at Valparaiso, 255.—The Night, 258.—A Contrast, 263.

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§ 228

Lieutenant Jansen

I HAVE been assisted in my investigations into these phenomena of the sea by many thinking minds; among those whose debtor I am, stands first and foremost the clear head and warm heart of a foreign officer, Lieutenant Marin Jansen, of the Dutch navy, whom I am proud to call my friend. He is an ornament to his profession; and a more accomplished officer it has never been my good fortune to meet in any service. He has entered this magnificent field of research *con amore*, and has proved to be a most zealous and efficient fellow-labourer. Promotion in the Dutch navy unfortunately goes by seniority; if it went by merit, I should I am sure, have the pleasure of writing of him as admiral.

§ 229

His contributions.

Jansen has served many years in the East Indies. He observed minutely and well. He has enriched my humble contributions to the "Physical Geography of the Sea" with contributions from the storehouse of his knowledge, set off and presented in many fine pictures, and has appended them to a translation of the first edition of this work into the Dutch language. He has added a chapter on the land and sea breezes; another on the

CHAPTER IV. changing of the monsoons in the East Indian Archipelago: he has also extended his remarks to the north-west monsoon, to hurricanes, the south-east trades of the South Atlantic, and to winds and currents generally.

§ 230 The sea-breeze. In many parts of the world the oppressive heat of summer is modified, and the climate of the sea-shore is made refreshing and healthful, by the alternation of winds which come from the sea by day and from the land by night. About ten in the morning the heat of the sun has played upon the land with sufficient intensity to raise its temperature above that of the water. A portion of this heat, being imparted to the superincumbent air, causes it to rise, when the air, first from the beach, then from the sea, to the distance of several miles, begins to flow in with a most delightful and invigorating freshness.

§ 231 Illustration. When a fire is kindled on the hearth, we may, if we will observe the motes floating in the room, see that those nearest to the chimney are the first to feel the draught and to obey it—they are drawn into the blaze. The circle of inflowing air is gradually enlarged, until it is scarcely perceived in the remote parts of the room. Now the land is the hearth, the rays of the sun the fire, and the sea, with its cool and calm air, the room; and thus we have at our firesides the sea-breeze in miniature.

§ 232 Land-breeze. When the sun goes down the fire ceases; then the dry land commences to give off its surplus heat by radiation, so that by nine or ten o'clock it and the air above it are cooled below the sea temperature. The atmosphere on the land thus becomes heavier than that on the sea, and, consequently, there is a wind seaward which we call the land-breeze.

Jansen thus describes this phenomenon in the East Indies, where one must live fully to appreciate its benign influences. CHAPTER IV. § 233

JANSEN'S ACCOUNT.*—"A long residence in the East Indian Archipelago, and, consequently, in that part of the world where the investigations of the Observatory at Washington have not extended, has given me the opportunity of studying the phenomena which there occur in the atmosphere, and to these phenomena my attention was, in the first place, directed. I was involuntarily led from one research to another, and it is the result of these investigations to which I would modestly give a place at the conclusion of Maury's 'Physical Geography of the Sea,' with the hope that these first-fruits of the log-books of the Netherlands may be speedily followed by more and better. § 234 Jansen's observations.

"Upon the northern coast of Java, the phenomenon of daily land and sea breezes is finely developed. There, as the gorgeous 'eye of day' rises almost perpendicularly from the sea with fiery ardour, in a cloudless sky, it is greeted by the volcanoes with a column of white smoke, which, ascending from the conical summits high in the firmament above, forms a crown, or assumes the shape of an immense bouquet,† that they seem to offer to the dawn; then the joyful land-breeze plays over the flood, which, in the torrid zone, furnishes, with its fresh breath, so much enjoyment to the inhabitants of that sultry belt § 235 Land and sea breezes on the northern coast of Java. Land-breeze.

* Jansen's Appendix to the "Physical Geography of the Sea," translated from the Dutch by Mrs. Dr. Breed, Washington.

† Upon the coast of Java I saw daily, during the east monsoon, such a column of smoke ascending at sunrise from Bromo, Lamongan, and Smiro. Probably there is then no wind above.—JANSEN.

CHAPTER IV. — It effects. of earth, for, by means of it, everything is refreshed and beautified. Then, under the influence of the glorious accompaniments of the break of day, the silence of the night is awakened, and we hear commencing everywhere the morning hymn of mute nature, whose gesticulation is so expressive and sublime. All that lives feels the necessity of pouring forth, each in its way, and in various tones and accents, from the depths of inspiration, a song of praise.

§ 236 "The air, still filled with the freshness of the evening dew, bears aloft the enraptured song, as, mingled with the jubilee tones which the contemplation of nature everywhere forces from the soul, it gushes forth in deep earnestness to convey the daily thank-offering over the sea, over hill and dale.*

§ 237 It dies away. "As the sun ascends the sky, the azure vault is bathed in dazzling light; now the land-breeze, wearied with play, goes to rest. Here and there it still plays over the water, as if it could not sleep; but finally becoming exhausted, it sinks to repose in the stillness of the calm. But not so with the atmosphere: it sparkles, and glitters, and twinkles, becoming clear under the increasing heat, while the gentle swelling of the now polished waves, reflects, like a thousand mirrors, the rays of light which dance and leap to the tremulous but vertical movements of the atmosphere.

§ 238 "Like pleasant visions of the night, that pass before the mind in sleep, so do sweet phantoms hover about the land-breeze as it slumbers upon the sea. The shore seems

* In the very fine mist of the morning, a noise—for example, the firing of cannon—at a short distance is scarcely heard, while at mid-day, with the sea-breeze, it penetrates for miles with great distinctness.—JANSEN.

to approach and to display all its charms to the mariner in the offing. All objects become distinct and more clearly delineated,* while, upon the sea, small fishing-boats loom up like large vessels. The seaman, drifting along the coast, and misled by the increasing clearness and mirage, believes that he has been driven by a current toward the land; he casts the lead, and looks anxiously out for the sea-breeze, in order to escape from what he believes to be threatening danger.† The planks burn under his feet; in vain he spreads the awning to shelter himself from the broiling sun. Its rays are oppressive; repose does not refresh; motion is not agreeable. CHAPTER IV. — Description.

"The inhabitants of the deep, awakened by the clear light of day, prepare themselves for labour. Corals, and thousands of crustacea, await, perhaps impatiently, the coming of the sea-breeze, which shall cause evaporation to take place more rapidly, and thus provide them with a bountiful store of building material for their picturesque and artfully constructed dwellings: these they know how to paint and to polish in the depths of the sea more beautifully than can be accomplished by any human art. Like them, also, the plants of the sea are dependent upon the winds, upon the clouds, and upon the sunshine; for upon these depend the vapour and the rains which feed the streams that bring nourishment for them into the sea.‡ § 239

* The transparency of the atmosphere is so great that we can sometimes discover Venus in the sky in the middle of the day.—JANSEN.

† Especially in the rainy season the land looms very greatly; then we see mountains which are from 5000 to 6000 feet high at a distance of 80 or 100 English miles.

‡ The archipelago of coral islands on the north side of the Straits of Sunda is remarkable. Before the salt water flowed from the Straits, it was deprived of the solid matter of which the *Thousand Islands* are constructed. A similar group of islands is found between the Straits of Macassar and Balie.—JANSEN.

CHAPTER IV.

§ 240 Description continued.

"When the sun reaches the zenith, and his stern eye, with burning glare, is turned more and more upon the Java Sea, the air seems to fall into a magnetic sleep; yet, even as the magnetizer exercises his will upon his subject, and the latter, with uncertain and changeable gestures, gradually puts himself in motion, and, sleeping, obeys that will, so also we see the slow efforts of the sea-breeze to repress the vertical movements of the air, and to obey the will which calls it to the land. This vertical movement appears to be not easily overcome by the horizontal, which we call wind. Yonder, far out upon the sea, arises and disappears alternately a darker tint upon the otherwise shining sea-carpet; finally, that tint remains and approaches; that is the long-wished-for sea-breeze; and yet it is sometimes one, yes, even two hours, before that darker tint is permanent, before the sea-breeze has regularly set in.

§ 241 "Now small white clouds begin to rise above the horizon; to the experienced seaman they are a prelude to a fresh sea-breeze. We welcome the first breath from the sea; it is cooling, but it soon ceases; presently it is succeeded by other grateful puffs of air, which continue longer; presently they settle down into the regular sea-breeze, with its cooling and refreshing breath.

§ 242 Sea-wind. "The sun declines, and the sea-wind—that is, the common trade-wind or monsoon which is drawn toward the land—is awakened. It blows right earnestly, as if it would perform its daily task with the greatest possible ado.

§ 243 "The air, itself refreshed upon the deep, becomes gray from the vapour which envelopes the promontories in mist, and curtains the inland with dark clouds. The land, relieved by the darker tint which it gives to the mist, looms up beautifully; the distance cannot be estimated. The sailor thinks himself farther from shore than he really is, and steers on his course carelessly, while the capricious wind lashes the waters, and makes a short and broken sea, from the white caps of which light curls are torn, with sportive hand, to float away like party-coloured streamers in the sunbeam. In the meanwhile clouds appear now and then high in air, yet it is too misty to see far.

Description continued.

"The sun approaches the horizon. Far over the land the clouds continue to heap up; already the thunder is heard among the distant hills; the thunder-bolts reverberate from hill-side to hill-side, while through the mist the sheets of lightning are seen.* § 244

"Finally, the 'king of day' sinks to rest; now the mist gradually disappears, and as soon as the wind has laid down the lash, the sea, which, chafing and fretting, had with curled mane resisted its violence, begins to go down also. Presently both winds and waves are hushed, and all is again still. Above the sea, the air is clearer or slightly clouded; above the land, it is thick, dark, and swollen. To the feelings, this stillness is pleasant. The sea-breeze, the driving brine that has made a salt-pan of the face, the short, restless sea, the dampness—all have grown wearisome, and welcome is the calm. There is, however, a somewhat of dimness in the air, an uncertain but threatening appearance. Presently, from the § 245

* At Buitenzorg, near Batavia, 40 English miles from the shore, 500 feet above the sea, with high hills around, these thunder-storms occur between 4 P.M. and 8 P.M.

CHAPTER IV. dark mass of clouds, which hastens the change of day into night, the thunder-storm peals forth. The rain falls in torrents in the mountains, and the clouds gradually overspread the whole sky. But for the wind, which again springs up, it would be alarming to the sailor, who is helpless in a calm. What change will take place in the air? The experienced seaman, who has to work against the trade-wind or against the monsoon, is off the coast, in order to take advantage of the land-breeze (the destroyer of the trade) so soon as it shall come. He rejoices when the air is released from the land, and the breeze comes, at first feebly, but afterward growing stronger, as usual, during the whole night. If the land-breeze meets with a squall, then it is brief, and becomes feeble and uncertain. We sometimes find then the permanent sea-breeze close to the coast, which otherwise remains twenty or more English miles from it.

§ 246 "One is not always certain to get the land-breeze at the fixed time. It sometimes suffers itself to be waited for; sometimes it tarries the whole night long.

§ 247 "During the greatest part of the rainy season, the land-breeze in the Java Sea cannot be depended upon. This is readily explained according to the theory which ascribes the origin of the sea and land breezes to the heating of the soil by day, and the cooling by means of radiation by night; for, during the rainy season, the clouds extend over land and sea, interrupting the sun's rays by day, and the radiation of heat by night, thus preventing the variations of temperature; and from these variations, according to this theory, the land and sea breezes arise. Yet there are other tropical regions where

Land-breeze in Java not to be depended on.

the land and sea breezes, even in the rainy season, regularly succeed each other. CHAPTER IV.

"The warming and the radiation alone are therefore not sufficient to explain all the phenomena of land and sea breezes, and other causes—electricity, rain, &c., appear to have an influence upon the regularity of the land winds.* § 248

"Upon the coast of Africa, the land-breeze is universally scorching hot, but the sea-breeze is cool and refreshing. When this is the case, the land-breeze certainly cannot be occasioned by the cooling of the earth by radiation. When we shall have brought together all the observations upon the various phenomena which the land and sea breezes afford, then we shall be able to begin to found upon facts a theory which shall explain the varied phenomena. Thus, among other things, upon the west coast of Africa, from 0° 27′ S. to 15° 24′ S., according to Thomas Miller,† from June to October, and, above all, in July, there are heavy dews, and when the dews are very heavy, then the land and sea breezes are invariably feeble—sometimes very faint." § 249

Land-breeze on the coast of Africa.

Observations by Thomas Miller.

[Lieutenant Jansen's remarks are both instructive and suggestive. It is true that a given difference of tem- § 250

* My observations lead me to suspect that the position of the moon is also herein concerned. In the eastern outlet of Sourabaya, during the east monsoon, there is at full moon little land-breeze, and at new moon little sea-breeze. I afterward made the same observation in the Gulf of Darien. *Feb.* 4, 1852.—At the Road of Carthagena (New Grenada), full moon, sea-breeze north, under reefed top-sail, fresh gale; at 11 P. M., feeble and easterly. *Feb.* 5.—11 A. M., sea-breeze grows faint. 1 P. M., stronger, and between 5 and 6 P. M. fresh gale; double-reefed top-sail. Each day somewhat later and less hard. Thermometer varying between 79° and 80°. Barometer varying between 763° and 759°. Upon leaving Chagres, with new moon, it was by day mostly feeble.—JANSEN.

† Nautical Magazine for June 1855.—JANSEN.

CHAPTER IV. perature between land and water, though it may be sufficient to produce the phenomena of land and sea breezes at one place, will not be adequate to the same effect at another; and the reason is perfectly philosophical.

§ 251 Philosophical reason why causes of land and sea-breezes at one place will not produce them at another. It is easier to obstruct and turn back the current in a sluggish than in a rapid stream. So, also, in turning a current of air first upon the land, then upon the sea—very slight alterations of temperature would suffice for this on the coast of Africa, in and about the equatorial calms, for instance; there the air is in a state of rest, and will obey the slightest call in any direction—not so in regions where the trades blow over the land, and are strong. It requires, under such circumstances, a considerable degree of rarefaction to check them, and produce a calm, and a still farther rarefaction to turn them back, and convert them into a regular sea-breeze.

§ 252 Scorching land-breeze on west coast of Africa. Hence the scorching land-breeze on the west coast of Africa: the heat there may not have been intense enough to produce the degree of rarefaction required to check and turn back the south-east trades. In that part of the world, their natural course is from the land to the sea, and therefore, if this view be correct, the sea-breeze should be more feeble than the land-breeze, neither should it last so long.

§ 253 Sea-breeze prevails on the coast of Brazil. But on the opposite side—on the coast of Brazil, as at Pernambuco, for instance—where the trade-wind comes from the sea, we should have this condition of things reversed, and the sea-breeze will prevail for most of the time—then it is the land-breeze which is feeble and of short duration: it is rarely felt.

§ 254 Again, the land and sea breezes in Cuba, and along the Gulf shores of the United States, will be more regular in their alternations than they are along the shores of Brazil or South Africa, and for the simple reason that the shore-wind named in North American waters lies nearly parallel with the course of the winds in their prevailing direction. In Rio de Janeiro, the sea-breeze is the regular trade-wind, made fresher by the daily action of the sun on the land. It is worthy of remark, also, that, for the reason stated by Jansen, the land and sea breezes in the winter time are almost unknown in countries of severe cold, though, in the summer, the alternation of wind from land to sea, and sea to land, may be well marked.

Cuba.

Rio de Janeiro.

In Valparaiso, the phenomenon of the sea-breeze is finely developed. Valparaiso is situated near the southern border of the calm belt of Capricorn, when it is at its farthest southern reach, which happens in our late winter and early spring—the Southern summer and autumn. This is the dry season, when the sky is singularly clear and bright. The atmosphere, being nearly in a state of equilibrium, is then ready to obey even the most feeble impulse, and to hasten toward the place of any, the slightest rarefaction. § 255

Phenomenon of sea-breeze finely developed in Valparaiso

At about ten in the morning, at this season of the year, the land begins to feel the sun, and there is a movement in the air. By 3 or 4 P.M., the sea-breeze comes rushing in from the southward and westward, and strikes the shipping in the harbour with the force of a gale. Vessels sometimes drag before it, and communication with the shore is suspended. By 6 P.M., however, the wind has spent its fury, and there is a perfect calm.] § 256

Begins at 3 or 4 p.m

CHAPTER IV.

§ 257 Quotation from Jansen.

"Happy he," continues Jansen, "who, in the Java Sea at evening, seeking the land-breeze off the coast, finds it there, after the salt-bearing, roaring sea-wind, and can, in the magnificent nights of the tropics, breathe the refreshing land-breeze, ofttimes laden with delicious odours.*

§ 258 Description by Jansen of land and sea breezes in the Java Sea.

"The veil of clouds, either after a squall, with or without rain, or after the coming of the land-breeze, is speedily withdrawn, and leaves the sky clearer during the night, only now and then flecked with dark clouds floating over from the land. Without these floating clouds the land-breeze is feeble. When the clouds float away from the sea, the land-breeze does not go far out from the coast, or is wholly replaced by the sea-breeze, or, rather, by the trade-wind. If the land-breeze continues, then the stars loom forth, as if to free themselves from the dark vault of the heavens, but their light does not wholly vanquish its deep blue, though the dark flecking of clouds comes out more distinctly near the Southern Cross, which smiles consolingly upon us, while Scorpio, the emblem of the tropical climate, stands like a warning in the heavens. The starlight, which is reflected by the mirrored waters, causes the nights to vie in clearness with the early twilight in high latitudes. Numerous shooting stars weary the eye, although they break the monotony of the sparkling firmament. Their unceasing motion in the unfathomable ocean affords a great contrast to the seeming quiet of the gently-flowing aerial current of the land-breeze. But at times, when, 30° or 40° above the horizon, a fire-ball arises, which suddenly illumines

* In the roads of Batavia, however, they are not very agreeable.—JANSEN.

the whole horizon, appearing to the eye the size of the fist, and fading away as suddenly as it appeared, falling into fiery nodules, then we perceive that, in the apparent calm of nature, various forces are constantly active, in order to cause, even in the invisible air, such combinations and combustions, the appearance of which amazes the crews of ships. CHAPTER IV.

"When the slender keel glides quickly over the mirrored waters upon the wings of the wind, it cuts for itself a sparkling way, and disturbs in their sleep the monsters of the deep, which whirl and dart quicker than an eight-knot ship; sweeping and turning around their disturber, they suddenly clothe the dark surface of the water in brilliancy. Again, when we go beyond the limits of the land-breeze, and come into the continuous trade-wind, we occasionally see from the low-moving, round black clouds (unless it thunders), light blue sparks collected upon the extreme points of the iron belaying-pins, &c.;* then the crew appear to fear a new danger, against which courage is unavailing, and which the mind can find no power to endure. The fervent, fiery nature inspires the traveller with deep awe. They who, under the beating of the storm and terrible violence of the ocean, look danger courageously in the face, feel, in the presence of these phenoma, insignificant, feeble, anxious. Then they perceive the mighty power of the Creator over the works of his creation. § 259 Phosphoric light. Electricity

"And how can the uncertain, the undetermined sensations arise which are produced by the clear yet sad light § 260

* I have seen this in a remarkable degree upon the south coast of Java; these sparks were then seen six feet above the deck, upon the frames of timber, *(kousscn der blokken)*, in the implements, &c.—JANSEN.

CHAPTER IV. of the moon?—she who has always great tears in her eyes, while the stars look sweetly at her, as if they loved to trust her and to share her affliction?*

§ 261 Fickleness of land-breeze. "In the latter part of the night, the land-breeze sinks to sleep, for it seldom continues to blow with strength, but is always fickle and capricious. With the break of day it again awakes, to sport a while, and then gradually dies away as the sun rises. The time at which it becomes calm after the land and sea breezes is indefinite, and the calms are of unequal duration.

§ 262 Calms that precede land and sea breezes. "Generally, those which precede the sea-breeze are rather longer than those which precede the land-breeze. The temperature of the land, the direction of the coast-line with respect to the prevailing direction of the trade-wind in which the land is situated, the clearness of the atmosphere, the position of the sun, perhaps also that of the moon, the surface over which the sea-breeze blows, possibly also the degree of moisture and the electrical state of the air, the heights of the mountains, their extent, and their distance from the coast, all have influence thereon. Local observations in regard to these can afford much light, as well as determine the distance at which the land-breeze blows from the coast, and beyond which the regular trade-wind or monsoon continues uninterruptedly to blow. The direction of land and sea winds must also be determined by local observations, for the idea is incorrect that they should always blow perpendicular to the coast-line.

Limits.

* Some one has ventured the remark, that at full moon, near the equator, more and darker dew falls than at new moon, and to this are ascribed the moonheads *(maan hoofden)*, which I have seen, however, but once during all the years which I have spent between the tropics. —JANSEN.

CHAPTER IV.

§ 263 Easterly part of East Indian archipelago.

"Scarcely has one left the Java Sea,—which is, as it were, an inland sea between Sumatra, Borneo, Java, and the archipelago of small islands between both of the last-named,—than, in the blue waters of the easterly part of the East Indian archipelago, nature assumes a bolder aspect, more in harmony with the great depth of the ocean. The beauty of the Java Sea, and the delightful phenomena which air and ocean display, have here ceased. The scene becomes more earnest. The coasts of the eastern islands rise boldly out of the water, far in whose depths they have planted their feet. The south-east wind, which blows upon the southern coasts of the chain of islands, is sometimes violent, always strong through the straits which separate them from each other, and this appears to be more and more the case as we go eastward. Here, also, upon the northern coast, we find land-breezes, yet the trade-wind often blows so violently that they have not sufficient power to force it beyond the coast.

§ 264 Effects of the obstruction of islands.

"Owing to the obstruction which the chain of islands presents to the south-east trade-wind, it happens that it blows with violence away over the mountains, apparently as the land breeze does upon the north coast;* yet this wind, which only rises when it blows hard from the south-east upon the south coast, is easily distinguished from the gentle land-breeze.

§ 265 Cause of regularity of land and sea breezes in Java Sea.

"The regularity of the land and sea breezes in the Java Sea and upon the coasts of the northern range of islands, Banca, Borneo, Celebes, &c., during the east monsoon, must in part be ascribed to the hindrances which the

* Such is the case, among others, in the Strait Madura, upon the heights of Bezoekie.

CHAPTER IV. south-east trade-wind meets in the islands which lie directly in its way; in part to the inclination toward the east monsoon which the trade-wind undergoes after it has come within the archipelago; and, finally, to its abatement as it approaches the equator. The causes which produce the land-breezes thus appear collectively not sufficiently powerful to be able to turn back a strong trade-wind in the ocean."

CHAPTER V.

RED FOGS AND SEA DUST.

CHAPTER V. § 266 Red fogs and sea-dust.

SEAMEN tell us of "red fogs" which they sometimes encounter, especially in the vicinity of the Cape de Verd Islands. In other parts of the sea, also, they meet showers of dust. What these showers precipitate in the Mediterranean is called "sirocco dust," and in other parts "African dust," because the winds which accompany them are supposed to come from the Sirocco desert, or some other parched land of the continent of Africa. It is of a brick-red or cinnamon colour, and it sometimes comes down in such quantities as to cover the sails and rigging, though the vessel may be hundreds of miles from the land.

Now, the patient reader who has had the heart to follow me, in the preceding chapter, around with "the wind in his circuits," will perceive that proof is yet wanting to establish it as a fact, that the north-east and south-east trades, after meeting and rising up in the equatorial calms, do cross over and take the paths represented by C and G, Plate I. § 267 Proof wanted that the trade-winds cross over and take the paths shown in Plate I.

Statements and reasons and arguments enough have already been made and adduced to make it highly probable, according to human reasoning, that such is the § 268

CHAPTER V. case; and though the theoretical deductions, showing such to be the case, be never so plausible, positive proof that they are true cannot fail to be received with delight and satisfaction.

§ 269 Difficulty of finding such proof. Were it possible to take a portion of this air, representing, as it travels along with the south-east trades, the general course of atmospherical circulation, and to put a tally on it by which we could follow it in its circuits and always recognise it, then we might hope actually to prove, by evidence the most positive, the channels through which the air of the trade-winds, after ascending at the equator, returns whence it came.

§ 270 But the air is invisible; and it is not easily perceived how either marks or tallies may be put upon it, that it may be traced in its paths through the clouds. The sceptic, therefore, who finds it hard to believe that the general circulation is such as Plate I. represents it to be, might consider himself safe in his unbelief were he to declare his willingness to give it up the moment any one should put tallies on the wings of the wind, which would enable him to recognise that air again, and those tallies, when found at other parts of the earth's surface.

§ 271 Ehrenberg's discovery. As difficult as this seems to be, it has actually been done. Ehrenberg, with his microscope, has established, almost beyond a doubt, that the air which the south-east trade-winds bring to the equator does rise up there and pass over into the northern hemisphere.

§ 272 Tallies put on the wind. The Sirocco, or African dust, which he has been observing so closely, has turned out to be tallies put upon the wind in the other hemisphere; and this beautiful instrument of his enables us to detect the marks on these little tallies as plainly as though those marks had been written upon labels of wood and tied to the wings of the wind. CHAPTER V.

§ 273 Microscopic examination of dust.
This dust, when subjected to microscopic examination, is found to consist of infusoria and organisms whose *habitat* is not Africa, but South America, and in the south-east trade-wind region of South America. Professor Ehrenberg has examined specimens of sea dust from the Cape de Verds and the regions thereabout, from Malta, Genoa, Lyons, and the Tyrol; and he has found a similarity among them as striking as it would have been had these specimens been all taken from the same pile. South American forms he recognises in all of them; indeed they are the prevailing forms in every specimen he has examined. Results.

§ 274 Upper current of air from South to North America.
It may, I think, be now regarded as an established fact, that there is a perpetual upper current of air from South America to North Africa; and that the volume of air which flows to the northward in these upper currents is nearly equal to the volume which flows to the southward with the north-east trade-winds, there can be no doubt.

§ 275 Rain dust most frequently falls in spring and autumn.
The "rain dust" has been observed most frequently to fall in spring and autumn; that is, the fall has occurred after the equinoxes, but at intervals from them varying from thirty to sixty days, more or less. To account for this sort of periodical occurrence of the falls of this dust, Ehrenberg thinks it "necessary to suppose *a dust-cloud to be held constantly swimming in the atmosphere by continuous currents of air, and lying in the region of the trade-winds, but suffering partial and periodical deviations.*" Ehrenberg's supposition.

CHAPTER V.

§ 276 It has already been shown,[1] that the rain or calm belt between the trades travels up and down the earth from north to south, making the rainy season wherever it goes. The reason of this will be explained in another place.

§ 277 This dust probably taken up in the dry, and not in the wet season.

This dust is probably taken up in the dry and not in the wet season. Instead, therefore, of its being "held in clouds suffering partial and periodical deviations," as Ehrenberg suggests, it more probably comes from one place about the vernal, and from another about the autumnal equinox; for places which have their rainy season at one equinox have their dry season at the other.

§ 278 Valley of the Lower Oronoco during vernal equinox parched with drought.

At the time of the vernal equinox, the valley of the Lower Oronoco is then in its dry season; everything is parched up with the drought; the pools are dry, and the marshes and plains become arid wastes. All vegetation has ceased; the great serpents and reptiles have buried themselves for hibernation;* the hum of insect life is hushed, and the stillness of death reigns through the valley.

Under these circumstances, the light breeze, raising dust from lakes that are dried up, and lifting motes from the brown savannas, will bear them away like clouds in the air.

§ 279 It is also swept over by whirlwinds.

This is the period of the year when the surface of the earth in this region, strewed with impalpable and feather-light remains of animal and vegetable organisms, is swept over by whirlwinds, gales, and tornadoes of terrific force. This is the period for the general atmospheric disturbances which have made characteristic the equinoxes. Do not these conditions appear sufficient to afford the "rain dust" for the spring showers?

* Humboldt.

[1] § 188.

At the period of the autumnal equinox, another portion of the Amazonian basin is parched with drought, and liable to winds that fill the air with dust, and with the § 280
remains of dead animal and vegetable matter; these impalpable organisms, which each rainy season calls into being, to perish the succeeding season of drought, are perhaps distended and made even lighter by the gases of decomposition which has been going on in the period of drought.

During the autumnal equinox another part of the Amazonian basin is parched

May not, therefore, the whirlwinds which accompany § 281
the vernal equinox, and sweep over the lifeless plains of the Lower Oronoco, take up the "rain dust" which descends in the northern hemisphere in April and May? and may it not be the atmospherical disturbances which accompany the autumnal equinox that take up the microscopic organisms from the Upper Oronoco and the great Amazonian basin for the showers of October?

May not these whirlwinds take up the rain dust.

The Baron von Humboldt, in his *Aspects of Nature*, § 282
thus contrasts the wet and the dry seasons there:

"When, under the vertical rays of the never-clouded sun, the carbonized turfy covering falls into dust, the indurated soil cracks asunder as if from the shock of an earthquake. If at such times two opposing currents of air, whose conflict produces a rotary motion, come in contact with the soil, the plain assumes a strange and singular aspect. Like conical-shaped clouds, the points of which descend to the earth, the sand rises through the rarefied air on the electrically-charged centre of the whirling current, resembling the loud water-spout, dreaded by the experienced mariner. The lowering sky sheds a dim, almost straw-coloured light on the desolate plain.

Contrast of the wet and dry season by Von Humboldt.

CHAPTER V.

The horizon draws suddenly nearer, the steppe seems to contract, and with it the heart of the wanderer. The hot, dusty particles which fill the air increase its suffocating heat, and the east wind, blowing over the long-heated soil, brings with it no refreshment, but rather a still more burning glow. The pools which the yellow, fading branches of the fan-palm had protected from evaporation, now gradually disappear. As in the icy north the animals become torpid with cold, so here, under the influence of the parching drought, the crocodile and the boa become motionless and fall asleep, deeply buried in the dry mud. . . . .

Contrast continued.

"The distant palm-bush, apparently raised by the influence of the contact of unequally heated and therefore unequally dense strata of air, hovers above the ground, from which it is separated by a narrow intervening margin. Half-concealed by the dense clouds of dust, restless with the pain of thirst and hunger, the horses and cattle roam around, the cattle lowing dismally, and the horses stretching out their long necks and snuffing the wind, if haply a moister current may betray the neighbourhood of a not wholly dried-up pool. . . . .

"At length, after the long drought, the welcome season of the rain arrives; and then how suddenly is the scene changed! . . . .

"Hardly has the surface of the earth received the refreshing moisture, when the previously barren steppe begins to exhale sweet odours, and to clothe itself with killingias, the many panicles of the paspulum, and a variety of grasses. The herbaceous mimosas, with renewed sensibility to the influence of light, unfold their drooping, slumbering leaves to greet the rising sun; and the early song of birds and the opening blossoms of the water-plants join to salute the morning." CHAPTER V.

The arid plains and deserts, as well as high mountain ranges, have, it may well be supposed, an influence upon the movements of the great aerial ocean, as shoals and other obstructions have upon the channels of circulation in the sea. The deserts of Asia, for instance, produce[1] a disturbance upon the grand system of atmospherical circulation, which, in summer and autumn, is felt in Europe, in Liberia, and away out upon the Indian Ocean, as far to the south as the equinoctial line. There is an indraught from all these regions toward these deserts. These indraughts are known as monsoons at sea; on the land, as the prevailing winds of the season. § 283

Effects of the deserts on atmospherical circulation

Imagine the area within which this indraught is felt, and let us ask a question or two, hoping for answers. The air which the indraught brings into the desert places, and which, being heated, rises up there, whither does it go? It rises up in a column a few miles high and many in circumference, we know, and we can imagine that it is like a shaft many times thicker than it is tall, but how is it crowned? Is it crowned like the stem of a mushroom, with an efflorescence or ebullition of heated air flaring over and spreading out in all directions, and then gradually thinning out as an upper current, extending even unto the verge of the area whence the indraught is drawn? If so, does it then descend and return to the desert plains as an indraught again? Then these desert places would constitute centres of circulation for the monsoon period; and if they were such centres, whence would § 284

Questions to be answered.

[1] § 203.

CHAPTER V. these winds get the vapour for their rains in Europe and Asia?

§ 285 Or, instead of the mushroom shape, and the flare at the top in all directions from centre to circumference, does the uprising column, like one of those submarine fountains which are said to be in the Gulf Stream off the coast of Florida, bubble up and join in with the flow of the upper current? The right answers and explanations to these questions would add greatly to our knowledge concerning the general circulation of the atmosphere. It may be in the power of the microscope to give light here. Let us hope.

§ 286 Colour of rain dust. The colour of the "rain dust," when collected in parcels and sent to Ehrenberg, is "brick-red," or "yellow ochre;" when seen by Humboldt in the air, it was less deeply shaded, and is described *by him* as imparting a "straw colour" to the atmosphere. In the search of spider lines for the diaphragm of my telescopes, I procured the finest and best threads from a cocoon of a mud-red colour; but the threads of this cocoon, as seen singly in the diaphragm, were of a golden colour; there would seem, therefore, no difficulty in reconciling the difference between the colours of the rain dust when viewed in little piles by the microscopist, and when seen attenuated and floating in the wind by the great traveller.

§ 287 A clew. It appears, therefore, that we here have placed in our hands a clew, which, attenuated and gossamer-like though it at first appears, is nevertheless palpable and strong enough to guide us along through the "circuits of the wind" even unto "the chambers of the south."

§ 288 The frequency of the fall of "rain dust" between the parallels of 17° and 25° north, and in the vicinity of the Cape Verd Islands, is remarked upon with emphasis by the microscopist. It is worthy of remark, because, in connection with the investigations at the Observatory, it is significant.

Frequency of fall of rain dust near the Cape Verd Islands.

§ 289 The latitudinal limits of the northern edge of the north-east trade-winds are variable. In the spring they are nearest to the equator, extending sometimes at this season not farther from the equator than the parallel of 15° north.

Latitudinal limits of trade-winds variable.

§ 290 The breadth of the calms of Cancer is also variable; so also are their limits. The extreme vibration of this zone is between the parallels of 17° and 38° north, according to the season of the year.

Breadth of calms of Cancer variable.

§ 291 According to the hypothesis[1] suggested by my researches, this is the zone in which the upper currents of atmosphere that ascended in the equatorial calms, and flowed off to the northward and eastward, are supposed to descend. This, therefore, is the zone in which the atmosphere that bears the "rain dust," or "African sand," descends to the surface; and this, therefore, is the zone, it might be supposed, which would be the most liable to showers of this "dust." This is the zone in which the Cape Verd Islands are situated; they are in the direction which theory gives to the upper current of air from the Oronoco and Amazon with its "rain dust," and they are in the region of the most frequent showers of "rain dust," all of which, though they do not absolutely prove, are nevertheless strikingly in conformity with, this theory as to the circulation of the atmosphere.

Confirmation of theory as to circulation of atmosphere.

§ 292 It is true that, in the present state of our information,

[1] § 130.

CHAPTER V. we cannot tell why this "rain dust" should not be gradually precipitated from this upper current, and descend into the stratum of trade-winds, as it passes from the equator to higher northern latitudes; neither can we tell why the vapour which the same winds carry along should not, in like manner, be precipitated on the way; nor why we should have a thunder-storm, a gale of wind, or the display of any other atmospherical phenomenon to-morrow, and not to-day: all that we can say is, that the conditions of to-day are not such as the phenomenon requires for its own development.

§ 293 *Fall of rain dust always occurs in same atmospherical vein.* Therefore, though we cannot tell why the "sea-dust" should not fall always in the same place, we may nevertheless suppose that it is not always in the atmosphere, for the storms that take it up occur only occasionally, and that when up, and in passing the same parallels, it does not, any more than the vapour from a given part of the sea, always meet with the conditions—electrical and others—favourable to its descent, and that these conditions, as with the vapour, may occur now in this place, now in that. But that the fall does occur always in the same atmospherical vein or general direction, my investigations would suggest, and Ehrenberg's researches prove.

§ 294 *General regularity of upper currents.* Judging by the fall of sea or rain dust, we may suppose that the currents in the upper regions of the atmosphere are remarkable for their general regularity, as well as for their general direction and sharpness of limits, so to speak.

§ 295 We may imagine that certain electrical conditions are necessary to a shower of "sea-dust," as well as to a thunder-storm; and that the interval between the time of the

CHAPTER V.

equinoctial disturbances in the atmosphere and the occurrence of these showers, though it does not enable us to determine the true rate of motion in the general system of atmospherical circulation, yet assures us that it is not less on the average than a certain rate.

Author's remarks.

I do not offer these remarks as an explanation with which we ought to rest satisfied, provided other proof can be obtained; I rather offer them in the true philosophical spirit of the distinguished microscopist himself, simply as affording, as far as they are entitled to be called an explanation, that explanation which is most in conformity with the facts before us, and which is suggested by the results of a novel and beautiful system of philosophical research. It is not, however, my province, or that of any other philosopher, to dictate belief. Any one may found hypotheses if he will state his facts and the reasoning by which he derives the conclusions which constitute the hypothesis. Having done this, he should patiently wait for time, farther research, and the judgment of his peers, to expand, confirm, or reject the doctrine which he may have conceived it his duty to proclaim. § 296

Another agent concerned in atmospheric circulation.

Thus, though we have tallied the air, and put labels on the wind, to "tell whence it cometh and whither it goeth," yet there evidently is an agent concerned in the circulation of the atmosphere whose functions are manifest, but whose presence has never yet been clearly recognized. § 297

When the air which the north-east trade-winds bring down meets in the equatorial calms that which the south-east trade-winds convey, and the two rise up together, what is it that makes them cross? Where is the power § 298

CHAPTER V. that guides that from the north over to the south, and that from the south up to the north?

The conjectures in the next chapter as to "the relation between magnetism and the circulation of the atmosphere" may perhaps throw some light upon the answer to this question.

CHAPTER VI.

ON THE PROBABLE RELATION BETWEEN MAGNETISM AND THE CIRCULATION OF THE ATMOSPHERE.

OXYGEN, philosophers say, comprises one-fifth part of the atmosphere, and Faraday has discovered that it is magnetic. CHAPTER VI.

§ 299 Oxygen is magnetic.

This discovery presents itself to the mind as a great physical fact, which is perhaps to serve as the keystone for some of the grand and beautiful structures which philosophy is building up for monuments to the genius of the age.

§ 300 Heat and diurnal rotation not sufficient to account for all the currents of sea and air

Certain facts and deductions elicited in the course of these investigations had directed my mind to the workings in the atmosphere of some agent, as to whose character and nature I was ignorant. Heat, and the diurnal rotation of the earth on its axis, were not, it appeared to me, sufficient to account for all the currents of both sea and air which investigation was bringing to light.

CHAPTER VI.

§ 301

Reason to suppose that the trade-winds cross at the calm belts.

For instance, there was reason to suppose that there is a crossing of winds at the three calm belts; that is, that the south-east trade-winds, when they arrive at the belt of equatorial calms and ascend, cross over and continue their course as an upper current to the calms of Cancer, while the air that the north-east trade-winds discharge into the equatorial calm belt continues to go south, as an upper current bound for the calms of Capricorn. But what should cause this wind to cross over? Why should there not be a general mingling in this calm belt of the air brought by the two trade-winds, and why should not that which the south-east winds convey there be left, after its ascent, to flow off either to the north or to the south, as chance directs?

§ 302 In the first place, it was at variance with my faith in the grand design; for I could not bring myself to believe that the operations of such an important machine as the atmosphere should be left to chance, even for a moment. Yet I knew of no agent which should guide the wind across these calm belts, and lead it out always on the side opposite to that on which it entered; nevertheless, certain circumstances seemed to indicate that such a crossing does take place.

§ 303

Evidence in favour of this supposition.

Evidence in favour of it seemed to be afforded by this circumstance, namely, our researches enabled us to trace from the belt of calms, near the tropic of Cancer, which extends entirely across the seas, an efflux of air both to the north and to the south; from the south side of this belt the air flows in a never-ceasing breeze, called the north-east trade-winds, toward the equator. (Plate I.)

On the north side of it, the prevailing winds come from it also, but they go toward the north-east. They are the well-known south-westerly winds which prevail along the route from this country to England, in the ratio of two to one. But why should we suppose a crossing to take place here?

§ 304 We suppose so, because these last-named winds are going from a warmer to a colder climate, and therefore it may be inferred that nature exacts from them what we know she exacts from the air under similar circumstances, but on a smaller scale, before our eyes, namely, more precipitation than evaporation.

§ 305 *Whence comes the vapour for replenishing the extra-tropical regions*

But where, it may be asked, does the vapour which these winds carry along, for the replenishing of the whole extra-tropical regions of the north, come from? They did not get it as they came along in the upper regions, a counter-current to the north-east trades, unless they evaporated the trade-wind clouds, and so robbed those winds of their vapour. They certainly did not get it from the surface of the sea in the calm belt of Cancer, for they did not tarry long enough there to become saturated with moisture. Thus circumstances again pointed to the south-east trade-wind regions as the place of supply.

§ 306 *North-east trade-winds for the most part dry.*

Moreover, these researches afforded grounds for the supposition that the air of which the north-east trade-winds are composed, and which comes out of the same zone of calms as do these south-westerly winds, so far from being saturated with vapour at its exodus, is dry; for near their polar edge, the north-east trade winds are, for the most part, dry winds. Reason suggests, and philosophy teaches, that, going from a lower to a higher temperature, the evaporating powers of these winds are

CHAPTER VI. increased; that they have to travel, in their oblique course toward the equator, a distance of nearly three thousand miles; that, as a general rule, they evaporate all the time, and all the way, and precipitate little or none on their route; investigations have proved that they are not saturated with moisture until they have arrived fully up to the regions of equatorial calms, a zone of constant precipitation.

This calm zone of Cancer borders also, it was perceived, upon a rainy region.

§ 307 By what agency is the vapour conveyed across the calm belt. Where does the vapour which here, on the northern edge of this zone of Cancer, is condensed into rains, come from?—and where, also—was the oft-repeated question—does the vapour which is condensed into rains for the extra-tropical regions of the north generally come from? By what agency is it conveyed across this calm belt from its birth-place between the tropics?

§ 308 I know of no law of nature or rule of philosophy which would forbid the supposition that the air which has been brought along as the north-east trade-winds to the equatorial calms does, after ascending there, return by the counter and upper currents to the calm zone of Cancer, here descend and re-appear on the surface as the north-east trade-winds again. I know of no agent in nature which would *prevent* it from taking this circuit, nor do I know of any which would compel it to take this circuit; but while I know of no agent in nature that would prevent it from taking this circuit, I know, on the other hand, of circumstances which rendered it probable that such, in general, is not the course of atmospherical circulation—that it does not take this circuit. I speak of the rule, not of the exceptions; these are infinite, and, for the most part, are caused by the land. CHAPTER VI.

§ 309 There are facts which strengthen the supposition that the winds cross.

And I moreover know of facts which go to strengthen the supposition that the winds which have come in the upper regions of the atmosphere from the equator, do not, after arriving at the calms of Cancer, and descending, return to the equator on the surface, but that they continue on the surface toward the pole. But why should they? What agent in nature is there that can compel these, rather than any other winds, to take such a circuit?

§ 310 Some of the facts.

The following are some of the facts and circumstances which give strength to the supposition that these winds do continue from the calm belt of Cancer toward the pole as the prevailing south-westerly winds of the extra-tropical north:

We have seen (Plate I.) that, on the north side of this calm zone of Cancer, the prevailing winds on the surface are from this zone toward the pole, and that these winds return as A through the upper regions from the pole; that, arriving at the calms of Cancer, this upper current A meets another upper current G from the equator, where they neutralize each other, produce a calm, descend, and come out as surface winds, namely, A as B, or the trade winds; and G as H, or the variable winds.

§ 311 Wet and dry winds.

Now, observations have shown that the winds represented by H are rain winds; those represented by B, dry winds; and it is evident that A could not bring any vapours to these calms to serve for H to make rains of; for the winds represented by A have already performed the circuit of surface winds as far as the pole, during which journey they parted with all their moisture, and, CHAPTER VI. returning through the upper regions of the air to the calm belt of Cancer, they arrived there as dry winds. The winds represented by B are dry winds; therefore it was supposed that these are but a continuation of the winds A.

§ 312 On the other hand, if the winds A, after descending, do turn about and become the surface winds H, they would first have to remain a long time in contact with the sea, in order to be supplied with vapour enough to feed the great rivers, and supply the rains for the whole earth between us and the north pole. In this case we should have an evaporating region on the north as well as on the south side of this zone of Cancer; but investigation shows no such region; I speak exclusively of the ocean.

No evaporating region on the north side of the zone of Cancer.

§ 313 Hence it was inferred that A and G do come out on the surface as represented by Plate I. But what is the agent that should lead them out by such opposite paths?

§ 314 According to this mode of reasoning, the vapours which supply the rains for H would be taken up in the south-east trade-wind region by F, and conveyed thence along the route G to H. And if this mode of reasoning be admitted as plausible—if it be true that G have the vapour which, by condensation, is to water with showers the extra-tropical regions of the northern hemisphere, Nature, we may be sure, has provided a guide for conducting G across this belt of calms, and for sending it on in the right way. Here it was, then, at this crossing of the winds, that I thought I first saw the foot-prints of an agent whose character I could not comprehend. Could it be the magnetism that resides in the oxygen of the air?

Conjecture about magnetism.

§ 315 Distribution of rain and wind not left to chance.

Heat and cold, the early and the latter rain, clouds and sunshine, are not, we may rely upon it, distributed over the earth by chance; they are distributed in obedience to laws that are as certain and as sure in their operations as the seasons in their rounds. If it depended upon chance whether the dry air should come out on this side or on that of this calm belt, or whether the moist air should return or not whence it came—if such were the case in nature, we perceive that, so far from any regularity as to seasons, we should have, or might have, years of droughts the most excessive, and then again seasons of rains the most destructive; but, so far from this, we find for each place a mean annual proportion of both, and that so regulated withal, that year after year the quantity is preserved with remarkable regularity.

§ 316 No reason for supposing the winds turn back to the equator.

Having thus shown that there is no reason for supposing that the upper currents of air, when they meet over the calms of Cancer and Capricorn, are turned back to the equator, but having shown that there is reason for supposing that the air of each current, after descending, continues on in the direction towards which it was travelling before it descended, we may go farther, and, by a similar train of circumstantial evidence, afforded by these researches and other sources of information, show that the air, kept in motion on the surface by the two systems of trade-winds, when it arrives at the belt of equatorial calms, and ascends, continues on thence, each current toward the pole which it was approaching while on the surface.

§ 317

In a problem like this, demonstration in the positive way is difficult, if not impossible. We must rely for our

CHAPTER VI. proof upon philosophical deduction, guided by the lights of reason; and in all cases in which positive proof cannot be adduced, it is permitted to bring in circumstantial evidence.

§ 318 Cause for conjecturing the agency of magnetism. I am endeavouring, let it be borne in mind, to show cause for the conjecture that the magnetism of the oxygen of the atmosphere is concerned in conducting the air which has blown as the south-east trade-winds—and after it has arrived at the belt of equatorial calms and risen up—over into the northern hemisphere, and so on through its channels of circulation, as traced on Plate I.

§ 319 Circumstantial evidence. But, in order to show reasonable grounds for this conjecture, I want to establish, by circumstantial evidence and such indirect proof as my investigations afford, that such is the course of the "wind in his circuits," and that the winds represented by F, Plate I., *do* become those represented by G, H, A, B, C, D, and E successively.

§ 320 The atmosphere passes freely from one hemisphere to another. In the first place, F represents the south-east trade-winds—*i.e.*, all the winds of the southern hemisphere as they approach the equator; and is there any reason for supposing that the atmosphere does not pass freely from one hemisphere to another? On the contrary, many reasons present themselves for supposing that it does.

§ 321 Its effect on man if it did not. If it did not, the proportion of land and water, and consequently of plants and warm-blooded animals, being so different in the two hemispheres, we might imagine that the constituents of the atmosphere in them would, in the course of ages, probably become different, and that consequently, in such a case, man could not safely pass from one hemisphere to the other.

§ 322 Consider the manifold beauties in the whole system of terrestrial adaptations; remember what a perfect and wonderful machine[1] is this atmosphere; how exquisitely balanced and beautifully compensated it is in all its parts. We know that it is perfect; that in the performance of its various offices it is never left to the guidance of chance —no, not for a moment. Therefore I was led to ask myself why the air of the south-east trades, when arrived at the zone of equatorial calms, should not, after ascending, rather return to the south than go on to the north? Where and what is the agency by which its course is decided?

CHAPTER VI. — Perfect machinery of the atmosphere.

Here I found circumstances which again induced me § 323
to suppose it probable that it neither turned back to the south nor mingled with the air which came from the regions of the north-east trades, ascended, and then flowed indiscriminately to the north or the south.

But I saw reasons for supposing that what came to the § 324
equatorial calms as the south-east trade-winds continued to the north as an upper current, and that what had come to the same zone as north-east trade-winds ascended and continued over into the southern hemisphere as an upper current, bound for the calm zone of Capricorn.

Supposition.

And these are the principal reasons and conjectures upon which these suppositions were based:

At the seasons of the year when the area covered by § 325
the south-east trade-winds is large, and when they are evaporating most rapidly in the southern hemisphere, even up to the equator, the most rain is falling in the northern. Therefore it is fair to suppose that much of the vapour which is taken up on that side of the equator is precipitated on this.

Evaporation and precipitation.

[1] § 169.

CHAPTER VI.

§ 326 More evaporating surface in southern than northern hemisphere.

The evaporating surface in the southern hemisphere is greater, much greater, than it is in the northern; still, all the great rivers are in the northern hemisphere, the Amazon being regarded as common to both; and this fact, as far as it goes, tends to corroborate the suggestion as to the crossing of the trade-winds at the equatorial calms.

§ 327 Temperature of tropical regions higher in the northern hemisphere.

Independently of other sources of information, my investigations also taught me to believe that the mean temperature of the tropical regions was higher in the northern than in the southern hemisphere; for they show that the difference is such as to draw the equatorial edge of the south-east trades far over on this side of the equator, and to give them force enough to keep the north-east trade-winds out of the southern hemisphere almost entirely.

§ 328 Consequently, as before stated, the south-east trade-winds being in contact with a more extended evaporating surface, and continuing in contact with it for a longer time or through a greater distance, they would probably arrive at the trade-wind place of meeting more heavily laden with moisture than the others.

§ 329 Whence come the vapours that feed the great rivers.

Taking the laws and rates of evaporation into consideration, I could find no part of the ocean of the northern hemisphere from which the sources of the Mississippi, the St. Lawrence, and the other great rivers of our hemisphere could be supplied.

§ 330 Rain maps.

A regular series of meteorological observations has been carried on at the military posts of the United States since 1819. Rain maps of the whole country* have been prepared from these observations by Mr. Lorin

* See Army Meteorological Observations, published 1855.

Blodget at the surgeon general's office, and under the direction of Dr. Cooledge, U. S. A. These maps, as far as they go, sustain these views in a remarkable manner; for they bring out facts in a most striking way to show that the dry season in California and Oregon is the wet season in the Mississippi Valley.

CHAPTER VI.

§ 331 The winds coming from the south-west, and striking upon the coasts of California and Oregon in winter, precipitate there copiously. They then pass over the mountains robbed in part of their moisture. Of course, after watering the Pacific shores, they have not as much vapour to make rains of, especially for the upper Mississippi Valley, as they had in the summer time, when they dispensed their moisture, in the shape of rains, most sparingly upon the Pacific coasts.

Wet and dry seasons in California and Mississippi Valley.

§ 332 According to these views, the dry season on the Pacific slopes should be the wet, especially in the upper Mississippi Valley, and *vice versa*. Blodget's maps show that such is actually the case.

§ 333 Meteorological observations in the "Red River country," and other parts of British America, would throw farther light, and give farther confirmation, I doubt not, both to these views and to this interesting question.

§ 334 These army observations, as expressed in Blodget's maps, reveal other interesting features also, touching the physical geography of the country. I allude to the two isothermal lines 45° and 65°,[1] which include between them all places that have a mean annual temperature between 45° and 65°.

Isothermal lines.

§ 335 I have drawn similar lines on the authority of Dove and Johnston (A. K., of Edinburgh), across Europe and

[1] Plate VIII.

CHAPTER VI.

Asia, for the sake of comparison. The isotherm of 65° skirts the northern limits of the sugar-cane, and separates the inter-tropical from the extra-tropical plants and productions. I have drawn these two lines across America, and the result shows how much we err when we reckon climates accord to parallels of latitude. The space that these two isotherms of 45° and 65° comprehend between the Mississippi and the Rocky Mountains, owing to the singular effect of those mountains upon the climate, is larger than the space they comprehend between the Mississippi and the Atlantic.

Climates not to be reckoned according to parallels of latitude.

Hyetographically it is also different, being dryer, and possessing a purer atmosphere. In this grand range of climate between the meridians of 100° and 110° W., the amount of precipitation is just about one half of what it is between those two isotherms east of the Mississippi. In this new country west of it, winter is the dry, and spring the rainy season. It includes the climates of the Caspian Sea, which Humboldt regards as the most salubrious in the world, and where he found the most delicious fruits that he saw during his travels. Such was the purity of the air there, that polished steel would not tarnish even by night exposure. These two isotherms, with the remarkable loop which they make to the north-west, beyond the Mississippi, embrace the most choice climates for the olive, the vine, and the poppy; for the melon, the peach, and almond. The finest of wool may be grown there, and the potato, with hemp, tobacco, maize, and all the cereals, may be cultivated there in great perfection. No climate of the temperate zone will be found to surpass in salubrity that of this Piedmont trans-Mississippi country.

Humboldt's opinion of the climates of the Caspian Sea.

CHAPTER VI.

§ 336 Extra-tropical regions of the north a condenser for the trade-winds of the southern hemisphere.

By such trains of thought and reasoning as are here sketched, and by such facts and circumstances as are stated above, I have been brought to regard the extra-tropical regions of the northern hemisphere as standing in the relation of a condenser to a grand steam machine,[1] the boiler of which is in the region of the south-east trade-winds, and to consider the trade-winds of this hemisphere as performing the like office for the regions beyond Capricorn.

§ 337 Calm zones.

The calm zone of Capricorn is the duplicate of that of Cancer, and the winds flow from it as they do from that, both north and south; but with this difference: that on the polar side of the Capricorn belt they prevail from the north-west instead of the south-west, and on the equatorial side from the south-east instead of the north-east.

§ 338 Mean circuit of a portion of the atmosphere.

Now, if it be true that the vapour of the north-east trade-winds is condensed in the extra-tropical regions of the southern hemisphere, the following path, on account of the effect of diurnal rotation of the earth upon the course of the winds, would represent the mean circuit of a portion of the atmosphere moving according to the general system of its circulation over the Pacific Ocean, namely, coming down from the north as an upper current, and appearing on the surface of the earth in about longitude 120° west, and near the tropic of Cancer, it would here commence to blow the north-east trade-winds of that region.

§ 339 Course of vapour-bearing winds.

To make this clear, see Plate VII., on which I have marked the course of such vapour-bearing winds; A being a breadth or *swath* of winds in the north-east trades; B, the same wind as the upper and counter-current to the

[1] § 168.

CHAPTER VI. south-east trades; and C, the same wind after it has descended in the calm belt of Capricorn, and come out on the polar side thereof, as the rain-winds and prevailing north-west winds of the extra-tropical regions of the south-western hemisphere.

§ 340 North-east trade-wind. This, as the north-east trades, is the evaporating wind. As the north-east trade-wind, it sweeps over a great waste of waters lying between the tropic of Cancer and the equator.

§ 341 Its route. Meeting no land in this long oblique track over the tepid waters of a tropical sea, it would, if such were its route, arrive somewhere about the meridian of 140° or 150° west, at the belt of equatorial calms, which always divides the north-east from the south-east trade-winds. Here, depositing a portion of its vapour as it ascends, it would, with the residuum, take, on account of diurnal rotation, a course in the upper region of the atmosphere to the south-east, as far as the calms of Capricorn. Here it descends and continues on toward the coast of South America, in the same direction, appearing now as the prevailing north-west wind of the extra-tropical regions of the southern hemisphere. Travelling on the surface from warmer to colder regions, it must, in this part of the circuit, precipitate more than it evaporates.

§ 342 Coincidence. Now, it is a coincidence, at *least*, that this is the route by which, on account of the land in the northern hemisphere, the north-east trade-winds have the fairest sweep over that ocean. This is the route by which they are longest in contact with an evaporating surface; the route by which all circumstances are most favourable to complete saturation; and this is the route by which they can pass over into the southern hemisphere most heavily laden with vapours for the extra-tropical regions of that half of the globe; and this is the supposed route which the north-east trade-winds of the Pacific take to reach the equator, and to pass from it. CHAPTER VI.

§ 343 Region of precipitation. Accordingly, if this process of reasoning be good, that portion of South America between the calms of Capricorn and Cape Horn, upon the mountain ranges of which this part of the atmosphere, whose circuit I am considering as a type, first impinges, ought to be a region of copious precipitation.

§ 344 Patagonia. Now, let us turn to the works on Physical Geography, and see what we can find upon this subject. In Berghaus and Johnston—department Hyetography—it is stated, on the authority of Captain King, R.N., that upward of twelve feet (one hundred and fifty-three inches) of rain fell in forty-one days on that part of the coast of Patagonia which lies within the sweep of the winds just described. So much rain falls there, navigators say, that they sometimes find the water on the top of the sea fresh and sweet.

§ 345 Becomes a dry wind in Buenos Ayres. After impinging upon the cold hill-tops of the Patagonian coast, and passing the snow-clad summits of the Andes, this same wind tumbles down upon the eastern slopes of the range as a dry wind; as such, it traverses the almost rainless and barren regions of cis-Andean Patagonia and South Buenos Ayres.

§ 346 Evidence in favour of conjecture. These conditions, the direction of the prevailing winds, and the amount of precipitation, may be regarded as evidence afforded by nature, if not in favour of, certainly not against, the conjecture that such may have been the voyage of this vapour through the air. At any rate, CHAPTER VI. here is proof of the immense quantity of vapour which these winds of the extra-tropical regions carry along with them toward the poles; and I can imagine no other place than that suggested, whence these winds could get so much vapour.

Theory. I am not unaware of the theory, or of the weight attached to it, which requires precipitation to take place in the upper regions of the atmosphere on account of the cold there, irrespective of proximity to mountain tops and snow-clad hills.

§ 347 Facts irreconcileable with it. But the facts and conditions developed by this system of research upon the high seas are in many respects irreconcileable with that theory. With a new system of facts before me, I have, independent of all preconceived notions and opinions, set about to seek among them for explanations and reconciliations.

§ 348 How do the currents of air cross each other These may not in all cases be satisfactory to every one; indeed, notwithstanding the amount of circumstantial evidence that has already been brought to show that the air which the north-east and the south-east trade-winds discharge into the belts of equatorial calms, does, in ascending, cross—that from the southern passing over into the northern, and that from the northern passing over into the southern hemisphere (see F and G, B and C, Plate I.)—yet some have implied doubt by asking the question, "How are two such currents of air to pass each other?" And, for the want of light upon this point, the correctness of reasoning, facts, inferences, and deductions have been questioned.

§ 349 Breadth of calm belt. In the first place, it may be said in reply, the belt of equatorial calms is often several hundred miles across, seldom less than sixty; whereas the depth of the volume of air that the trade-winds pour into it is only about three miles, for that is supposed to be about the height to which the trade-winds extend.

CHAPTER VI. — Height of trade-winds.

§ 350 Columns of air can cross without interfering with each other.

Thus we have the air passing into these calms by an opening on the north side for the north-east trades, and another on the south for the south-east trades, having a cross section of three miles vertically to each opening. It then escapes by an opening upward, the cross section of which is sixty or one hundred, or even three hundred miles. A very slow motion upward there will carry off the air in that direction as fast as the two systems of trade-winds, with their motion of twenty miles an hour, can pour it in; and that *curds* or columns of air can readily cross each other and pass in different directions without interfering the one with the other, or at least to that degree which obstructs or prevents, we all know.

§ 351 Illustration.

For example, open the window of a warm room in winter, and immediately there are two currents of air ready at once to set through it, namely, a current of warm air flowing out at the top, and one of cold coming in below.

§ 352 Striking evidence.

But the brown fields in summer afford evidence on a larger scale, and in a still more striking manner, of the fact that, in nature, columns, or streamlets, or curdles of air do really move among each other without obstruction. That tremulous motion which we so often observe above stubble-fields, barren wastes, or above any heated surface, is caused by the ascent and descent, at one and the same time, of columns of air at different temperatures, the cool coming down, the warm going up. They do not readily commingle, for the astronomer, long after nightfall, when

CHAPTER VI. he turns his telescope upon the heavens, perceives and laments the unsteadiness they produce in the sky.

§ 353 Difference of temperature of trade-winds would prevent them from mingling. If the air brought down by the north-east trade-winds differ in temperature (and why not?) from that brought by the south-east trades, we have the authority of nature for saying that the two currents would not readily commingle. Proof is daily afforded that they would not, and there is reason to believe that the air of each current, in streaks, or patches, or *curdles*, does thread its way through the air of the other without difficulty. Now, if the air of these two currents differs as to magnetism, might not that be an additional reason for their not mixing, and for their taking the direction of opposite poles after ascending?

§ 354 Assumption. Therefore we may assume it as a postulate which nature concedes, that there is no difficulty as to the two currents of air, which come into those calm belts from different directions, crossing over, each in its proper direction, without mingling.

§ 355 Additional evidence that they cross. Thus, having shown that there is nothing to *prevent* the crossing of the air in these calm belts, I return to the process of reasoning by induction, and offer additional circumstantial evidence to prove that such a crossing does take place. Let us therefore catechise, on this head, the waters which the Mississippi pours into the sea, inquiring of them as to the channels among the clouds through which they were brought from the ocean to the fountains of that mighty river.

§ 356 Rain in Mississippi Valley. It rains more in the valley drained by that river than is evaporated from it again. The difference for a year is the volume of water annually discharged by that river into the sea.[1]

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[1] § 165.

At the time and place that the vapour which supplies this immense volume of water was lifted by the atmosphere up from the sea, the thermometer, we may infer, stood higher than it did at the time and place where this vapour was condensed and fell down as rain in the Mississippi Valley. § 357

I looked to the south for the springs in the Atlantic which supply the fountains of this river with rain. But I could not find spare evaporating surface enough for it, in the first place; and if the vapour, I could not find the winds which would convey it thence to the right place. § 358

Where does it come from

The prevailing winds in the Caribbean Sea and southern parts of the Gulf of Mexico are the north-east trade-winds. They have their offices to perform in the river basins of inter-tropical America, and the rains which they may discharge into the Mississippi Valley now and then are exceptions, not the rule. § 359

The winds from the north cannot bring vapours from the great lakes to make rains for the Mississippi, for two reasons: 1*st*, The basin of the great lakes receives from the atmosphere more water in the shape of rain than they give back in the shape of vapour. The St. Lawrence River carries off the excess. 2*d*, The mean climate of the lake country is colder than that of the Mississippi Valley, and therefore, as a general rule, the temperature of the Mississippi Valley is unfavourable for condensing vapour from that quarter. § 360

It cannot come from the north, for two reasons.

It cannot come from the Atlantic, because the greater part of the Mississippi Valley is to the windward of the Atlantic. The winds that blow across this ocean go to Europe with their vapours; and in the Pacific, from the § 361

Nor from the Atlantic.

CHAPTER VI. parallels of California down to the equator, the direction of the wind at the surface is from, not toward the basin of the Mississippi. Therefore it seemed to be established with some degree of probability, or, if that expression be too strong, with something like apparent plausibility, that the rain winds of the Mississippi Valley do not, as a general rule, get their vapours from the North Atlantic Ocean, nor from the Gulf of Mexico, nor from the great lakes, nor from that part of the Pacific Ocean over which the north-east trade-winds prevail.

§ 362 *We must look to South Pacific.* The same process of reasoning which conducted us[1] into the trade-wind region of the northern hemisphere for the sources of the Patagonian rains, now invites us into the trade-wind regions of the South Pacific Ocean to look for the vapour springs of the Mississippi.

§ 363 *Reasons.* If the rain winds of the Mississippi Valley come from the east, then we should have reason to suppose that their vapours were taken up from the Atlantic Ocean and Gulf Stream; if the rain winds come from the south, then the vapour springs might, perhaps, be in the Gulf of Mexico; if the rain winds come from the north, then the great lakes might be supposed to feed the air with moisture for the fountains of that river; but if the rains come from the west, where, short of the great Pacific Ocean, should we look for the place of evaporation?

Wondering where, I addressed a circular letter to farmers and planters of the Mississippi Valley, requesting to be informed as to the direction of their rain winds.

§ 364 *Direction of rain winds.* I received replies from Virginia, Mississippi, Tennessee, Missouri, Indiana, and Ohio; and, subsequently, from Col. W. A. Bird, Buffalo, New York, who says, "The south-

[1] § 342.

west winds are our fair-weather winds; we seldom have rain from the south-west." Buffalo may get much of its rains from the Gulf Stream with easterly winds. But I speak of the Mississippi Valley; all the respondents there, with the exception of one in Missouri, said, "The south-west winds bring us our rains."

CHAPTER VI.

South-west winds bring rain.

These winds certainly cannot get their vapours from the Rocky Mountains, nor from the Salt Lake, for they rain quite as much upon that basin as they evaporate from it again; if they did not, they would, in the process of time, have evaporated all the water there, and the lake would now be dry. § 365

They cannot get vapours from Salt Lake or the Rocky Mountains

These winds, that feed the sources of the Mississippi with rain, like those between the same parallels upon the ocean, are going from a higher to a lower temperature; and these winds in the Mississippi Valley, not being in contact with the ocean, or with any other evaporating surface to supply them with moisture, must bring with them from some sea or another that which they deposit. § 366

These winds go from a higher to a lower temperature.

Therefore, though it may be urged, inasmuch as the winds which brought the rains to Patagonia[1] came direct from the sea, that they therefore took up their vapours as they came along, yet it cannot be so urged in this case; and if these winds could pass with their vapours from the equatorial calms through the upper regions of the atmosphere to the calms of Cancer, and then as surface winds into the Mississippi Valley, it was not perceived why the Patagonian rain winds should not bring their moisture by a similar route. These last are from the north-west, from warmer to colder latitudes; therefore, being once charged with vapours, they must precipitate § 367

[1] § 344.

CHAPTER VI. Alternation of rainy and dry seasons.

as they go, and take up less moisture than they deposit. The circumstance that the rainy season in the Mississippi Valley[1] alternates with the dry season on the coast of California and Oregon, indicates that the two regions derive vapour for their rains from the same fountains.

§ 368 This, however, could be regarded only as circumstantial evidence. Not a fact had yet been elicited to prove that the course of atmospherical circulation suggested by my investigations is the actual course in nature. It is a case in which I could yet hope for nothing more direct than such conclusions as might legitimately flow from circumstances.

§ 369 American Arctic expedition. My friend Lieutenant De Haven was about to sail in command of the American Arctic Expedition in search of Sir John Franklin. Infusoria are sometimes found in sea-dust, rain-drops, hail-stones, or snow-flakes; and if by any chance it should so turn out that the *locus* of any of Infusoria. the microscopic infusoria which might be found descending with the precipitation of the Arctic regions should be identified as belonging to the regions of the south-east trade-winds, we should thus add somewhat to the strength of the many clews by which we have been seeking to enter into the chambers of the wind, and to "tell whence it cometh and whither it goeth."

§ 370 It is not for man to follow the "wind in his circuits;" and all that could be hoped was, after a close examination of all the facts and circumstances which these researches upon the sea have placed within my reach, to point out that course which seemed to be most in accordance with them; and then, having established a probability, or even a possibility, as to the true course of the atmospheric

[1] § 330.

circulation, to make it known, and leave it for future investigations to confirm or set aside. CHAPTER VI.

§ 371 Clew found in Ehrenberg's work. It was at this stage of the matter that my friend, Baron von Gerolt, the Prussian minister, had the kindness to place in my hand Ehrenberg's work, "Passat-Staub und Blut-Regen."

Here I found the clew which I hoped, almost against hope, De Haven would place in my hands[1] from the north pole.

§ 372 Blood-rain and sea-dust. That celebrated microscopist reports that he found South American infusoria in the blood-rains and sea-dust of the Cape Verd Islands, Lyons, Genoa, and other places.[2]

§ 373 Increased probability that the trade-winds cross in calms of Cancer. Thus confirming, as far as such evidence can, the indications of our observations, and increasing the probability that the general course of atmospherical circulation is in conformity with the suggestions of the facts gathered from the sea as I had interpreted them, namely, that the trade-winds of the southern hemisphere, after arriving at the belt of equatorial calms, ascend and continue in their course toward the calms of Cancer as an upper current from the south-west, and that, after passing this zone of calms, they are felt on the surface as the prevailing south-west winds of the extra-tropical parts of our hemisphere; and that, for the most part, they bring their moisture with them from the trade-wind regions of the opposite hemisphere.

§ 374 Supposed track of the "Passat-Staub." I have marked on Plate VII. the supposed track of the "Passat-Staub," showing where it was taken up in South America, as at P, P, and where it was found, as at S, S; the part of the line in dots denoting where it was in the upper current, and the unbroken line where it was wafted

[1] § 369. [2] § 273.

CHAPTER VI. by a surface current; also on the same plate is designated the part of the South Pacific in which the vapour-springs for the Mississippi rains are supposed to be. The hands (☞) point out the direction of the wind. Where the shading is light, the vapour is supposed to be carried by an upper current.

§ 375 *Suspicion of some other agent.* Such is the character of the circumstantial evidence which induced me to suspect that some agent, whose office in the grand system of atmospherical circulation is neither understood nor recognised, was at work in these calm belts.

§ 376 *Faraday's discoveries* Dr. Faraday has shown that, as the temperature of oxygen is raised, its paramagnetic force diminishes, being resumed as the temperature falls again.

"These properties it carries into the atmosphere, so that the latter is, in reality, a magnetic medium, ever varying, from the influence of natural circumstances, in its magnetic power. If a mass of air be cooled, it becomes more paramagnetic; if heated, it becomes less paramagnetic (or diamagnetic), as compared with the air in a mean or normal condition." *

§ 377 *Probability that magnetism is the agent.* Now, is it not more than probable that here we have, in the magnetism of the atmosphere, that agent which guides the air from the south[1] through the calms of Capricorn, of the equator, and of Cancer, and conducts it into the north; that agent which causes the atmosphere, with its vapours and infusoria, to flow above the clouds from one hemisphere into the other, and whose footprints had become so palpable?

* Philosophical Magazine and Journal of Science, 4th Series, No. I., January, 1851, page 73.

[1] § 373.

Taking up the theory of Ampère with regard to the magnetic polarity induced by an electrical current, according as it passes through wire coiled *with* or coiled *against* the sun, and expanding it in conformity with the discoveries of Faraday and the experiments of a Prussian philosopher,* we perceive a series of facts and principles which, being applied to the circulation of the atmosphere, make the conclusions to which I have been led touching these crossings in the air, and the continual "whirl" of the wind in the Arctic regions *against*, and in the Antarctic *with the hands of a watch*, very significant. § 378

Theory of Ampère.

Significant facts.

In this view of the subject, we see light springing up from various sources, by which the shadows of approaching confirmation are clearly perceived. One such source of light comes from the observations of my excellent friend Quetelet, at Brussels, which show that the great electrical reservoir of the atmosphere is in the upper regions of the air. It is filled with positive electricity, which increases as the temperature diminishes. § 379

Observations of Quetelet at Brussels.

May we not look, therefore, to find about the north and south magnetic poles these atmospherical nodes or calm regions which I have theoretically pointed out there? In other words, are not the magnetic poles of the earth in those atmospherical nodes, the two standing in the relation of cause and effect, the one to the other? § 380

Supposed calm regions at the poles.

This question was first asked several years ago,† and I was then moved to propound it by the inductions of theoretical reasoning.

Observers, perhaps, will never reach those inhospitable § 381

* Professor Von Feilitzsch, of the University of Griefswald. Philosophical Magazine, January, 1851.

† Maury's Sailing Directions.

CHAPTER VI.

Opinions of Parry and Barrow.

regions with their instruments to shed light upon this subject; but Parry and Barrow have found reasons to believe in the existence of a perpetual calm about the north pole, and, later, Bellot has reported the existence of a calm region within the frigid zone. Professor J. H. Coffin, in an elaborate and valuable paper* on the "WINDS OF THE NORTHERN HEMISPHERE," arrives by deduction at a like conclusion. In that paper he has discussed the records at no less than five hundred and seventy-nine meteorological stations, embracing a totality of observations for two thousand eight hundred and twenty-nine years. He places his "meteorological pole"—pole of the winds—near latitude 84° north, longitude 105° west. The pole of maximum cold, by another school of philosophers, Sir David Brewster among them, has been placed in latitude 80° north, longitude 100° west; and the magnetic pole, by still another school,† in latitude 73° 35′ north, longitude 95° 39′ west.

Professor Coffin's conclusion

Position of the poles.

Sir David Brewster.

§ 382 Neither of these poles is a point susceptible of definite and exact position. The polar calms are no more a point than the equatorial calms are a line; and, considering that these poles are areas or discs, not points, it is a little curious that philosophers in different parts of the world, using different data, and following up investigation each through a separate and independent system of research, and each aiming at the solution of different problems, should nevertheless agree in assigning very nearly the same position to them all? Are these three poles grouped together by chance, or by some physical cause? By the

Difficulty of defining their exact position.

Philosophers assign nearly the same position to them all.

* Smithsonian Contributions to Knowledge, vol. vi., 1854.

† Gauss.

latter undoubtedly. Here, then, we have another of those gossamer-like clews, that sometimes seem almost palpable enough for the mind, in its happiest mood, to lay hold of, and follow up to the very portals of knowledge, where, pausing to knock, we may boldly demand that the chambers of hidden things be thrown wide open, that we may see and understand the mysteries of the winds, the frost, and the trembling needle.

CHAPTER VI.

A clew.

In the polar calms there is[1] an ascent of air; if an ascent, a diminution of pressure and an expansion; and if expansion, a decrease of temperature. Therefore we have palpably enough a connecting link here between the polar calms and the polar place of maximum cold. Thus we establish a relation between the pole of the winds and the pole of cold, with evident indications that there is also a physical connection between these and the magnetic pole. Here the outcroppings of the relation between magnetism and the circulation of the atmosphere again appear. § 383

Relation between the poles.

May we not find in such evidence as this threads, attenuated and almost air-drawn though they be when taken singly and alone, yet nevertheless proving, when brought together, to have a consistency sufficient, with the lights of reason, to guide us as we seek to trace the wind in his circuits? The winds approach these polar calms[2] by a circular or spiral motion, travelling in the northern hemisphere *against*, and in the southern *with*, the hands of a watch. The circular gales of the northern hemisphere are said also to revolve in like manner against the hands of a watch, while those in the southern hemisphere travel the other way. Now, should not this dis- § 384

Evidence to guide us in tracing the wind.

Winds approach polar calms with a spiral motion.

[1] § 139. [2] § 155.

CHAPTER VI.

Encouragement to look at magnetism as a cause.

covery of these three poles, this coincidence of revolving winds, with the other circumstances that have been brought to light, encourage us to look to the magnetism of the air for the key to these mysterious but striking coincidences?

Speculation.

§ 385 Indeed, so wide is the field for speculation presented by these discoveries, that we may in some respects regard this great globe itself, with its "cups" and spiral wires of air, earth, and water, as an immense "pile" and helix, which, being excited by the natural batteries in the sea and atmosphere of the tropics, excites in turn its oxygen, and imparts to atmospherical matter the properties of magnetism.

Supposed effect of magnetism on the trade-winds.

§ 386 With the lights which these discoveries cast, we see (Plate I.) why air, which has completed its circuit to the whirl* about the Antarctic regions, should then, according to the laws of magnetism, be repelled from the south, and attracted by the opposite pole toward the north.

§ 387 And when the south-east and the north-east trade-winds meet in the equatorial calms of the Pacific, would not these magnetic forces be sufficient to determine the course of each current, bringing the former, with its vapours of the southern hemisphere, over into this, by the courses already suggested?

§ 388 This force, and the heat of the sun, would propel it to the north. The diurnal rotation of the earth propels it to the east; consequently its course, first through the upper regions of the atmosphere and then on the surface of the earth, after being conducted by this newly-discovered agent across the calms of Cancer, would be *from*

* "It whirleth about continually."—BIBLE.

the southward and westward to the northward and eastward. CHAPTER VI.

These are the winds[1] which, on their way to the north from the South Pacific, would pass over the Mississippi Valley, and they appear[2] to be the rain winds there. Whence, then, if not from the trade-wind regions of the South Pacific, can the vapours for those rains come? § 389

Rain winds in Mississippi Valley.

According to this view, and not taking into account any of the exceptions produced by the land and other circumstances upon the general circulation of the atmosphere over the ocean, the south-east trade-winds, which reach the shores of Brazil near the parallel of Rio, and which blow thence for the most part over the land, should be the winds which, in the general course of circulation, would be carried, after crossing the Andes and rising up in the belt of equatorial calms, toward Northern Africa, Spain, and the South of Europe. § 390

South-east trade-wind

They might carry with them the infusoria of Ehrenberg,[3] but, according to this theory, they would be wanting in moisture. Now, are not those portions of the Old World, for the most part, dry countries, receiving but a small amount of precipitation? § 391

Hence the general rule. Those countries to the north of the calms of Cancer, which have large bodies of land situated to the southward and westward of them, in the south-east trade-wind region of the earth, should have a scanty supply of rain, and *vice versa*. § 392

General rule.

Let us try this rule: The extra-tropical part of New Holland comprises a portion of land thus situated in the southern hemisphere. Tropical India is to the northward and westward of it; and tropical India is in the north- § 393

Application of rule.

[1] § 181. [2] § 364. [3] § 273.

CHAPTER VI. east trade-wind region, and should give extra-tropical New Holland a slender supply of rain. But what modifications the monsoons of the Indian Ocean may make to this rule, or what effect they may have upon the rains in New Holland, my investigations in that part of the ocean have not been carried far enough for final decision, though New Holland is a dry country. Referring back to page 80 for what has been already said concerning the "METEOROLOGICAL AGENCIES"[1] of the atmosphere, it will be observed that cases are there brought forward which afford trials for this rule, every one of which holds good.

§ 394 Great probability that magnetism is an agent in atmospherical circulation

Thus, though it be not proved as a mathematical truth that magnetism is the power which guides the storm from right to left and from left to right, which conducts the moist and the dry air each in its appointed paths, and which regulates the "wind in his circuits," yet that it is such a power is rendered very probable; for, under the supposition that there is such a crossing of the air at the five calm places, as Plate I. represents, we can reconcile a greater number of known facts and phenomena than we can under the supposition that there is no such crossing. The rules of scientific investigation always require us, when we enter the domains of conjecture, to adopt that hypothesis by which the greatest number of known facts and phenomena may be reconciled; and, therefore, we are entitled to assume, that this crossing probably does take place, and to hold fast to the theory so maintaining until it is shown not to be sound.[2]

§ 395 That the magnetism of the atmosphere is the agent which guides the air across the calm belts, and prevents

[1] § 159. [2] § 1003.

CHAPTER VI.

No other known agent can perform the same offices.

that which enters them from escaping on the side upon which it entered, we cannot, of our own knowledge, positively affirm. Suffice it to say, that we recognise in this property of the oxygen of air an agent that, for aught we as yet know to the contrary, may serve as such a guide; and we do not know of the existence of any other agent in the atmosphere that can perform the offices which the hypothesis requires. Hence the suspicion that magnetism and electricity are among the forces concerned in the circulation of the atmosphere.

CHAPTER VII.

CURRENTS OF THE SEA.

Governed by Laws, § 396.—The Capacity of Water to convey Heat, 399.—The Red Sea Current, 404.—The per centum of Salt in Sea Water, 418.—The Mediterranean Current, 423.—Under Current from, 424.—Admiral Smyth's Soundings, 426.—Lyell's Views, 429.—Admiral Smyth's Views, 436.—Currents of the Indian Ocean, 439.—Gulf Stream of the Pacific, 441.—Its resemblance to that of the Atlantic, 442.—An ice-bearing Current between Africa and Australia, 449.—Currents of the Pacific, 451.—A Sargossa Sea in the Pacific, 452.—Drift-wood upon the Aleutian Islands, 453.—Cold Ochotsk, 454.—Humboldt's Current, 455.—Warm Current in the South Pacific, 456.—Equatorial Currents in the South Pacific, 458.—The Effect of Rain and Evaporation upon Currents, 459.—Under Currents of the Atlantic, 461.—Equilibrium of the Sea maintained by Currents, 467.—The Brazil Current, 469.

CHAPTER VII.

§ 396 Currents of the sea.

LET us, in this chapter, set out with the postulate that the sea, as well as the air, has its system of circulation, and that this system, whatever it be, and wherever its channels lie, whether in the waters at or below the surface, is in obedience to physical laws. The sea, by the circulation of its waters, doubtless has its offices to perform in the terrestrial economy; and when we see the currents in the ocean running hither and thither, we feel that they were not put in motion without a cause. On the contrary, reason assures us that they move in obedience to some law of nature, be it recorded down in the depths below, never so far beyond the reach of human ken; and being a law of nature, we know who gave it, and that neither chance nor accident had anything to do with its enactment.

They move in obedience to the laws of nature.

§ 397 Nature grants us all that this postulate demands, repeating it to us in many forms of expression; she utters it in the blade of green grass which she causes to grow in climates and soils made kind and genial by warmth and moisture that some current of the sea or air has conveyed far away from under a tropical sun. She murmurs it out in the cooling current of the north; the whales of the sea tell of it,[1] and all its inhabitants proclaim it.

Nature proclaims this.

§ 398 The fauna and the flora of the sea are as much the creatures of climate,[2] and are as dependent for their well-being upon temperature as are the fauna and the flora of the dry land. Were it not so, we should find the fish and the algæ, the marine insect and the coral, distributed equally and alike in all parts of the ocean. The polar whale would delight in the torrid zone, and the habitat of the pearl oyster would be also under the iceberg, or in frigid waters colder than the melting ice.

The fauna and flora of the sea as dependent on temperature as those of the land.

§ 399 Now water, while its capacities for heat are scarcely exceeded by those of any other substance, is one of the most complete of non-conductors. Heat does not permeate water as it does iron, for instance, or other good conductors. Heat the top of an iron plate, and the bottom becomes warm; but heat the top of a sheet of water, as in a pool or basin, and that at the bottom remains cool. The heat passes through iron by conduction, but to get through water it requires to be conveyed by a motion, which in fluids we call currents.

Water a non-conductor.

§ 400 Therefore the study of the climates of the sea involves a knowledge of its currents, both cold and warm. They are the channels through which the waters circulate, and by means of which the harmonies of old ocean are preserved.

Knowledge of its currents necessary for studying the climates of the sea.

§ 401 Hence, in studying the system of oceanic circulation,

[1] § 70. [2] § 76.

CHAPTER VII.

Assumption on which is based the system of currents.

we set out with the very simple assumption, namely, that from whatever part of the ocean a current is found to run, to the same part a current of equal volume is bound to return; for upon this principle is based the whole system of currents and counter-currents of the air as well as of the water.

§ 402 Whirlpools. Currents of water, like currents of air, meeting from various directions, create gyrations, which in some parts of the sea, as on the coast of Norway, assume the appearance of whirlpools, as though the water were drawn into a chasm below. The celebrated Maelstrom is caused by such a conflict of tidal or other streams. Admiral Beechey, R.N.,* has given diagrams illustrative of many "rotatory streams in the English Channel, a number of which occur between the outer extremities of the channel tide and the stream of the oceanic or parent wave." "They are clearly to be accounted for," says he, "by the streams acting obliquely upon each other."

Rotatory streams in English Channel.

§ 403 Currents of the sea can run up hill. It is not necessary to associate with oceanic currents the idea that they must of necessity, as on land, run from a higher to a lower level. So far from this being the case, some currents of the sea actually run up hill, while others run on a level.

Gulf Stream one of these. The Gulf Stream is of the first class.[1]

§ 404 Those running into the Red Sea and Mediterranean are the reverse. The currents which run from the Atlantic into the Mediterranean, and from the Indian Ocean into the Red Sea, are the reverse of this. Here the bottom of the current is probably a water-level, and the top an inclined plane, running *down hill*. Take the Red Sea current as

* See an interesting paper by him on Tidal Streams of the North Sea and English Channel, pp. 703; Phil. Transactions, Part ii., 1851.

[1] § 9.

an illustration. That sea lies, for the most part, within a rainless and riverless district. It may be compared to a long and narrow trough. Being in a rainless district, the evaporation from it is immense; none of the water thus taken up is returned to it either by rivers or rains. It is about one thousand miles long; it lies nearly north and south, and extends from latitude 13° to the parallel of 30° north.

CHAPTER VII.

Red Sea.

Its size and latitude.

§ 405 From May to October, the water in the upper part of this sea is said to be two feet lower than it is near the mouth.* This change or difference of level is ascribed to the effect of the wind, which, prevailing from the north at that season, is supposed to blow the water out.

Difference of level in it.

§ 406 But from May to October is also the hot season; it is the season when evaporation is going on most rapidly; and when we consider how dry and how hot the winds are which blow upon this sea at this season of the year, we may suppose the daily evaporation to be immense; not less, certainly, than half an inch, and probably twice that amount. We know that the waste from canals by evaporation, in the summer time, is an element which the engineer, when taking the capacity of his feeders into calculation, has to consider. With him it is an important element; how much more so must the waste by evaporation from this sea be, when we consider the physical conditions under which it is placed. Its feeder, the Arabian Sea, is a thousand miles from its head; its shores are burning sands; the evaporation is *ceaseless;* and none of the vapours, which the scorching winds that blow over it carry away, are returned to it again in the shape of rains.

Immense evaporation.

Its physical conditions.

* Johnston's Physical Atlas.

CHAPTER VII.

§ 407 Cause of depression in its level.

The Red Sea vapours are carried off and precipitated elsewhere. The depression in the level of its head waters in the summer time, therefore, it appears, is owing to the effect of evaporation as well as to that of the wind blowing the waters back.

§ 408 Supposed average evaporation.

The evaporation in certain parts of the Indian Ocean[1] is from three-fourths of an inch to an inch daily. Suppose it for the Red Sea in the summer time to average only half an inch a day.

§ 409 Average velocity of current running into it.

Now, if we suppose the velocity of the current which runs into that sea to average, from mouth to head twenty miles a day, it would take the water fifty days to reach the head of it. If it lose half an inch from its surface by evaporation daily, it would, by the time it reaches the Isthmus of Suez, lose twenty-five inches from its surface.

§ 410 Its waters lower at Suez than Babelmandeb.

Thus the waters of the Red Sea ought to be lower at the Isthmus of Suez than they are at the Straits of Babelmandeb. Independently of the waters forced out by the wind, they ought to be lower from two other causes, namely, evaporation and temperature, for the temperature of that sea is necessarily lower at Suez, in latitude 30°, than it is at Babelmandeb, in latitude 13°.

§ 411 Illustration.

To make it quite clear that the surface of the Red Sea is not a sea level, but is an inclined plane, suppose the channel of the Red Sea to have a perfectly smooth and level floor, with no water in it, and a wave ten feet high to enter the Straits of Babelmandeb, and to flow up the channel at the rate of twenty miles a day for fifty days, losing daily, by evaporation, half an inch; it is easy to perceive that, at the end of the fiftieth day, this wave

[1] § 33.

would not be so high, by two feet (twenty-five inches), as it was the first day it commenced to flow. CHAPTER VII.

The top of that sea, therefore, may be regarded as an inclined plane, made so by evaporation. § 412

But the salt water, which has lost so much of its freshness by evaporation, becomes salter, and therefore heavier. The lighter water at the Straits cannot balance the heavier water at the Isthmus, and the colder and salter, and therefore heavier water, must either run out as an under current, or it must deposit its surplus salt in the shape of crystals, and thus gradually make the bottom of the Red Sea a salt-bed, or it must abstract all the salt from the ocean to make the Red Sea brine—and we know that neither the one process nor the other is going on. Hence we infer that there is from the Red Sea an under or outer current, as there is from the Mediterranean through the Straits of Gibraltar, and that the surface waters near Suez are salter than those near the mouth of the Red Sea. § 413

Inference of an under current from the Red Sea.

And, to show why there should be an outer and under current from each of these two seas, let us suppose the case of a long trough, opening into a vat of oil, with a partition to keep the oil from running into the trough. Now suppose the trough to be filled up with wine on one side of the partition to the level of the oil on the other. The oil is introduced to represent the lighter water as it enters either of these seas from the ocean, and the wine the same water after it has lost some of its freshness by evaporation, and therefore has become salter and heavier. Now suppose the partition to be raised, what would take place? Why, the oil would run in as § 414

Illustration of upper and under currents.

CHAPTER VII. an upper current, overflowing the wine, and the wine would run out as an under current.

§ 415 Beautiful system of compensation which preserves the equilibrium of the seas. The rivers which discharge in the Mediterranean are not sufficient to supply the waste of evaporation, and it is by a process similar to this that the salt which is carried in from the ocean is returned to the ocean again; were it not so, the bed of that sea would be a mass of solid salt. The equilibrium of the seas is preserved, beyond a doubt, by a system of compensation as exquisitely adjusted as are those by which the "music of the spheres" is maintained.

§ 416 It is difficult to form an adequate conception of the immense quantities of solid matter, in solution, which the current from the Atlantic carries into the Mediterranean. In the abstract log for March 8th, 1855, Mr. William Grenville Temple, master of the United States ship Levant, homeward bound, has described the indraught there:

Extract from log of U.S. ship Levant. "Weather fine; made $1\frac{1}{4}$ pt. lee-way. At noon, stood in to Almiria Bay, and anchored off the village of Roguetas. Found a great number of vessels waiting for a chance to get to the westward, and learned from them that at least a thousand sail are weather-bound between this and Gibraltar. Some of them have been so for six weeks, and have even got as far as Malaga, only to be swept back by the current. Indeed, no vessel has been able to get out into the Atlantic for three months past."

§ 417 Strong current into the Mediterranean. Now, suppose this current, which baffled and beat back this fleet for so many days, ran no faster than two knots the hour. Assuming its depth to be 400 feet only, and its width seven miles, and that it carried in with it the average proportion of solid matter—say one thirtieth —contained in sea water; and admitting these postulates into calculation as the basis of the computation, it appears that salts enough to make no less than 88 cubic miles of solid matter, of the density of water, were carried into the Mediterranean during these 90 days. Now, unless there were some escape for all this solid matter, which has been running into that sea, not for 90 days merely, but for ages, it is very clear that the Mediterranean would, ere this, have been a vat of very strong brine, or a bed of cubic crystals.

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Computation as to amount of salt carried in by this current.

§ 418 Let us see the results of actual observation upon the density of water in the Red Sea and the Mediterranean, and upon the under currents that run out from these seas.

Density of water in Red Sea and Mediterranean.

§ 419 Four or five years ago, Mr. Morris, chief engineer of the Oriental Company's steam-ship Ajdaha, collected specimens of Red Sea water all the way from Suez to the Straits of Babelmandeb, which were afterward examined by Dr. Giraud, who reported the following results:*

Results reported by Dr. Giraud.

	Latitude. Degrees.	Longitude. Degrees.	Spec. Grav.	Saline Cont. 1000 parts.
No. 1. Sea at Suez	—	—	1027	41.0
No. 2. Gulf of Suez	27.49	33.44	1026	40.0
No. 3. Red Sea	24.29	36.	1024	39.2
No. 4. do.	20.55	38.18	1026	40.5
No. 5. do.	20.43	40.03	1024	39.8
No. 6. do.	14.34	42.43	1024	39.9
No. 7. do.	12.39	44.45	1023	39.2

§ 420 These observations agree with the theoretical deductions just announced, and show that the surface waters at the head are heavier and salter than the surface waters at the mouth of the Red Sea.

* Transact. of the Bombay Geograph. Soc., vol. ix., May 1849 to August 1850.

CHAPTER VII.

§ 421 Temperature of air between Suez and Aden. Average evaporation. Assumption of Dr. Buist.

In the same paper, the temperature of the air between Suez and Aden often rises, it is said, to 90°, "and probably averages little less than 75° day and night all the year round. The surface of this sea varies in heat from 65° to 85°, and the difference between the wet and dry bulb thermometers often amounts to 25°—in the kamsin, or desert winds, to from 30° to 40°; the average evaporation at Aden is about eight feet for the year." "Now, assuming," says Dr. Buist, "the evaporation of the Red Sea to be no greater than that of Aden, a sheet of water eight feet thick, equal in area to the whole expanse of that sea, will be carried off annually in vapour; or, assuming the Red Sea to be eight hundred feet in depth at an average—and this, most assuredly, is more than double the fact—the whole of it would be dried up, were no water to enter from the ocean, in one hundred years. The waters of the Red Sea, throughout, contain some four per cent. of salt by weight—or, as salt is a half heavier than water, some 2.7 per cent. in bulk—or, in round numbers, say three per cent. In the course of three thousand years, on the assumptions just made, the Red Sea ought to have been one mass of solid salt, if there were no current running out."

§ 422 Red Sea is three thousand years old.

Now we know the Red Sea is more than three thousand years old, and that it is not filled with salt; and the reason is, that as fast as the upper currents bring the salt in at the top, the under currents carry it out at the bottom.

§ 423 Mediterranean currents.

MEDITERRANEAN CURRENTS.—With regard to an under current from the Mediterranean, we may begin by remarking that we know that there is a current always setting in at the surface from the Atlantic, and that this is a salt-water current, which carries an immense amount of salt into that sea. We know, moreover, that that sea is not salting up; and therefore, independently of the postulate,[1] and of observations, we might infer the existence of an under current, through which this salt finds its way out into the broad ocean again.*

Existence of an under current inferred.

With regard to this outer and under current, we have observations telling of its existence as long ago as 1712.

Observations regarding it.

§ 424 "In the year 1712," says Dr. Hudson, in a paper communicated to the Philosophical Society in 1724, "Monsieur du L'Aigle, that fortunate and generous commander of the privateer called the Phœnix, of Marseilles, giving chase near Ceuta Point to a Dutch ship bound to Holland, came up with her in the middle of the Gut between Tariffa and Tangier, and there gave her one broadside, which directly sunk her, all her men being saved by Monsieur du L'Aigle; and a few days after, the Dutch ship, with

Extract from a paper by Dr. Hudson.

* Dr. Smith appears to have been the first to *conjecture* this explanation, which he did in 1683 (*vide* Philosophical Transactions). This continual indraught into the Mediterranean appears to have been a vexed question among the navigators and philosophers even of those times. Dr. Smith alludes to several hypotheses which had been invented to solve these phenomena, such as subterraneous vents, cavities, exhalation by the sun's beams, &c., and then offers his *conjecture*, which, in his own words, is, "that there is an under current, by which as great a quantity of water is carried out as comes flowing in. To confirm which, besides what I have said above about the difference of tides in the offing and at the shore in the Downs, which necessarily supposes an under current, I shall present you with an instance of the like nature in the Baltic Sound, as I received it from an able seaman, who was at the making of the trial. He told me that, being there in one of the king's frigates, they went with their pinnace into the mid stream, and were carried violently by the current; that, soon after this, they sunk a bucket with a heavy cannon ball to a certain depth of water, which gave a check to the boat's motion; and, sinking it still lower and lower, the boat was driven ahead to the windward against the upper current: the current aloft, as he added, not being over four or five fathoms deep, and that the lower the bucket was let fall, they found the under current the stronger."

[1] § 401.

CHAPTER VII. her cargo of brandy and oil, arose on the shore near Tangier, which is at least four leagues to the westward of the place where she sunk, and directly against the strength of the current, which has persuaded many men that there is a recurrency in the deep water in the middle of the Gut that sets outward to the grand ocean, which this accident very much demonstrates; and, possibly, a great part of the water which runs into the Straits returns that way, and along the two coasts before mentioned; otherwise, this ship must, of course, have been driven towards Ceuta, and so upward. The water in the Gut must be very deep, several of the commanders of our ships of war having attempted to sound it with the longest lines they could contrive, but could never find any bottom."

§ 425 In 1828, Dr. Wollaston, in a paper before the Philosophical Society, stated that he found the specific gravity of a specimen of sea water, from a depth of six hundred and seventy fathoms, fifty miles within the Straits, to have a "density exceeding that of distilled water by more than four times the usual excess, and accordingly leaves, upon evaporation, more than four times the usual quantity of saline residuum. Hence it is clear that an under current ontward of such denser water, if of equal breadth and depth with the current inward near the surface, would carry out as much salt below as is brought in above, although it moved with less than one-fourth part of the velocity, and would thus prevent a perpetual increase of saltness in the Mediterranean Sea beyond that existing in the Atlantic."

Dr. Wollaston's observations on density.

§ 426 The doctor obtained this specimen of sea water from Captain, now Admiral Smyth, of the English navy, who had collected it for Dr. Marcet. Dr. Marcet died before receiving it, and it had remained in the admiral's hands some time before it came into those of Wollaston. CHAPTER VII.

It may, therefore, have lost something by evaporation; for it is difficult to conceive that all the river water, and three-fourths of the sea water which runs into the Mediterranean, is evaporated from it, leaving a brine for the under current having four times as much salt as the water at the surface of the sea usually contains. Very recently, M. Coupvent des Bois is said to have shown, by actual observation, the existence of an outer and under current from the Mediterranean. § 427

Observation of M. Coupvent des Bois.

However that may be, these facts, and the statements of the Secretary of the Geographical Society of Bombay,[1] seem to leave no room to doubt as to the existence of an under current both from the Red Sea and Mediterranean, and as to the cause of the surface current which flows into them. I think it a matter of demonstration. It is accounted for[2] by the salts of the sea. § 428

Facts leave no doubt as to the existence of an under current.

Writers whose opinions are entitled to great respect differ with me as to the conclusiveness of this demonstration. Among these writers are Admiral Smyth, of the British navy, and Sir Charles Lyell, who also differ with each other. In 1820, Dr. Marcet, being then engaged in studying the chemical composition of sea water, the admiral, with his usual alacrity for doing "a kind turn," undertook to collect for the doctor specimens of Mediterranean water from various depths, especially in and about the Straits of Gibraltar. Among these was the one[3] taken fifty miles within the Straits from the depth of six hundred and seventy fathoms (four thousand and twenty § 429

Difference of opinion in regard to it.

Specimens of water collected by Admiral Smyth.

[1] § 421. [2] § 413. [3] § 425.

CHAPTER VII. feet), which, being four times salter than common sea water, left, as we have just seen,[1] no doubt in the mind of Dr. Wollaston as to the existence of this under current of brine.

§ 430 Depth in the Straits. But the indefatigable admiral, in the course of his celebrated survey of the Mediterranean, discovered that, while inside of the Straits the depth was upwards of nine hundred fathoms, yet in the Straits themselves the depth across the shoalest section is not more than one hundred and sixty* fathoms.

Sir Charles Lyell's deductions. "Such being the case, we can now prove," exclaims Sir Charles Lyell, "that the vast amount of salt brought into the Mediterranean *does not* pass out again by the Straits; for it appears by Captain Smyth's soundings, which Dr. Wollaston had not seen, that between the Capes of Trafalgar and Spartel, which are twenty-two miles apart, and where the Straits are shallowest, the deepest part, which is on the side of Cape Spartel, is only two hundred and twenty fathoms.† It is therefore evident, that if water sinks in certain parts of the Mediterranean, in consequence of the increase of its specific gravity, to greater depths than two hundred and twenty fathoms, it can never flow out again into the Atlantic, since it must be stopped by the submarine barrier which crosses the shallowest part of the Straits of Gibraltar."‡

§ 431 His reasoning not conclusive. According to this reasoning, all the cavities, the hollows and the valleys at the bottom of the sea, especially in the trade-wind region, where evaporation is so constant and great, ought to be salting up or filling up with brine.

* "The Mediterranean." † One hundred and sixty, Smyth.
‡ Lyell's Principles of Geology, p. 334–5, ninth edition. London, 1853.
[1] § 425.

Is it probable that such a process is actually going on? No. CHAPTER VII.

§ 432 According to this reasoning, the water at the bottom of the great American lakes ought to be salt, for the rivers and the rains, it is admitted, bring salts from the land continually and empty them into the sea. It is also admitted that the great lakes would from this cause be salt, if they had no sea drainage. The Niagara river passes these river salts from the upper lakes into Ontario, and the St. Lawrence conveys them thence to the sea. Now the basins or bottoms of all these upper lakes are far below the *top* of the rock over which the Niagara pitches its flood. And, were the position assumed by this writer correct, namely, that if the water in any of these lakes should, in consequence of its specific gravity, once sink below the level of the shoals in the rivers and straits which connect them, it never could flow out again, and consequently must remain there for ever*—were this principle physically correct, would not the water at the bottom of the lakes gradually have received salt sufficient, during the countless ages that they have been sending it off to the sea, to make this everlastingly pent-up water briny, or at least quite different in its constituents from that of the surface? We may presume that the water at the bottom of every extensive and quiet sheet of water, whether salt or fresh, is at the bottom by reason of specific gravity; but that it does not remain there for ever we have abundant proof. If so, the Niagara River would be fed by Lake Erie only from that layer of water which is above the level of the top of the rock at the

What would be the effects on the great American lakes if this reasoning were correct.

* See paragraph quoted (p. 178) from "Lyell's Principles of Geology."

CHAPTER VII. Falls. Consequently, wherever the breadth of that river is no greater than it is at the Falls, we should have a current as rapid as it is at the moment of passing the top of the rock to make the leap. To see that such is not the way of Nature, we have but to look at any common mill pond when the water is running over the dam. The current in the pond that feeds the overflow is scarcely perceptible, for "still water runs deep." Moreover, we know it is not such a skimming current as the geologist would make, which runs from one lake to another; for, wherever above the Niagara Falls the water is deep, there we are sure to find the current sluggish in comparison with the rate it assumes as it approaches the Falls; and it is sluggish in deep places, rapid in shallow ones, because it is fed from below. The common "wastes" in our canals teach us this fact.

§ 433 The reasoning of this celebrated geologist appears to be founded upon the assumption that when water, in consequence of its specific gravity, once sinks below the bottom of a current where it is shallowest, there is no force of traction in fluids, nor any other power, which can draw this heavy water up again. If such were the case, we could not have deep water immediately inside of the bars which obstruct the passage of the great rivers into the sea. Thus the bar at the mouth of the Mississippi, with only fifteen feet of water on it, is estimated to travel out to sea at rates varying from one hundred to twenty yards a year.

Assumption on which Sir Charles Lyell's opinion was founded.

Rate at which the bar of the Mississippi travels out to sea.

§ 434 In the place where that bar was when it was one thousand yards nearer to New Orleans than it now is, whether it were fifteen years ago or a century ago, with only fifteen or sixteen feet of water on it, we have now four or five times that depth. As new bars were successively formed seaward from the old, what dug up the sediment which formed the old, and lifted it up from where specific gravity had placed it, and carried it out to sea over a barrier not more than a few feet from the surface? Indeed, Sir Charles himself makes this majestic stream to tear up its own bottom to depths far below the top of the bar at its mouth. He describes the Mississippi as a river having nearly a uniform breadth to the distance of two thousand miles from the sea.* He makes it cut a bed for itself out of the soil, which is heavier than Admiral Smyth's deep sea water, to the depth of more than two hundred feet† below the top of the bar which obstructs its entrance into the sea. Could not the same power which scoops out this solid matter for the Mississippi, draw the brine up from the pool in the Mediterranean, and pass it out across the barrier in the Straits?

New bars formed.

§ 435

Force of traction on rail-roads. May not deep-sea currents have power derived from a like force.

The *traction* of locomotives on rail-roads, and the force of that traction, is well understood. Now, have not currents in the deep sea power derived from some such force? Suppose this under current from the Mediterranean to extend one hundred and sixty fathoms down, so as to chafe the barrier across the Straits. Upon the bottom of this current, then, there is a pressure of more than fifty atmospheres. Have we not here a source of

* "From near its mouth at the Balize, a steamboat may ascend for two thousand miles with scarcely any perceptible difference in the width of the river."—*Lyell*, p. 263.

† "The Mississippi is continually shifting its course in the great alluvial plain, cutting frequently to the depth of one hundred, and even sometimes to the depth of two hundred and fifty feet."—*Lyell*, p. 273.

CHAPTER VII. power that would be capable of drawing up, by almost an insensibly slow motion, water from almost any depth? At any rate, it appears that the effect of currents by *traction*, or friction, or whatever force, does extend far below the level of their beds in shallow places. Were it not so—were the brine not drawn out again—it would be easy to prove that this indraught into the Mediterranean has taken, even during the period assigned by Sir Charles to the formation of the Delta of the Mississippi—one of the newest formations—salt enough to fill up the whole basin of the Mediterranean with crystals. Admiral Smyth brought up bottom with his briny sample of deep sea water (six hundred and seventy fathoms), but no salt crystals.

§ 436 *Admiral Smyth's suggestion* The gallant admiral—appearing to withhold his assent both from Dr. Wollaston in his conclusions as to this under current, and from the geologist in his inferences as to the effect of the barrier in the Straits—suggests the probability that, in sounding for the heavy specimen of sea water, he struck a brine spring. But the specimen, according to analysis, was of sea water, and how did a brine spring of sea water get under the sea but through the process of evaporation on the surface, or by parting with a portion of its fresh water in some other way?

§ 437 *If Sir Charles Lyell's principle be admitted, the harmonies of the sea are gone.* If we admit the principle assumed by Sir Charles Lyell, that water from the great pools and basins of the sea can never ascend to cross the ridges which form these pools and basins, then the harmonies of the sea are gone, and we are forced to conclude they never existed. Every particle of water that sinks below a submarine ridge is, *ipso facto*, by his reasoning, stricken from the channels of circulation, to become thenceforward for ever motionless matter. The consequence would be "cold obstruction" in the depths of the sea, and a system of circulation between different seas of the waters only that float above the shoalest reefs and barriers. I do not believe in the existence of any such imperfect terrestrial mechanism, or in any such failures of design. To my mind, the proofs —the theoretical proofs—the proofs derived exclusively from reason and analogy—are as clear in favour of this under current from the Mediterranean as they were in favour of the existence of Leverrier's planet before it was seen through the telescope at Berlin.

Author's opinion.

§ 438 Now suppose, as Sir Charles Lyell maintains, that none of these vast quantities of salt which this surface current takes into the Mediterranean find their way out again. It would not be difficult to show, even to the satisfaction of that eminent geologist, that this indraught conveys salt away from the Atlantic faster than all the *fresh*-water rivers empty fresh supplies of salt into the ocean. Now, besides this drain, vast quantities of salts are extracted from sea water for madrepores, coral reefs, shell banks, and marl beds; and by such reasoning as this, which is perfectly sound and good, we establish the existence of this under current, or else we are forced to the very unphilosophical conclusion that the sea must be losing its salts, and becoming less and less briny.

Salt is extracted from sea-water for the formation of shells, corals, &c.

§ 439 The Currents of the Indian Ocean.—By carefully examining the physical features of this sea,[1] and studying its conditions, we are led to look for warm currents that have their genesis in this ocean, and that carry from it volumes of overheated water, probably exceeding in

Warm currents in Indian Ocean.

[1] Plates VIII and IX.